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Analysis of Power Quality in Microgrid Systems with Renewable Energy Integration Utilizing Multi-Signal Discrete Wavelet Transform

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Abstract- Microgrids (MG) have emerged as a promising solution for enhancing energy efficiency, integrating renewable energy sources, and ensuring reliable power supply in localized areas. However, the incorporation of Distributed Energy Resources (DERs) in MG introduces novel challenges related to Power Quality (PQ). It is essential to assess and quantify the MG network's PQ to mitigate the issue. The proposed work investigates the PQ challenges that arise due to the integration of DERs in fully meshed and radial microgrids using a 1-dimensional new Multi-Signal Discrete Wavelet Transform (MSDWT). The assessment is carried out by considering voltage and frequency variations, Voltage Unbalance Factor (VUF), power losses, and Total Harmonics Distortion both in on-grid and off-grid modes of operation. The impacts of Solar Photo Voltaic (PV) and Wind Turbine (WT) are tabulated at constant and variable irradiance and wind speed. The results of the PQ analysis will help in the development and implementation of effective control and mitigation techniques to improve the overall PQ of the MG.

Keywords Discrete Wavelet Transform, Power Quality, Microgrid, Renewable Energy Resources.

1. Introduction

The increasing integration of renewable energy sources and distributed generation has led to the proliferation of microgrids as a promising solution for enhancing energy resilience and sustainability. However, the fluctuating nature of renewable energy sources can pose challenges to the overall PQ within the MG. Ensuring a reliable power supply necessitates a thorough grasp of PQ issues and their mitigation techniques. Power quality is a critical aspect of microgrid operation, primarily due to the inclusion of renewable energy resources (RES).

The key concepts of PQ analysis in microgrid consists of voltage and frequency stability in microgrids, harmonics, and their impact on microgrid operation. Flicker and its effect on sensitive loads and transient phenomena. The PQ analysis results will help develop and implement effective control and mitigation techniques to enhance the overall power quality of the microgrid.

This literature review seeks to offer a comprehensive outline of the studies conducted on power quality analysis in microgrids, highlighting the key findings, methodologies used, and challenges faced. One common aspect examined in the literature is the influence of intermittent RES, such as wind and PV, on PQ in MGs. Various studies have investigated the effects of voltage fluctuations, harmonics, and unbalance caused by these sources. Furthermore, power quality issues arising from the interaction between different types of distributed energy resources and the grid have been investigated. The PQ issues like voltage drop, harmonic distortion and phase unbalanced are evaluated and its mitigation is done by optimizing generation, storage, and load at the tertiary control level is proposed [1]. The traditional way of assessing PQ problems in microgrids needs to be improved and the author in [2] proposed a CRITIC and dynamic coefficient method where dynamic changes of a microgrid are also represented by using node weight calculation. The model prediction control is proposed to address PQ issues of microgrids in grid-connected, islanded, and interconnected modes. The proper control of the power converter is achieved by the proposed technique to boost the PQ [3]. The need for fast and effective monitoring of microgrid systems is very much essential to avoid blackouts. Hence, an author [4], a new fuzzy controller with Sugeno rule-based model is implemented for effective management of power flow between RES, storage system, grid and load. Bipolar DC microgrids are emerging as an intriguing power distribution alternative. The inherent problem of voltage imbalance in bipolar DC is that it might emerge depending on the converter design and load sharing [5].

The PQ disturbances are created by switching the different types of loads in the microgrid and the PQ assessment is done by using multiscale recurrence quantification decomposition combined with support vector machine and the author is compared with other popular methods [6]. The AWO-ANFIS technique was introduced by Padhmanabhaiyappan et al. [7] to minimize power loss and inaccuracy. The power differential between the source and destination sides was set by the AWOA. The ANFIS method reduced the error to a minimum. The current for the PV and WT was managed by an MPPT controller. Anup and N Patnaik [8] developed Power Angle Control (PAC) approach depending on Synchronous Reference Frame (SRF) for improving the PQ of the MG system. A unified PQ conditioner inverter under the unbalanced source voltage condition is managed by the equivalent reactive power sharing among the shunt with the series inverter. The performance of microgrids consisting of PV and storage systems in islanded and grid-connected modes is evaluated and is improved by proposing an adaptive reweighted zero-attracting least mean square method control strategy [9]. In [10], a Bayesian regularised neural network-based PQ detection technique is trained and tested by creating PQ problems by switching the RLC loads using a circuit breaker in the SIMULINK platform. The PQ is evaluated based on voltage sag, swell, current and voltage harmonics, voltage unbalance, and variations. The author also covered Supraharmonics which was rarely considered in the literature and its mitigation strategies like custom power devices, optimization techniques, virtual impedance, etc in terms of different aspects are presented [11]. A compact PQ meter enabled with IoT with an added feature of protection is developed to remotely monitor the low-voltage distribution system [12]. The integration of renewable in MG increases the performance of MG by reducing the power losses and increasing voltage level [13] and also leads to low inertia resulting in poor PQ and frequency instability. This problem is addressed by developing virtual inertia and frequency is regulated by a linear quadratic integral regulator and the issue can also be addressed by using flywheel technology [14]. The performance of both virtual inertia and the proposed system was compared in the MG environment [15]. The power converters are designed and developed to integrate PV into microgrids. The droop control is incorporated to minimize the voltage and frequency quality [16]. Considering the drawback of open-loop virtual impedances, wang et. al. [17] proposed a new closed-loop virtual impedance control to reduce the harmonics and balance the power. The dynamics are also addressed by using a fuzzy controller. Depending on the application or kind of resources, various layouts might be used to ensure improved dependability [18]. Lokesh M et al [19] carried out transient stability, voltage and frequency analysis in a microgrid test system using DWT in LLLG fault and proposes the need for PQ mitigation techniques in the islanded mode of operation. But the analysis is carried out for constant irradiance and constant wind speed.

Drawing from the insights gleaned through the literature review, it can be summarised the power quality analysis in microgrids has been conducted using various tools such as PQ monitoring instruments, analyzing voltage and current waveforms, harmonic analysis, transient analysis, PQ indices, frequency analysis, load monitoring and profiling, simulation models, field measurements, and data analytics. Simulation-based studies enable the assessment of PQ under different operating conditions and the evaluation of different control strategies. Field measurements provide real-time data for analyzing power quality issues in existing microgrids. Data analytics techniques, including machine learning algorithms, have been employed to analyze large datasets and extract valuable insights. It becomes evident that the presence of intermittent RES– notably wind and PV systems – within MGs can have notable effects on PQ parameters. The intermittent nature of these RES introduces unique challenges that manifest in various PQ issues. These issues encompass voltage fluctuations, frequency variations, harmonics distortion, and transient disturbances, among others. As the penetration of intermittent RES increases within MGs, these PQ concerns become increasingly pronounced, necessitating proactive measures and advanced control strategies to mitigate their impact and ensure the overall stability and reliability of the MG's power supply. The findings from the literature underscore the significance of addressing these challenges to facilitate the seamless integration of intermittent RES into MGs while upholding desired PQ standards. Several challenges have been identified in the literature regarding PQ analysis in microgrids. These include the integration of different energy resources with varying power quality characteristics, the development of advanced control strategies to regulate power quality, and the standardization of power quality criteria specific to microgrids.

The research focuses on the analysis of power quality in a microgrid test system of different structures, leveraging the potential of the Multi-Signal Discrete Wavelet Transform for signal processing and analysis. This research contributes to the efficient and reliable operation of microgrids, which are an essential component of the future smart grid infrastructure. Moreover, the application of multi-signal analysis tools in microgrids, provides valuable insights into the behavior of complex power systems, improving our understanding of their dynamic behavior under various operating conditions.

The rest of the article gives an introduction to MSDWT in Section 2, Section 3 explains the working of the proposed algorithm with a flow chart. The MG test system considered for the said analysis is presented in Section 4 along with load and DGs data. Section 5 provides a detailed discussion of the PQ analysis followed by the conclusion in Section 6.

2. Multi-Signal Discrete Wavelet Transform

Signals are concurrently analyzed in the time and frequency domains using the Wavelet Transform. It is particularly useful when signals have non-stationary characteristics. The MSDWT is a powerful tool for detecting and characterizing transient and harmonic disturbances in electrical signals. Its multiresolution and time-frequency analysis capabilities make it particularly suitable for studying power quality in dynamic systems like microgrids. When choosing a wavelet for a specific application, the Daubechies wavelets are often considered due to their orthogonality, good frequency localization, and efficient implementation. Hence, the Daubechies-2 (Db2) Level 10 wavelet is used as a mother wavelet. The Daubechies wavelets have the desirable property of being orthogonal wavelets, which means they can provide exact signal reconstruction without any loss of information. The general equation for the Daubechies wavelet is as follows:

$$\psi(t)=\sum \llbracket h[n]\,\sqrt{2}\,\varphi(2t-n)\rrbracket \qquad (1)$$

where:

ψ (t) is the Daubechies wavelet function.
φ(t) is the scaling (mother) wavelet function.
h[n] represents the Daubechies wavelet filter coefficients.

Feature extraction using Db2 involves applying the MSDWT to multiple signals and then selecting relevant information from the resulting coefficients as features for further analysis. The following are the signal features extracted to carry out statistical analysis of voltage and frequency signal:

2.1 Mean

The mean of the wavelet coefficients can be calculated at each decomposition level. It represents the average value of the coefficients at that level. The mean can provide information about the overall energy or DC component of the signal at each scale.

$$\mu(i)=1/(N(i)) \sum \llbracket X(i,k)\rrbracket \qquad (2)$$

where:

N(i) is the total number of coefficients at level i.

X (i, k) represents the k-th coefficient at level i.

2.2 Median

The median is the middle value in a sorted list of values. In the context of the DWT, you can calculate the median of the wavelet coefficients at each decomposition level.

If *N(i)* is odd: $\text{Median}(i)=(X(i,N(i)+1)))/2$

If *N(i)* is even: $\text{Median}(i)=(X(i,N(i)/(2))+X(i,N(i)/2+1)))/2$

2.3 Standard Deviation:

The standard deviation is a measure of the dispersion or spread of a set of values. It quantifies how much the coefficients deviate from their mean value at each decomposition level. A higher standard deviation implies a wider spread of coefficient values and potentially more variability in the signal at that scale.

$$\sigma(i)=\sqrt{(1/(N(i))*(X(i,k)-\mu(i))^2)} \qquad (3)$$

where:
μ(i) is the mean of the coefficients at level i

2.4 Voltage Unbalance Factor (VUF):

VUF is a measure used to assess the imbalance in a three-phase electrical system. The measure of VUF quantifies the relationship between the negative sequence voltage and the positive sequence voltage within a three-phase system. It is often expressed as a percentage and can be calculated using the following formula:

$$\text{VUF}\%=V_n/V_p*100 \qquad (4)$$

Where:
Vp is the magnitude of the positive sequence voltage.
Vn is the magnitude of the negative sequence voltage.

By analyzing these statistical measures across different scales, you can gain insights into the distribution of frequency content and the signal's overall behavior at different resolutions.

3. Proposed Methodology

The article presents a statistical assessment of IEEE fully meshed MG and radial MG systems integrated with DERs in different working conditions. PQ assessment typically involves the analysis of voltage profiles. Within the scope of this study, the key power quality metrics under consideration encompass power losses, variations in frequency, changes in voltage magnitude, voltage fluctuations (flicker severity), voltage asymmetry (unbalance), as well as the presence of voltage and current harmonics, and instances of rapid voltage fluctuations. The PQ analysis is executed before and after the formation of MG both in on-grid and islanded modes of operation. In this case, PV is operated at both constant & variable irradiance and Induction Generator Based Wind Turbine (WTIG) is operated at both constant and variable speed. The Statistical method adopted in the proposed work by decomposing voltage and frequency signal at all the nodes using the MSDWT technique. The simulation is carried out for 5sec in MATLAB/SIMULINK and the working flow is shown in Fig 1.

4. Test Systems

The Fully meshed IEEE benchmark microgrid test system where the system parameters are very close to practical systems consisting of 6 buses and 11 branches connected with total active load of 10.017MW and a reactive load of 2.464MVAr respectively is considered to carry out PQ analysis using the proposed method. The line and load related data are presented in [20]. The single-line diagram of the proposed test system is presented in Fig 2. It consists of 3 PVs with total rating of 6400 kW and 3 emergency standby synchronous generators with total rating of 6000 kVA and the details of DERs are tabulated in Table 1

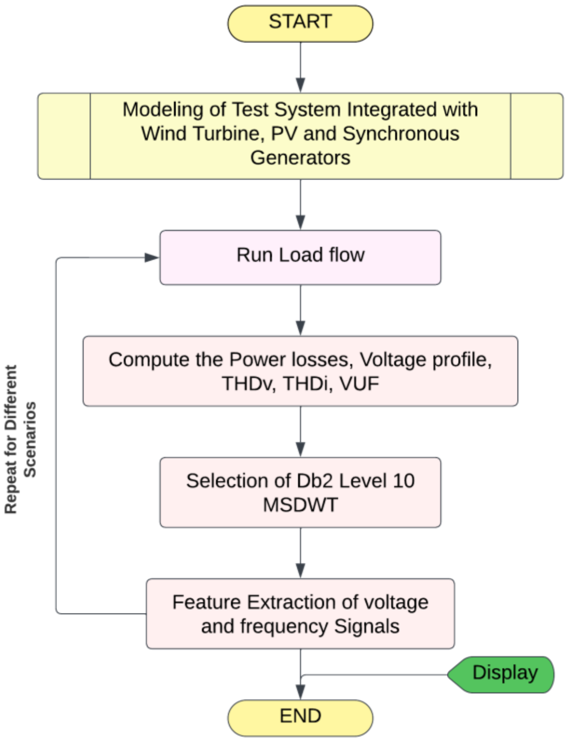


Fig.1. Proposed Methodology for PQ Analysis

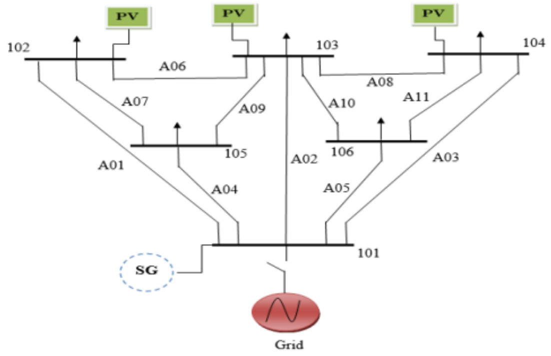


Fig.2. 6-Bus Fully Meshed MG Test System

Table 1. DERs Integrated with Fully Meshed MG

Bus No.	DG Type	No. of DGs	Size
101	SG	3	2000 kVA
102	PV	1	2000 kW
103	PV	1	2400 kW
104	PV	1	2000 kW

The proposed analysis is also evaluated on the IEEE standard radial microgrid test system consisting of 9 buses, 8 branches connected with constant RL load of real power 7.302MW and reactive power of 1.528MVAr respectively. The line and load data are presented in [16]. The single-line diagram of the proposed test system is illustrated in Fig.3. The MG is equipped with Three PVs with total rating of 5600 kW, two induction generator-based wind turbine with total rating of 1300 kW and three emergencies standby synchronous generators of total size 6000 kVA. The detail of DERs is tabulated in Table 2.

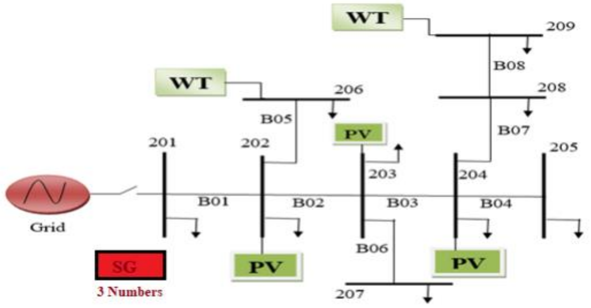


Fig.3. 9-Bus Radial MG Test System

Table 2. DERs Integrated with Radial MG

Bus No.	DG Type	Number of DGs	Size
201	SG	03	2000 kVA
202	PV	01	1600 kW
203	PV	01	1600 kW
204	PV	01	2400 kW
206	WT	01	800 kW
209	WT	01	500

5. Results and Discussions

PQ assessment of fully meshed and radial MGs using MSDWT is discussed. The PQ assessment for both the MG is performed separately by assessing power flow between the resources, Power losses, Voltage disturbances, frequency disturbances and THDv. The mathematical model of the test system along with PV, Induction generator-based wind turbine, and synchronous generators is done in SIMULINK and executed for 5 seconds which is sufficient to capture the required dynamic data of microgrid after which it attains steady state. Synchronous generators are employed as backup source, offering reactive power support exclusively when the system operates in islanded mode. The PQ assessment is presented in the following five different cases for MG1 and MG2.

Case 1: Test System without DERs.
Case 2: MG in Grid-connected Mode with constant irradiance and wind speed.

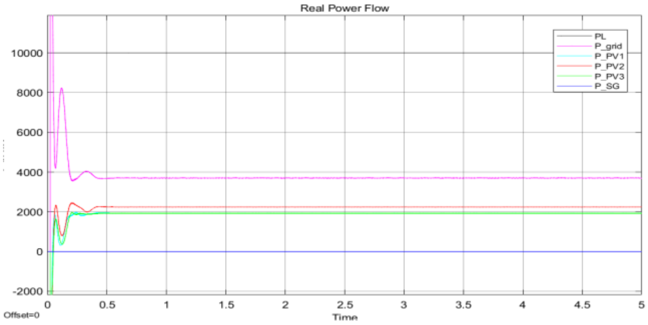
Case 3: MG in Grid-connected Mode with variable irradiance and wind speed.

Case 4: MG in Islanded Mode with constant irradiance and wind speed.

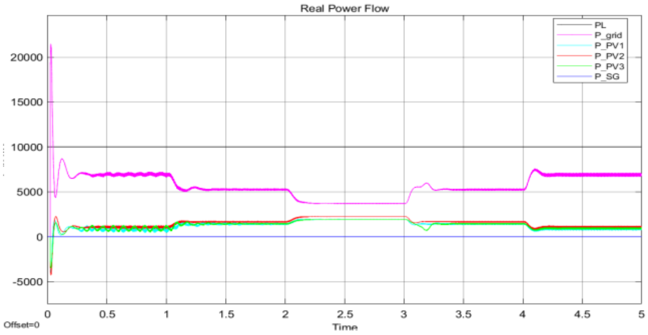
Case 5: MG in Islanded Mode with variable irradiance and wind speed.

A. *IEEE 6-Bus Fully Meshed Microgrid Test System-MG1*

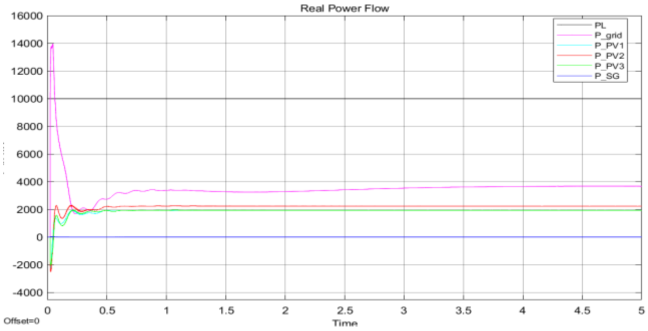
The active power sharing between the grid, PVs and loads for different cases is shown in Fig 4. In case 3 and case 5, a disturbance is due to changes in irradiance and wind speed. The line losses in different cases are presented in Figure 5. It can be observed that integration of PV i.e case-2 into the test system case-1, reduces the losses from 13.8 kW and 18.86 kVAr to 3.2 kW and 4.3kVAr respectively. During islanded mode in case 4, the losses reduced to 2.68kW and 3.6kVAr respectively. This proves that the microgrid operation provides optimal power flow thus reducing the line losses at its extreme.



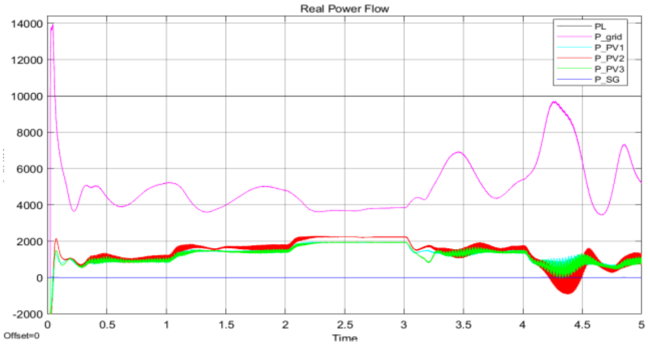
Case-2



Case-3



Case-4



Case-5

Fig.4. Active Power Sharing between DERs and Loads in MG1

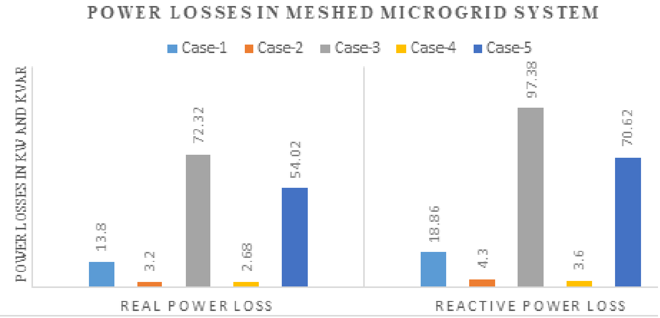
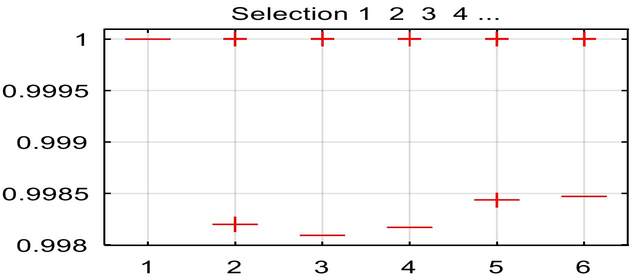
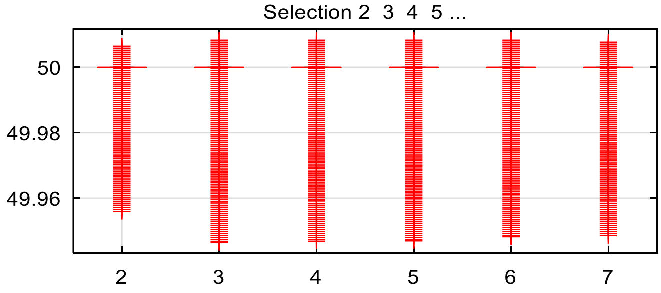


Fig.5. MG1 active and reactive power losses for different cases

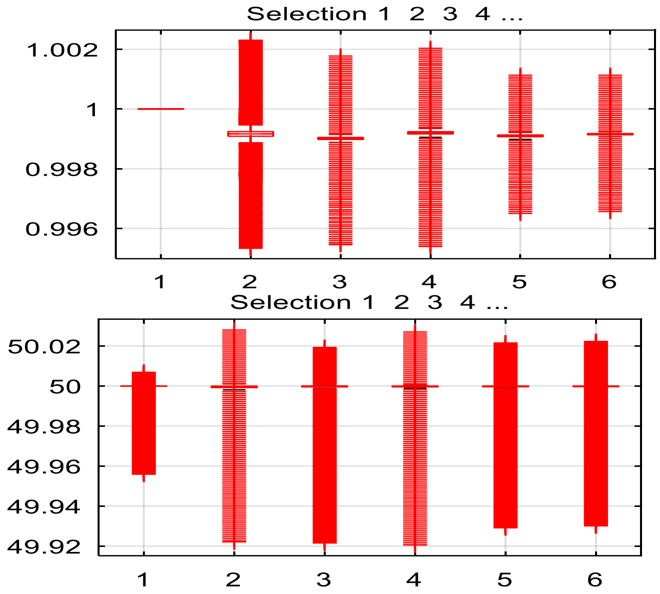
The voltage and frequency signal at every node is investigated using MSDWT to extract its features. The extracted statistical data is graphically represented in Fig 6. The boxplot indicates the mean, minimum, maximum and also the range of fluctuation which yields accurate and fast PQ analysis. Case 1 is the reference to compare the collapse in PQ for other cases. Even though the frequency in case 4 and case 5 is within the acceptable limit (standards 49.5 to 50.5 Hz). i.e 49.8Hz and 49.5 Hz respectively, fluctuation of frequency is more because of the islanded mode of operation.



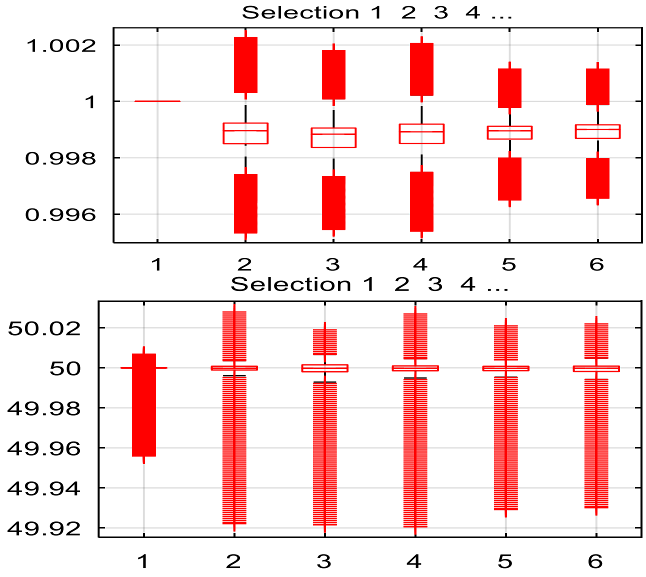
In grid-connected mode i.e. case-2 and case-3, fluctuation in frequency and voltage is less and the frequency settles at 50Hz and voltage at 1PU at all buses. The voltage variation is more in case 4 and case 5 due to islanded condition. The voltage at all the buses in case 5 is 0.96PU because of variable irradiance in PV.



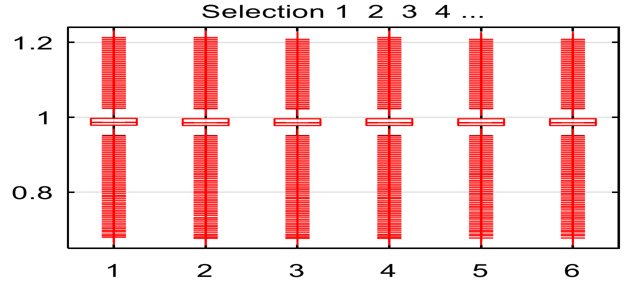
Case 1

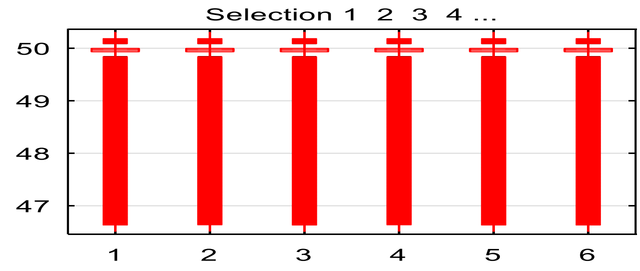


Case 2

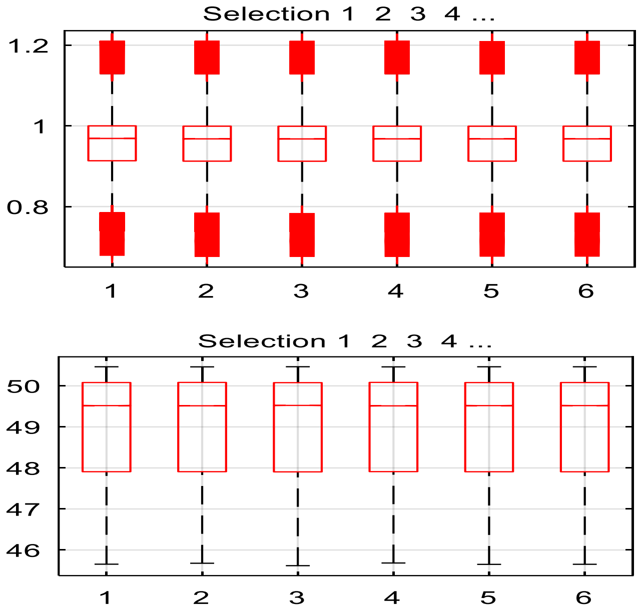


Case 3





Case 4



Case 5

Fig.6. Fully Meshed MG Voltage and Frequency Signal Analysis using MSDWT

Further, the voltage symmetry in three phase system is measured by using voltage unbalance factor. As shown in Fig.7, due to the absence of non-linear loads, faults, and unbalanced load, the VUF is zero for case 1 and also minimum for all other cases except case 5. In case 5, VUF is 4.178% due to variable irradiance in islanded conditions where the acceptable limit is only 2%. The THD of voltage is graphically presented in Fig.8. The THDv is maximum at bus 2 in case 3 and case 5 because of the intermittent nature of PV. Hence need for active filters is essential to reduce the harmonics as per IEEE 519-2022 standards.

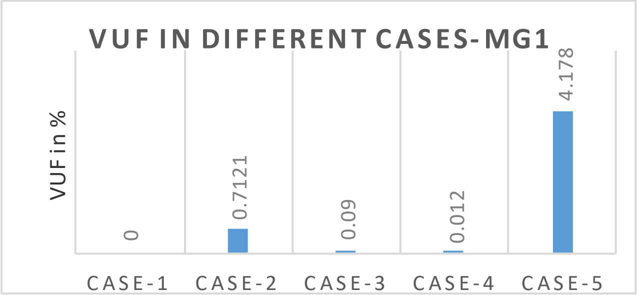


Fig.7. MG1 Voltage unbalance factor for different cases

B. IEEE 9-Bus Radial Microgrid Test System

The real and reactive power sharing between the grid, PVs, WTs and loads for different cases are shown in Figure 9 and Fig.10. The induction generator-based WT provides active power support to the grid along with the PV and absorbs reactive power from the grid. In this microgrid, the utility provides only the reactive power for the load and WT. The line losses in different cases are presented in Fig.11. It can be observed that integration of DERs i.e case-2 into the test system case-1 reduces the losses from 43.82 kW and 55.58 kVAr to 1.626 kW and 17.716 kVAr respectively. During islanded mode in case 4, the losses were reduced to 2.087 kW and 2.305 kVAr respectively. Both in case 3 and case 5, the losses increase compare to case 2 and case 4 because of variable wind speed and variable irradiance. This proves that the microgrid operation provides optimal power flow thus reducing the line losses at its extreme.

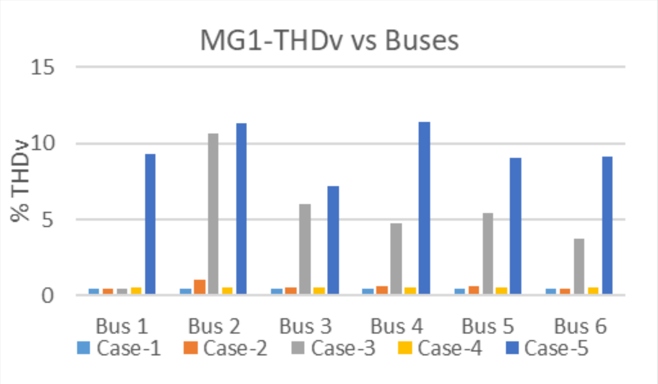
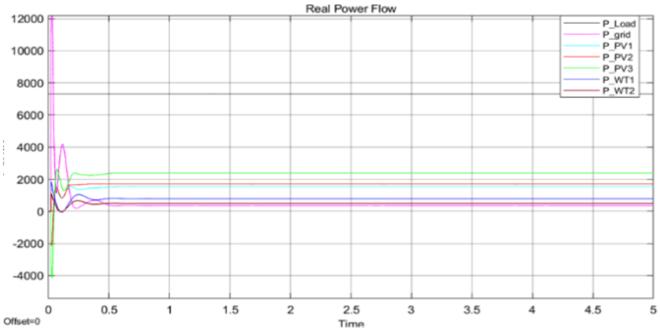
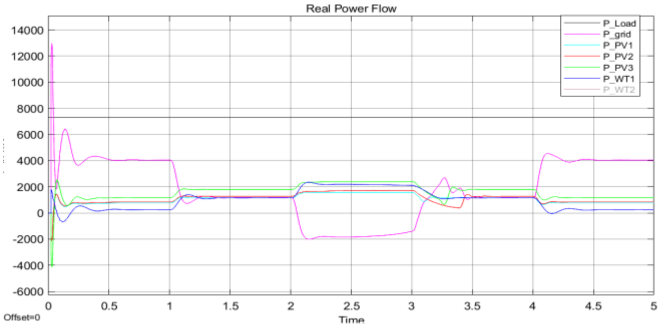


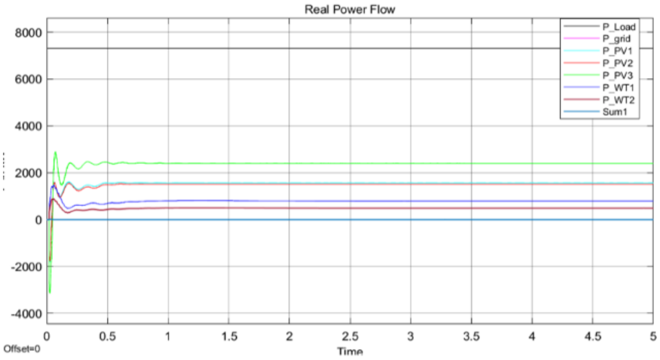
Fig.8. THDv for different cases in MG1



Case-2



Case-3



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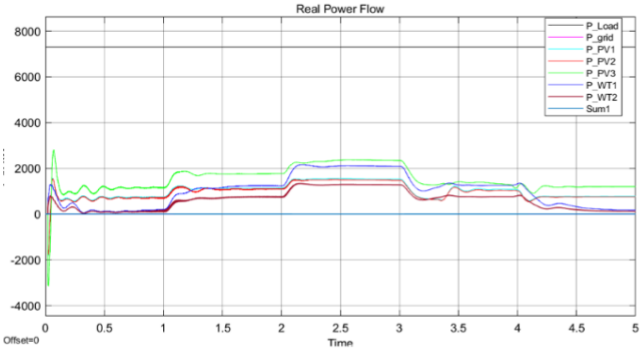
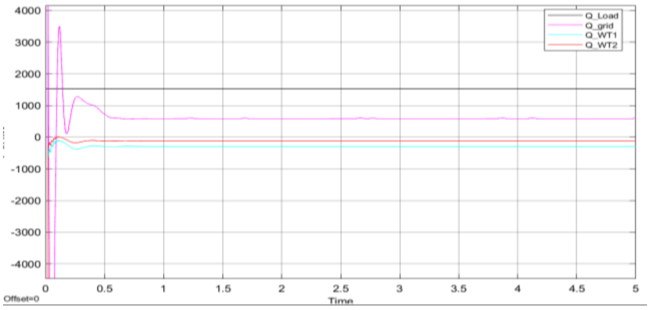
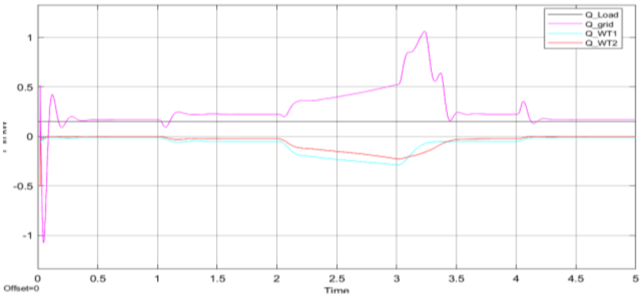


Case-5

Fig.9. Active Power Sharing between DERs and Load in MG2



Case-2



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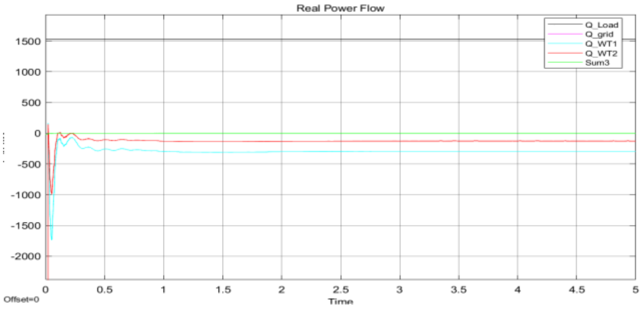
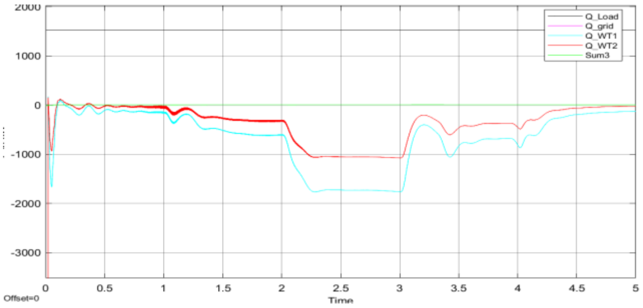


Case-4



Case-5

Fig.10. Reactive Power Sharing between DERs and Load in MG2

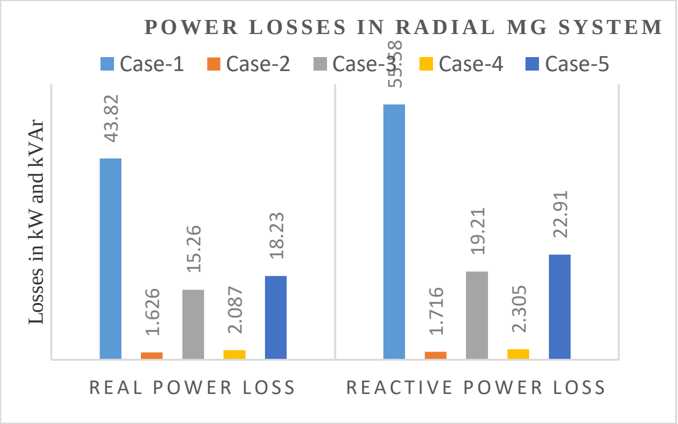
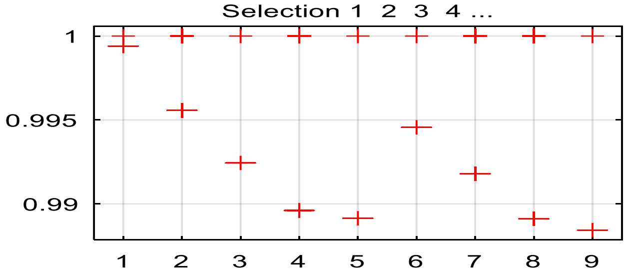
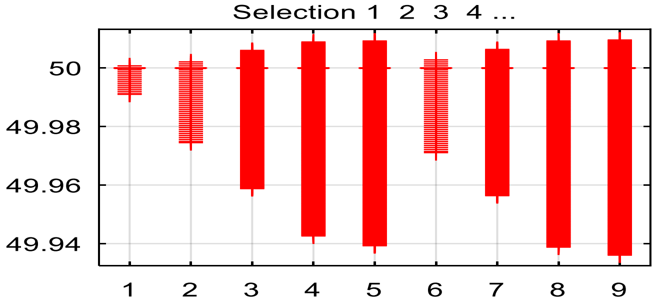


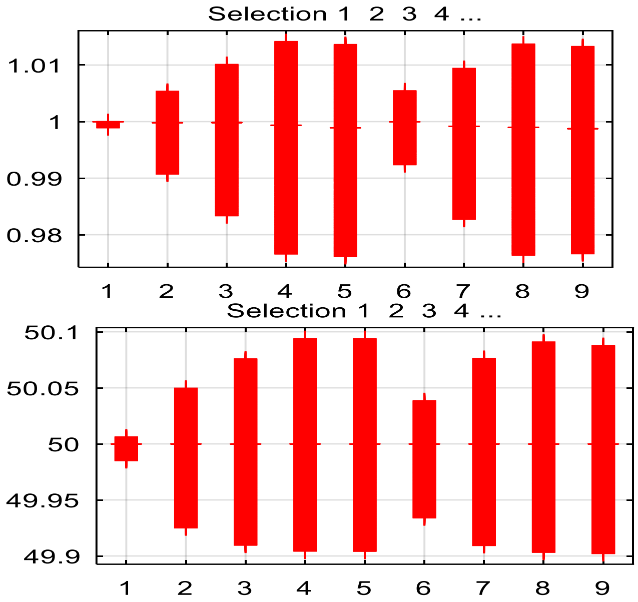
Fig.11. MG2 active and reactive power losses for different cases

The voltage and frequency signal at every node are investigated using MSDWT to extract its features. The extracted statistical data is graphically represented in Fig.12. The boxplot indicates the mean, minimum, maximum and also the range of fluctuation which yields accurate and fast PQ analysis. Case 1 is the reference to compare the collapse in PQ for other cases. The voltage and frequency at all the buses in grid connected mode i.e case 2 and case 3 is within the acceptable limit with minimum fluctuation during switching of PVs and WTs. Even though the frequency in case 4 and case 5 are within the acceptable limit i.e. 49.8Hz and 50.5 Hz respectively, the fluctuation of frequency is more because of an islanded mode of operation. The fluctuation is more at the point of common coupling. From the observations, the MG performance is poor concerning PQ during islanded conditions in variable irradiance and variable speed. Therefore, the need of storage systems is very much essential for MG to operate in islanded conditions.

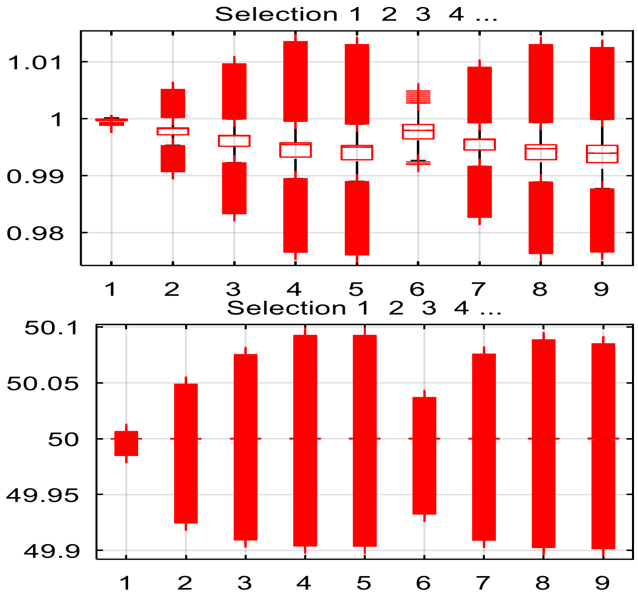




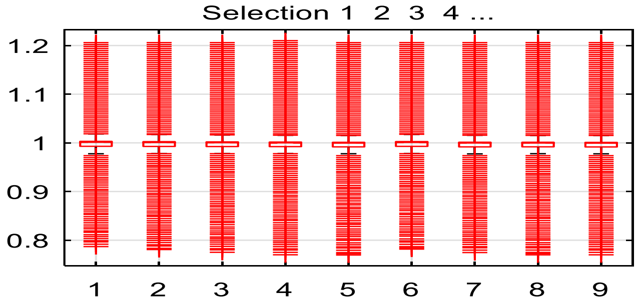
Case 1

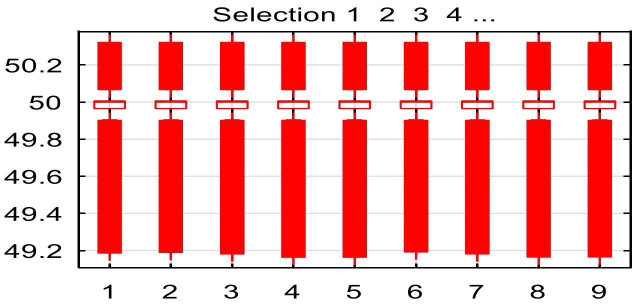


Case 2

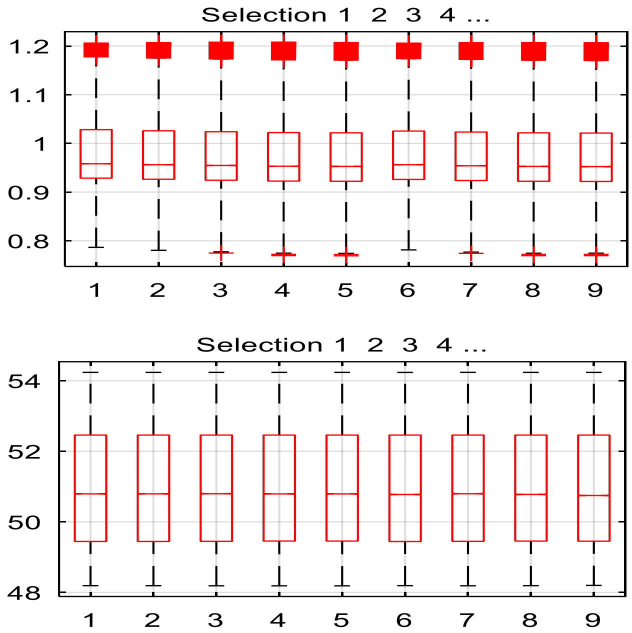


Case 3





Case 4



Case 5

Fig.12. MG2 Voltage and Frequency Signal Analysis using MSDWT

The voltage symmetry in three phase system is measured by using the voltage unbalance factor. The VUF is zero for all the cases except case 5 and in case 5, VUF is 4.175% due to variable irradiance and variable speed in islanded conditions where the acceptable limit is only 2%.

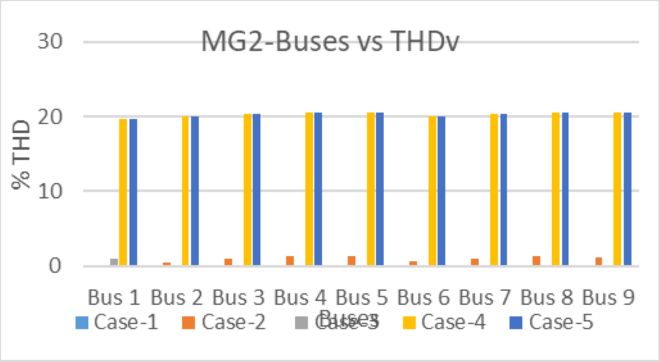


Fig.13. THDv for different cases in MG2

The THD of voltage is graphically presented in Fig.13. In the radial microgrid, the THDv is around 20% in case 4 and case 5 because of islanded operation. Harmonics is more during variable irradiance and variable wind speed. Hence need for active filters is essential to reduce the harmonics as per IEEE 519-2022 standards.

6. Conclusion

Power Quality issues like frequency and voltage variation, unbalanced voltage, power losses and THD level were analyzed in the IEEE medium voltage network of fully meshed and radial MG system through an MSDWT approach. The PQ is assessed before and after the implementation of MG in different scenarios. The integration of DERs into the test system drastically reduces the real and reactive power losses in both microgrids. From the statistical data, it was very clear that the fluctuation and deviation in frequency and voltage are very minimum during grid-connected mode and also within the acceptable limit as per IEEE 519-2022 standards. Whereas the deviation is more in islanded mode of operation and it worsens in the case of variable irradiance PV. VUF in fully meshed MG is minimum for grid-connected MG however in radial connected MG system is zero. The voltage unbalance is beyond the limit in islanded variable irradiance PV case for both the microgrid. In this case, VUF has to be maintained within the limit as per the standards IEC 61000. The THDv is high in the case of variable irradiance PV both in on-grid and off-grid for meshed type MG. However, in radial MG the THDv is high in the case of the islanded condition. The statistical analysis is helpful to researchers to adopt different methodologies to tackle these challenges and proposed control strategies to mitigate power quality issues.

References

[1] G. d'Hoop, O. Deblecker, and D. Thomas, 'Power Quality Improvement of a Microgrid with a Demand-Side-Based Energy Management System', Micro-grids - Applications, Operation, Control and Protection. IntechOpen, Sep. 11, 2019. doi: 10.5772/intechopen.83604.

[2] Shi H, Li Y, Jiang Z, Zhang J. Comprehensive power quality evaluation method of microgrid with dynamic weighting based on CRITIC. Measurement and Control. 2021;54(5-6):1097-1104. doi:10.1177/00202940211016092

[3] Garcia-Torres, F.; Vazquez, S.; Gil-de-Castro, A.; Roncero-Sanchez, P.; Moreno-Munoz, A. Microgrids Power Quality Enhancement Using Model Predictive Control. Electronics 2021, 10, 328. https://doi.org/10.3390/electronics10030328

[4] Babita Nanda*, R. K. Jena & B. P. Muni. (2022). Power Quality Analysis in Microgrid by using TSK-Fuzzy Controller. Computer Integrated Manufacturing Systems, 28(11), 427–443. Retrieved from http://cims-journal.com/index.php/CN/article/view/229.

[5] V. F. Pires, A. Cordeiro, D. Foito and J. F. Silva, "A DC-DC Converter with Capability to Support the Voltage Balance of DC Bipolar Microgrids," 2022 11th International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey, 2022, pp. 50-55, doi: 10.1109/ICRERA55966.2022.9922819.

[6] Cortes-Robles, Emilio Barocio, J.Segundo, D.Guillen and J.C. Olivares "A Qualitative-Quantitative hybrid

approach for power quality disturbance monitoring on microgrid systems” Volume 154,2020,107453,ISSN 0263-2241, https://doi.org/10.1016/j.measurement.2019.107453.

[7] P. Padhmanabhaiyappan, R. Karthik, and K. Ayyar, “Optimal utilization of interconnected RESs to microgrid: a hybrid AWO-ANFIS technique,” Soft computing, vol. 24, no. 14, 2020, doi: 10.1007/s00500-019-04558-3.

[8] P. Annapandi, R. Banumathi, N. S. Pratheeba, and A. A. Manuela, “An efficient optimal power flow management based microgrid in hybrid renewable energy system using hybrid technique,” Transactions of the Institute of Measurement and Control, vol. 43, no. 1, 2021, doi: 10.1177/0142331220961687.

[9] V. Narayanan and B. Singh, "Improved Power Quality Multifunctional Solar PV-Battery Based Microgrid Interfaced to Utility Grid/Diesel Generator Set for Uninterrupted Power," 2021 IEEE 4th International Conference on Computing, Power and Communication Technologies (GUCON), Kuala Lumpur, Malaysia, 2021, pp. 1-7, doi: 10.1109/GUCON50781.2021.9573719.

[10] N. Chaudhari, C. Nimbargi, S. Gupta, A. Kumar and C. Khadse, "Power Quality Analysis in Microgrid System with Bayesian Regularized Neural Network," 2021 2nd International Conference on Communication, Computing and Industry 4.0 (C2I4), Bangalore, India, 2021, pp. 1-5, doi: 10.1109/C2I454156.2021.9689222.

[11] A. A. Alkahtani et al., "Power Quality in Microgrids Including Supraharmonics: Issues, Standards, and Mitigations," in IEEE Access, vol. 8, pp. 127104-127122, 2020, doi: 10.1109/ACCESS.2020.3008042.

[12] I. Hafidz, A. Priyadi, M. Pujiantara, D. O. Anggriawan and M. H. Purnomo, "Development of IoT-Based Portable Power Quality Monitoring on Microgrids by Enhancing Protection Features," in IEEE Access, vol. 11, pp. 49481-49492, 2023, doi: 10.1109/ACCESS.2023.3276241.

[13] Lokesh Mallaiah, M B Ravishankar, Sandeep Kumar K J, A.D Kulkarni,” Optimal siting for different level of DG penetration and Its Impact on Radial Distribution system under different voltage-dependent load Model”, International Journal of Renewable Energy Research, Volume 13, No.1, 2023 https://doi.org/10.20508/ijrer.v13i1.13701.g8705.

[14] Sadullah Esmer, Erdal Bekiroglu “Design of PMaSynRM for Flywheel Energy Storage System in Smart Grids”,Volume 6, No. 4 (2022), rg/10.20508/ijsmartgrid.v6i4.255.g254.

[15] M. Maaruf, S. E. Ferik, F. Saleh Al-Ismail and M. Khalid, "Robust Optimal Virtual Inertia Control for Microgrid Frequency Regulation Considering High Renewable Energy Penetration," 2022 11th International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey, 2022, pp. 369-373, doi: 10.1109/ICRERA55966.2022.9922718.

[16] Innocent Ewaen Agbongiague Davidson, Elutunji Buraimoh,” Modelling of a Photovoltaic-Based Grid Supporting Microgrid and Fault Ride-Through Control Application”, International Journal of Smart Grid-IJSMARTGRID, Issue No.02, Volume 7, https://doi.org/10.20508/ijsmartgrid.v7i2.284.g273

[17] Wang, Y., Tang, J., Si, J. et al. Power quality enhancement in islanded microgrids via closed-loop adaptive virtual impedance control. Prot Control Mod Power Syst 8, 10 (2023). https://doi.org/10.1186/s41601-023-00284-z

[18] N. Altin and S. E. Eyimaya, "A Review of Microgrid Control Strategies," 2021 10th International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey, 2021, pp. 412-417, doi: 10.1109/ICRERA52334.2021.9598699.

[19] M. Lokesh, A. D. Kulkarni, T. Ananthapadmanabha, N. Gurav and K. J. Sandeep Kumar, "Enhancement of Transient Stability and Voltage Quality of Microgrid with Multiple DERs," 2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS), Madurai, India, 2021, pp. 686-691, doi: 10.1109/ICICCS51141.2021.9432127.

[20] M. N. Alam, S. Chakrabarti and X. Liang, "A Benchmark Test System for Networked Microgrids," in IEEE Transactions on Industrial Informatics, vol. 16, no. 10, pp. 6217-6230, Oct. 2020, doi: 10.1109/TII.2020.2976893.