Advancement in techniques towards power quality improvement in Microgrid system: A comprehensive review

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Abstract. Power quality is one of the prime views of modern energy schemes. Renewable-energy-based microgrids offer an attractive solution for improving the power quality of remote or isolated areas while diminishing greenhouse gas discharges. However, incorporating renewable energy origins into the grid can introduce significant challenges, mainly power fluctuations, voltage instability, harmonics, and frequency deviation. Here, a literature-based study has been done on the power quality improvement in microgrid. This review paper analyses 30 literature review papers published between 2018 to 2022, focusing on power quality improvement in recoverable -energy-based Microgrids. It also analyses the different techniques, simulation environments, and controllers used in each research work. Moreover, the advantages and research gaps in the collected research articles are also analyzed. Ultimately, the research gaps identified are also mentioned to assist future researchers in developing a novel and efficient approach for power quality improvement in microgrid-based systems.

Table 1. Nomenclature

Abbreviation	Description
ALO	Ant Lion Optimization
ANN	Artificial Neural Network
ASFC	Adaptive Switched Filter Compensator
ASO	Atom Search Optimization
DSP	Digital Signal Processor
DVR	Dynamic Voltage Restorer
EMS	Energy Management System
FACTS	Flexible AC transmission system
FOPI	Fractional Order Proportional Integral
FOPID	Fractional Order Proportional Integral Derivative

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GOA	Grasshopper's Optimization Algorithm
GSA	Genetic Search Algorithm
GWO	Grey Wolf Optimization
HSAPF	Hybrid Shunt Active Power Filter
LVRT	Low Voltage Ride Through
WTG	Wind Turbine Generator

1. Introduction

Recently, the power quality is playing a major role in the electronic industry. The reduction in power quality has a negative impact on the power consumers. Reduced power quality also contributes to production losses, equipment damage, communication line interference, increased power outages, and other problems. These PQ disturbances propagate to the equipments of consumers connected at the PCC. This propagation of disturbances may result in overheating of motors, transformers, cables, compensation capacitors, and mal-operation of protection devices [1]. The transmission and distribution networks would experience higher power losses as a result. Due to the electromagnetic interference that these disturbances cause, the communication systems could also be harmed. It is essential to maintain a conventional quality of power as a result [2]. The residential-tertiary section and manufacturing are the two main consumers of electricity, but due to the emission of CO2, this consumption significantly harms the environment. Solar and WECS are the two most popular and technologically advanced renewable energy generation systems. The recurring nature of solar and wind energy systems will cause problems with their grid connections. There will be issues when solar and wind energy systems are connected to the grid because of their recurrent nature. The primary issues with the distribution network are the voltage sag and swell [3, 4]. As a result, the quality of the power delivered to consumers and loads will be lower, which will have an impact on the loads and power electronic equipment. The distribution system's filters and FACTS devices can help to solve these issues. In order to raise the quality of the power delivered, it is necessary to research various PQ improvement techniques. In the literature, PQ detection and classification methods based on real data taken from recorded waveforms are reported [5].

The entire work has been divided in three sections. Section: 1 contains the literature review about Power Quality Improvement, Section: 2 contains the research gaps and challenges, and the last section, the conclusion is carried out.

2. Literature Review

Some of the recent research work related to power quality improvement is reviewed in this section.

2.1 Power quality improvement

In 2020, Bharathi et al. [1] have improved the feature of the electrical supply to the three-phase grid by reducing faults that occur during power transmission. Implementation of the UPQC with a PI controller based on MGWO. This was integrated with renewable energy sources like wind turbines to effectively eliminate voltage and current harmonic faults. The main goal was to eliminate errors that occurred during power transmission and to improve or make up for the power quality factor. Figure 1 shows the renewable energy of microgrid in power quality systems.

In 2018, Benali *et al.* [2] suggested a DVR to increase the LVRT capability and power attribute affiliated to a cross-distribution generation arrangement. DFIG generator associated was an increment converter makes up the WTG. Through a two-stage energy conversion, PV was associated to the PCC. First, through the progressive technique, this topology enabled the extraction of maximum power. Moreover, Naidu *et al.* [3] have introduced DPFC controller to address PQ issues. The coordinated PQ theory and FOPID controller was used. Results obtained using the suggested system demonstrated improved presentation as to compensated voltage and lesser oscillations of the load active power.

In 2020, Goud *et al.* [4] suggested the GWO with UPQC to address issues in PQ. FOPID with GWO improves UPQC performance. The results show that, when compared to other algorithms like BBO, GA, and GSA with an existing PI controller, the proposed GWO algorithm has a number of advantages, including early convergence and obtaining optimized fitness values.

In 2021, Thakur *et al.* [5] presented the enthalpy-based GWO model to address the problems of a power system's node electric potential deviation, feeder power losses, and power factor. owed it clarity quick convergence, and elevated search precision, the conclusions of the submitted model were equated with those of various conventional approaches and are built to be the most advantageous.

In 2020, Kumaresan *et al.* [6] provided an efficient method for enhancing the power quality framework on the convenience side using a shunt active power filter when a BLDC drive was allied to the delivery network. Hysteresis current control was used to implement the compensation current controller, and sliding mode control was used to implement the DC-link voltage controller.

In 2019, Pati *et al.* [7] developed a novel control technique for the purpose of improving power quality in GC hybrid PV battery systems based on ternary DBI. An up-to-date decrease observational paradigm has been used to test the suggested control technique. The bidirectional converter for battery operation, outstanding monitoring effectiveness of the RC robust nonlinear control by FL control for the boost inverter, and the composite control technique have been prepared and examined for power quality development.

In 2018, Pradhan *et al.* [8] used DVR to defend serious loads from voltage-related power quality challenges. A smaller amount of energy storage was needed to the adaptation of the submitted algorithm's energy-optimized series voltage compensation. The proposed DVR control scheme could protect the load from voltage-related power quality difficulties. The three-phase three-leg split capacitor inverter's three legs was used to introduce series compensation voltage into the system's various phases. Simultaneous observational findings and model-based computer simulation analyses verify the productiveness of the suggested control algorithm.

In 2018, Prasad *et al.* [9] suggested a technique to use RSC-MLC merged with PV system to optimize the distribution static compensator's dc-link voltage based on load compensation terms. Reactive power, unbalance, and harmonics required by three-phase unbalanced and nonlinear loads connected to the distribution side could be compensated by the suggested method, improving power quality. When necessary, it could also actually support the load with power, keeping the source from being overloaded. The dc-link voltage could be decreased to a lessen level during off-peak loads to reduce switching losses and the voltage stress across the inverter's switches.

In 2019, Jamil *et al.* [10] discussed power quality improvement for efficient power transfer in a hybrid system using grid-integrated planetary photovoltaic and wind-driven. Based on photovoltaic energy output and wind energy conversion, the hybrid system was a farm for renewable energy. AC loads and the amount of power generated by the renewable farm frequently cause system disturbances.

In 2018, Mortezaei *et al.* [11] discussed tractable power conditioning in smart grid applications using a cascaded multilevel converter. The main component of the suggested design was the use of independent DC links with lower voltages, which makes it a perfect candidate for medium- and high-power applications with improved reliability.

In 2019, Liu *et al.* [12] suggested a TIFS for harmonic stifling in the industrialized DCfeed device. The proposed TIFS have the advantages of lower transformer loss, forceful harmonic elimination capability, and higher integration of the electric equipment in high-power for industrial use. It was designed for the charged environment with large current and severe harmonic contamination as well as the installation space with the limited planned zone. The inductive filtering transformer with an integrated reactor was introduced, along with its winding configuration.

In 2021, Goud *et al.* [13] discussed the grid integration of bioenergy sources like PV,wind, and storage cells. For harmonic reduction under disconnected and uneven load requirements, HSHAPF was optimized with the GWO and FOPI controller. The tuning of the FOPI parameters using GWO efficaciously reduces the harmonics.

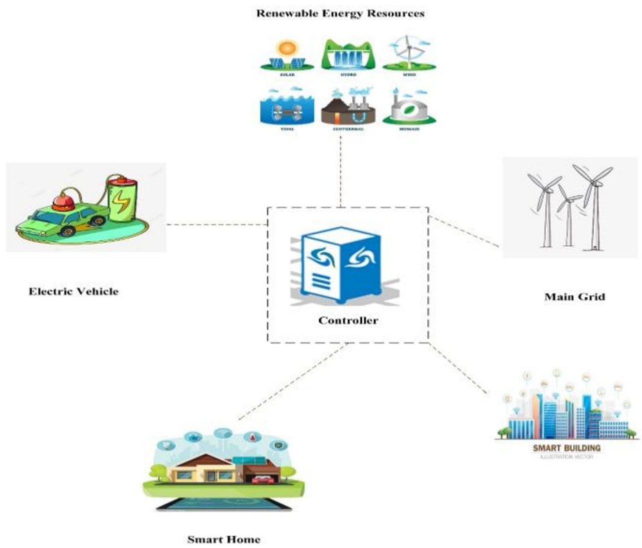

Fig. 1. Power Quality management in Renewable energy

In 2021, Goud *et al.* [14] addressed PQ challenges in the HRES of using ASO with UPQC. The work's primary goal was to reduce PQ difficulties and balance the load demand in the HRES system. The system's UPQC device aids in the resolution of PQ issue issues. By integrating a FOPID with an ASO-based controller in series and a shunt active power filter to address current and voltage PQ issues, the UPQC performance was improved. HRES was initially designed with a PV system, a WT, and a BESS that was coupled to the load system. Moreover, Jahan *et al.* [15] have suggested improving the power quality and various dynamic responses of an NPC converter-fed grid-tied PV system by using a proportional-integral resonance controller with feedback from a harmonic compensator and a lead compensator (PIR + HC + LC). The suggested controller offered excellent PV array output voltage performance besides good inverter performance in the face of erratic load changes and power system disturbances. With a sinusoidal output voltage and current and a unity power factor, the proposed controller was demonstrated.

In 2019, Omar *et al.* [16] presented a new control strategy with low complexity for controlling a DVR's voltage. To ensure superior power quality functioning as concerns voltage betterment and stabilization of the buses, fuel-saving utilization, and harmonic distortion reduction in a distribution network, the proposed scheme makes use of an error-driven PID controller.

In 2020, Elmetwaly *et al.* [17] presented an ASFC with a customized PID controller to better the MGs' dynamic accomplishment. The GOA was used to apply self-tuning and adaptive behavior to the PID's controller gains because the operating conditions may change while the MG was operating.

In 2019, Alshehri *et al.* [18] developed a BESS control strategy using two intelligent decoupled controllers. To achieve the restoration system voltage and frequency while taking into account a variety of disturbances in order to avoid a decline in power quality. A hybrid control system is formed by compounding two important techniques, DEO and ANN, in order to take advantage of the complementary strengths of all strategies.

In 2020, Anu *et al.* [19] investigated the capability of DCES to ameliorate the power quality of a DC microgrid fed by an SPV system. The experiment system is made up of a battery, DCES, loads, and PV sources with MPPT using the perturb and follow-up procedure. MATLAB/Simulink was used for the analysis, both with and without DCES.

In 2020, Poongothai *et al.* [20] used single-phase UPQC depending on a scalar template control algorithm for its grid connection of photovoltaic activity, such as voltage sags/swell, unit power factor correction, voltage, and current harmonic cancellation.

In 2020, Molla *et al.* [21] focused on the use of DVR, which involved various devices, to enhance the power quality of hydroelectricity systems under conditions where sensitive loads experience voltage fluctuations. To increase the effectiveness and caliber of the power supply and ensure conformity with IEEE nominal voltage standards, balanced and asymmetrical fault scenarios are put to the test. Presented results for sensitive load phase voltage rather than and while DVR system input.

In 2019, Syed *et al.* [22] presented renewable energy power feedback like in conventional schemes, integrated a central control for energy management with source power feedback. Compared to traditional algorithms, the proposed energy management plan responds to changes in load faster. For lilting the circuit breakers of clean resource energy battery and fuel cell systems, the energy management control generated a trip signal.

In 2019, AR *et al.* [23] presented UPQC which was accomplished using a fuzzy logic controller. The efficiency of the transmission and generation systems was monitored, controlled, and optimized by the EMS, which was used by electrical utility network operators. To address power quality issues, the system model was built using MATLAB.

In 2022, Stanley [24] proposed a system for keeping smart hybrid multi- imperishable energy. The system employs a DC to AC inverter with a pulse-generating process controlled by a fuzzy controller to get better power quality factors. The effectiveness of the proposal was also analyzed.

In 2021, Rajesh *et al.* [25] suggested a novel control design to execute the power quality of RES. IBSMFO was the proposed plan, which combined the two algorithms. It is presented to upgrade HRES to a DC-DC converter with the Optimal PQ.

In 2021, Das *et al.* [26] focused on improving PQ. The grid system's quality of power, particularly in microgrids connected to non-linear and unbalanced loads, was improved by using the proposed controller. The system's configuration combines a hybrid arrangement of PV with WECS, FC, and CAES, and the power management was handled by a distributed power-sharing algorithm. Using the FC, which serves as the hybrid system's compensator, reduces the voltage distortions at the PCC.

In 2018, Ashwin *et al.* [27] presented a high-concert DC-DC converter-based power inverter for microgrid applications. A paleochannel system's monographic seismic inversion lowers voltage harmonics and voltage unbalance while also enhancing the functionality of the microgrid. Voltage level of the inverter has no bearing on the use of elongated or disorganized loads. The suggested five-level three-phase inverter uses active power control to lower harmonics and boost performance.

In 2021, Sridhar *et al.* [28] proposed a droop controller that was used to investigate the MG's power management. The droop controller's goal was to manage MG's energy as efficiently as possible. The ALO and Bat algorithms were combined in the suggested method to improve the power management of MG. It mimics the natural ant lions' chasing behavior. The ALO algorithm's insect lion position was refreshed using the Bat algorithm.

In 2019, Ovaskainen *et al.* [29] examined the techniques of a BESS, along with the management equipment necessary to implement the power characteristic traits. Simulation outcomes were presented to demonstrate the viability of these features. The simulations showed how a BESS, in addition to performing active power exchange, could significantly contribute to microgrid stability.

In 2020, Thomas *et al.* [30] have presented the operation program of a microgrid's generating means was coordinated as a means of mitigating power quality problems. The proposed tool was operated in two stages sequentially. Table 1 shows the various authors reviews related to Power Quality Improvement.

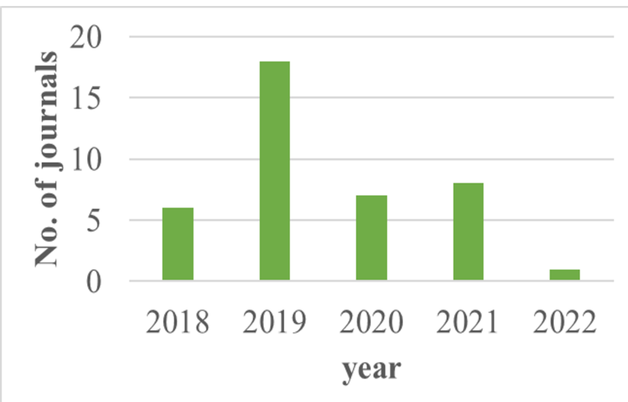

Fig. 2. Comparison Year graph

Fig. 2 shows the comparison graph of Years. In this review, 30 papers are collected from the year 2018- 2022. In 2018, 6 Research Articles are collected. In 2019, 8 Research Articles are collected. In 2020, 7 Research Articles are collected. In 2021, 8 Research Articles are collected and in 2022 1 Research Article is collected.

2.2 Research gap and challenges

Microgrids are increasingly incorporating renewable energy sources like solar, wind, and hydropower to increase their sustainability and lower their carbon footprint. However, the incorporation of renewable energy sources can result in poor power quality problems like harmonics, frequency deviations, and voltage fluctuations that can harm equipment and shorten the life of electrical components. Therefore, to ensure the dependability and efficiency of these microgrids, improving power quality in microgrids with renewable energy sources is a crucial issue that needs to be addressed. In microgrids with renewable energy sources, conventional power quality improvement techniques like voltage regulators, active filters, and passive filters may not be enough to solve these problems. In order to enhance power quality in microgrids using renewable energy sources, new and creative techniques like machine learning, deep learning, and optimization have been suggested. To guarantee the efficacy of these techniques in various microgrid scenarios, however, there are a number of research gaps and obstacles that must be overcome. By integrating renewable energy sources, energy storage systems, and controllable loads on a smaller scale, microgrids are emerging as a promising solution to improve the reliability and resiliency of the power grid. Voltage fluctuations, frequency deviations, harmonics, and other disturbances brought on by poor power quality can harm equipment and shorten the life of the electrical parts. Researchers are investigating the use of machine learning, deep learning, and optimization techniques to enhance power quality in microgrids to get around these problems. In microgrids, maintaining power quality is a significant challenge. Power quality problems like voltage fluctuations and frequency deviations can be predicted and detected in real-time using machine learning techniques, allowing for proactive management of these problems. To increase the efficiency of machine learning techniques for improving power quality, a number of research gaps must be filled. The choice of appropriate features for machine learning model training is one of the main challenges. It can be difficult to pinpoint the key characteristics for forecasting and identifying power quality issues in microgrid data because of its high degree of complexity and multivariate nature. Therefore, methods for data cleaning, outlier detection, and noise reduction must be developed in order to address issues with data quality. Finally, because of the constrained computational resources available, the deployment of machine learning models in microgrids can be difficult. Therefore, it is necessary to create compact machine-learning models that can be implemented in resource-restricted settings like microgrids. By discovering intricate patterns in the data, deep learning techniques can also be used to enhance power quality in microgrids. But the interpretability of deep learning models is one of the main issues.

However, due to the distributed nature of the system and the absence of standardized data formats, data collection in microgrids can be difficult. As a result, methods like transfer learning or data synthesis must be developed to address the data requirements. Finally, because of the constrained computational resources available, the deployment of deep learning models in microgrids can be difficult. Therefore, methods for optimizing deep learning models for deployment in environments with limited resources, like microgrids, must be developed. Therefore, it is necessary to create methods for making the optimization problem simpler while keeping the results' accuracy. Finding the best solutions can be difficult because the optimization problem may be highly nonlinear. Therefore, methods for dealing with non-linearity, like convex relaxation or linearization, must be developed. Finally, because of the constrained computational resources available, the deployment of optimization techniques in microgrids can be difficult. Therefore, it is necessary to create lightweight optimization methods that can be applied in environments with limited resources, like microgrids. In general, applying optimization, deep learning, and machine learning techniques to improve power quality in microgrids has the potential to increase the resiliency and effectiveness of microgrids. To guarantee the efficacy of these methods, it is crucial to address the issues and research gaps mentioned above. It's also important to keep in mind that the effectiveness of these techniques can change depending on the microgrid's unique features, such as its size, topology, and energy resource mix. Therefore, additional research is required to assess these techniques' performance in various microgrid scenarios and pinpoint their drawbacks.

The implementation of integrated strategies that integrate multiple techniques for power quality improvement in microgrids is one specific research area that needs more attention. For instance, by anticipating and identifying power quality issues and optimizing the operation of the microgrid components to mitigate these issues, the combination of machine learning and optimization techniques can offer a comprehensive approach to power quality improvement. To explore the potential advantages and constraints of these integrated approaches, more research is required as there has only been a limited amount of study on the integration of these techniques for improving power quality in microgrids.

Microgrids are proving to be a promising way to increase energy efficiency and guarantee a steady supply of electricity, particularly in outlying or rural areas. Power quality problems like voltage fluctuations, harmonics, and transient disturbances can arise from the use of power electronics in microgrids and the integration of distributed renewable energy sources. For microgrids to be stable and reliable, these power quality issues must be resolved. There are still many research gaps and difficulties in the field of power quality improvement, despite the growing interest in microgrids. The limited knowledge of the financial effects of power quality issues on microgrid performance is one of the major research gaps. Few studies have examined the financial ramifications of these solutions, despite the fact that many have examined the technical aspects of power quality improvement. Installing equipment to reduce power quality, such as capacitors or filters, can be expensive and not always yield a sizable return on investment. In order to assess the effectiveness of various power quality improvement strategies and their effects on microgrids' overall financial performance, more research is required. For measuring power quality in microgrids, there is currently no accepted international standard, which makes it difficult to compare the findings of different studies. Moreover, a multidisciplinary approach to power quality monitoring and assessment is necessary due to the complexity of microgrid systems and the variety of sources of power quality problems. Therefore, more study is required to create standardized techniques for determining and rating power quality in microgrids.

3. Conclusion

Power quality is a crucial component of contemporary power systems, and ensuring it is essential for the grid's dependable operation. Microgrids powered by renewable energy present an alluring way to improve power quality in isolated or remote areas while cutting greenhouse gas emissions. Power fluctuations, voltage instability, and frequency deviation are just a few of the significant problems that grid integration with renewable energy sources can bring about. An analysis of the literary theory on the improvement of power quality is conducted in this research project. This review paper assesses 30 literature review articles that have been published in reputable journals between 2018 and 2022. The primary focus is on progressing the quality of power in microgrids that operate on renewable energy sources. Specifically, the paper explores the application of a hybrid deep learning approach as a means to enhance power quality in these microgrids.

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