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Microgrid Power Quality Enhancement with Adaptive Control Strategies: A Literature Survey

***Abstract**. Renewable energy technologies are becoming more and more common for generating electricity because they are environmentally friendly and can meet local electricity needs. They reduce network congestion and also lighten the load on conventional based power plants. Within the last few decades, grid-connected renewable energy systems have seen a rise in the significance of Power Quality issues, particularly as a result of the extensive usage of nonlinear electronics and the sporadic nature of these systems. With the emergence of power electronic converters through powerful control technology, renewable energy systems be interconnected to a large extent with the power grid or used as isolation systems in remote areas. Using additional competent control strategies can enhance not only improve the concert of these systems, but also calibre the quality of energy generated, distributed and used at the load side of Power System. Hence, this paper reviews various control strategies adopted for alleviation of power quality problems of renewable energy coordinated microgrid system and can be useful as research study for further research.*

***Streszczenie.** Technologie energii odnawialnej stają się coraz bardziej powszechne w wytwarzaniu energii elektrycznej, ponieważ są przyjazne dla środowiska i mogą zaspokoić lokalne zapotrzebowanie na energię elektryczną. Zmniejszają przeciążenie sieci, a także zmniejszają obciążenie konwencjonalnych elektrowni. W ciągu ostatnich kilku dekad systemy energii odnawialnej podłączone do sieci odnotowały wzrost znaczenia kwestii jakości energii, szczególnie w wyniku szerokiego wykorzystania nieliniowej elektroniki i nieciągłego charakteru tych systemów. Wraz z pojawieniem się przetwornic energoelektronicznych dzięki zaawansowanej technologii sterowania, systemy energii odnawialnej mogą być w dużym stopniu połączone z siecią energetyczną lub wykorzystywane jako systemy izolacji w odległych obszarach. Zastosowanie dodatkowych kompetentnych strategii sterowania może nie tylko poprawić działanie tych systemów, ale także poprawić jakość energii wytwarzanej, dystrybuowanej i wykorzystywanej po stronie obciążenia Systemu Elektroenergetycznego. W związku z tym niniejszy artykuł zawiera przegląd różnych strategii sterowania przyjętych w celu złagodzenia problemów z jakością energii w skoordynowanym systemie mikrosieci energii odnawialnej i może być przydatny jako studium badawcze do dalszych badań. (**Poprawa jakości energii w mikrosieciach za pomocą strategii sterowania adaptacyjnego: przegląd literatury**)*

Keywords: Power Quality, Microgrid, Power Converter Control, Renewable Energy.
Słowa kluczowe: Jakość energii, mikrosieci, sterowanie przetwornicą mocy, energia odnawialna.

1. Introduction

Now-a-days, some environmental issues arise due to carbon emissions from fossil fuel power plants, which cause environmental pollution and global warming. Alternatively, Renewable Energy (RE) based generating systems are regarded clean and cheap in comparison with conventional electricity generation. Various RE sources are Solar PV energy, Wind energy, Small Hydroelectric plants, Biogas, Geothermal energy, and Tidal and Wave energy. Of these resources, Solar PV and Wind energy systems hold the majority promise owing to the low cost of electricity production and the ability to track maximum power points over an ample range of wind and sunlight discrepancies [1]. Because of this, governments and some private firms are solicitude in increasing the production of energy from renewable sources by replacing production based on fossil fuels. By 2030, in compliance with the International Renewable Energy Agency, the worldwide plan for the integration of RE resources are of 36% of global energy demand and is expected to come from renewables [2]. Due to the unavailability and pollution of traditional energy resources, the integration of RE resources into the grid has completely changed the structure of modern power systems. Hence, the microgrid (MG) concept has attracted a lot of attention from system operators in order to improve operational efficiency and ensure a more reliable, sustainable and economical power system [3].

Microgrid can be considered an alternative to the consumption of traditional plants based on fossil fuels to reduce the energy supply deficit. It enables the benefits of efficient and sustainable energy supply, reduced carbon emissions, and delayed expansion of distribution infrastructure. A Microgrid has the ability to operate as a single system, and if there is a problem with the grid, it can be disconnected or independent from the main power system and reconnected to the grid when the problem is resolved [4]. One-off the core intention for the progress of the MG structure is the incursion of RE sources. Thus, the basic characteristic parts of MG have Dispersed Energy Resources (DER), consumers, and regulators, as depicted in the Fig.1. below. However, integrating renewable energy into the main grid becomes an exigent task due to the intermittency of energy sources nature and so adaptive control strategies are required for power converter control [5] as described in the following sections to improve Power Quality (PQ) in a microgrid.

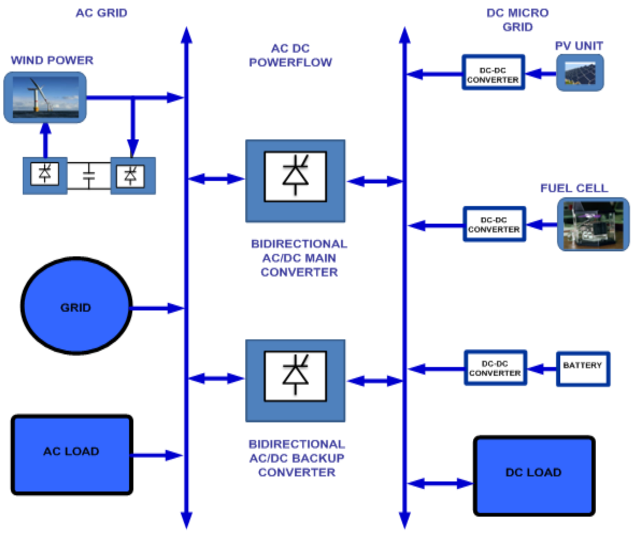

Fig.1. Typical RE based Microgrid System

In this paper, an introduction is dealt in section-1, section-2 mention Power Quality issues, challenges and possible solutions in microgrid, section-3 explains the different power quality enhancing methods, section-4 describes power converter controller strategies for PQ issues and conclusion part in section-5.

2. Power Quality Issues in a Microgrid

The term "Power Quality" (PQ) in general refers to distribution bus voltage that remains nearly sinusoidal at rated amplitude and frequency. Furthermore, the energy made available to customers has got to be well-thought-out from a reliability viewpoint [6, 7]. The impact of power quality problems once microgrid connected to the main grid have concern due to the augmented penetration of non-linear loads and distributed energy systems with power electronic converter (PEC) interfaces. Challenging problems of grid integration are related to power quality issues related to current harmonics and that of voltage like voltage sag/swell, voltage imbalances & distortions caused by grid failures; frequency fluctuations, energy optimal layout and system isolation in abnormal conditions [8]. Proper control of the RE resources connected power electronic converter is essential that ensures stable operation in a period of transients and changes in AC system parameters. Renewable energy must be controlled using PEC to meet load requirements in stand-alone system applications and meet grid codes in grid-tied mode. It is reported that the Islanded mode is more likely to experience disturbances, such as voltage distortions and unbalances, since load distribution is unbalanced and line impedance is very high compared to grid-connected mode. To filter harmonics and smother unbalances, PE interfaced converters (inverters) could be effectively controlled [9]. In the grid-connection mode, disturbances such as grid voltage imbalance and voltage drop are the most common problems. Power Quality and stability of the system can be achieved via suitable control techniques incorporated to the power converter control circuit. Due to these impacts, improvement of the power quality of electric systems becomes a mandatory requirement. Hence, power quality problems get remunerated in control strategies applied to the interfacing inverter as mentioned in following section.

2.1 PQ Challenges and Solutions in a Microgrid

Now-a-days, some progressive technologies and techniques are being used continuously to develop and address the power quality challenges and their mitigation brought about by the incorporation of renewable energy in a microgrid [10]. Table 1. outlines the foremost challenges faced by grid-connected and islanded microgrid systems along with feasible remedies or mitigations.

Table 1. PQ Challenges and possible mitigating remedies in a microgrid [11]-[15]

Operational Mode	Challenges	Mitigating Solution
Grid Connected	Irregular Solar (PV) radiation and Voltage fluctuations due to variations in the wind speeds	Series &Shunt APFs. Power compensators like Fixed and/ or Switched Capacitor or Static Compensator. Utilities line conditioning systems and less sensitive consumer's equipment's to power disturbance/ voltage distortions.
Grid Connected	Frequency fluctuations for unexpected variations in active power caused by loads	PWM inverter control for regulating the frequency and voltage of a 3-Φ AC local bus in a Microgrid.
Grid Connected	Harmonics due to Power Electronic Controllers and non-linear appliances	Switching PWM Converter and applying the proper filters.
Grid Connected	Synchronization	Phased Locked Loop (PLL). In addition, grid voltages can be monitored for zero crossings and filter combinations can be used in conjunction with non-linear transformations
Stand-alone	Discontinuous in Energy and Power Quality	Incorporating RE resources with BESS or fuel cells, in a few situations with Diesel generator support systems.
Stand-alone	Protection	Appropriate protection & control equipment have to be incorporated for security reasons including upgrading existing systems when RE resource is connected.
Stand-alone	High Cost of Energy Storage	Incorporating both solar PV and Wind energies will curtail storage necessities and eventually on the whole system cost.
Stand-alone	Storage come to an end	Assimilate PV, Wind energies with Fuel-Cells.

3. Microgrid Power Quality

Currently, a major area of research in industry and academia is the network interaction of RE's for improved system performance. In the incidence of non-linear loads, a microgrid powered by a RE's integrated into the main grid generates harmonic currents that are in phase opposite to the reactive currents of the load [16]. Harmonic components are introduced by RE integration, which lowers the quality of the power at the point of common connection (PCC) into the network which must not exceed certain limits. The various measures have been carried out to enhance the quality RE resources generation, including that of the application of improved management strategies and the usage of various auxiliary equipment [17]. This section discusses controllers that encompass premeditated literature intended for mitigating power quality problems in a microgrid.

Power Electronics Converters are known to be the heart of the REs; these devices are responsible for injecting harmonics into the system. Various advanced methods of controlling inverters of RE systems for harmonic suppression are presented in [18]. The improvement of power quality with the use of filters or auxiliary equipment was suggested in [19] for hybrid PV/wind power plants. PQ issues namely power oscillations, harmonics, power factor, and voltage imbalances are significantly improved by FACTS controllers in highly RE perforated systems [20]. The power quality is improved by using a variety of energy storage devices, particularly for the purpose of power smoothing in RE systems discussed in [21, 22]. These include batteries, supercapacitors, and flywheel energy storage. Additionally, various techniques such as electric springs [23], soft computing-based approaches [24], and modular multilevel converters (MMC) are used in refining the power quality of RE systems [25]. The summary of the different strategies discussed in this section for improving the power quality of the system are as shown in Fig.2 below.

4. Controller Strategies for Power Quality Enhancement

This section provides an enhanced Islanded/grid-connected converter control techniques using adaptive control to enhance performance and repress harmonics in a microgrid where local steady and dynamic AC/DC loads are also coupled to the point of common connector (PCC). Controllers for these microgrids must include fast transitions between grid-tied as well as islanded modes of operation to mitigate the effects of mains outages and reduce the impact of RE's intermittency and compensate for the existence of harmonic or unbalanced loads, thereby improving microgrid power quality.

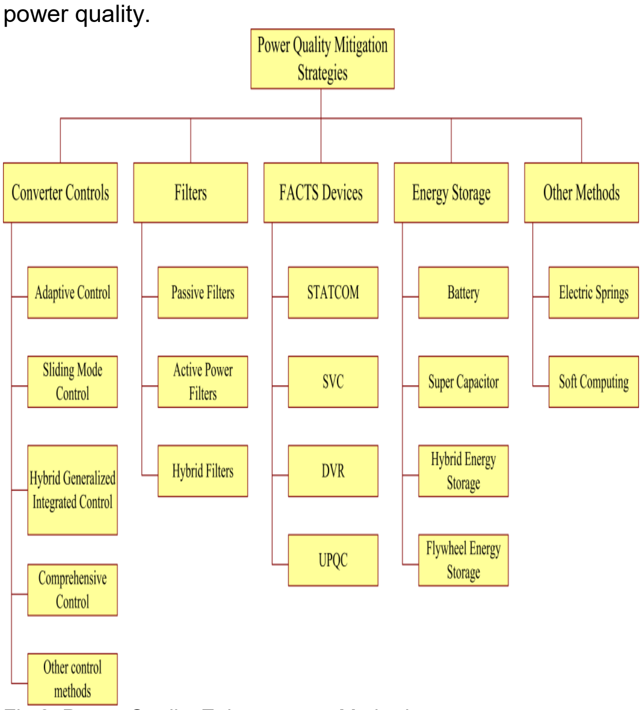

Fig.2. Power Quality Enhancement Methods

Hence, power quality problems get remunerated in control strategies applied to the interfacing inverter as shown in the Table 2. below.

Table 2. Different Power Converter Control Strategies

Reference	Controller Strategy	Features
[26, 27]	PI Controller (Natural Reference Frame)	Simple control structure. Regulates the basic component. Unbalanced systems cannot be guaranteed to perform effectively.
[28, 29]	PI Controller (Synchronous Reference frame)	It shows satisfactory performance in the regulation of DC variables. Ensure zero error in the steady-state. Poor lower order harmonic compensation
[30, 31]	Proportional Resonant (PR) Controller	Robust current controller. Ensure zero error in the steady-state. Obtains high gain values. Resonance problems are caused by changes in load parameters and in operating conditions.
[32, 33]	Hysteresis Current Control	Simple structure. Essentially robust. Not considering of changes in load parameters. It provides great dynamics. Lower order harmonics has no concern. There is no fixed switching frequency.
[34, 35]	Repetitive Controller	Periodic disturbances eliminated. Essentially robust. Ensure that the Steady-State Error is zero for all harmonic frequencies. Stability is a problem when the load disturbance is aperiodic. Slow response when load varies.
[36, 37]	Deadbeat Control	Simple in nature. Highly tracking speed and control accurateness is obtained. Performance relies on the sample frequency. Sensitive to system parameter variations.
[38, 39]	H∞ Control method	Suitable for Multi Input Multi Output (MIMO) systems. It offer less THD and better performance. Considers plant complexity, uncertainties, perturbations or dynamics. It makes sure of good performance under each type of loads. Slow dynamics. Because modelling is complex, it requires knowledge of advanced mathematics.
[40, 41]	Fuzzy Controller	Able to control the nonlinear behaviour of complex control structures using heuristic and expert knowledge of controlled process. Insensible to system changes. Slow control method.
[42, 43]	Neural Networks method	Used by current controllers because they are robust in nature. Offline training methods lack efficiency.

Table 2. lists some of the different features of distinct controller's methods. Hence, from the above discussion it can be found that PI controller, Hysteresis Current control and Fuzzy method controllers are extensively used as the power converter controller strategies. Although, many deliberations are made in the studies on control methodologies in improving power quality of the microgrid systems, no single control technique can solve all power quality problems simultaneously. Therefore, future research will capable of focusing on the development of control techniques that meet the requirements and highly dependent on proper system modelling with the application of advanced control strategies such as optimization techniques [44, 45, 46] applied to the microgrid system controller design.

4.1 Power Quality Enhancement with Optimization/AI techniques

The goal of power quality in microgrids is solved using a variety of AI-based optimization strategies. Optimized linear and nonlinear models are suitable for grid connected as well as islanded modes of microgrid [47]. PSO is an intelligent computing technique that searches for the best parameter settings in real-time [48]. For the purpose of removing voltage harmonics in microgrid systems with numerous DG sources, a union of PSO based PWM and SPWM inverters was proposed in [49]. A concurrent self-tuning technique was described in [50] as the basis for an optimal control approach considering the criteria of Voltages, frequency regulation, and power-sharing in performance evaluation during microgrid operational mode changes and sudden load variations. With the intention of improving power quality in multi-bus microgrids, the authors [51] suggested an optimization technique with primary goal was to mark voltage regulation at specific buses. A controller with gains derived from system admittance and tuned via Ant-Lion Colony (ALC) algorithm was proposed in [52]. In [53], a PI controller with settings adjusted using a whale's optimization algorithm (WOA) was suggested. The apparent controller regulates voltage and frequency within an autonomous microgrid that is powered by inverters.

The authors in [54] devised a control approach that uses the Grasshopper optimization technique to govern the optimal gains in the PI controller meant for power quality enhancement in photovoltaic-based microgrids running in the autonomous mode. A Slap Swarm Optimization (SSO) based PI controller was implemented in [55] for improving power quality under conditions of dynamic loads.

5. Conclusion

- This article provides a comprehensive review on various control strategies and state-of-art-tools utilized for extenuating power quality issues in a renewable energy coordinated microgrid.
- Different controllers and their control strategies that are intended for enhancing power quality are discussed with possible challenges and solutions thoroughly.
- Also, the study deals several optimization approaches for renewable energy resources interfacing power electronic converter in terms of power quality performance.
- Further studies are recommended in the usage of adaptive control techniques and hybrid optimization algorithms which results in better performance and efficacy in improving the power quality of a microgrid.

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