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A Review on Improved Secondary Distribution Network for Power Quality in Grid Integration of Small-Scale Photovoltaic System

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ABSTRACT

The grid integration of small-scale photovoltaic systems involves connecting the distributed energy resources to the electricity grid. To design an improved secondary distribution network for enhanced power quality in the integrated grid of small-scale photovoltaic systems, it is imperative to address various technical challenges. Hence, this review paper presents a comprehensive overview of the recent developments in various power quality improvement methods for power quality enhancement in grid integration, focusing on PI-Based Reactive Power Control Systems, Flicker Logistic Control Methods, Automated Filtering Mechanisms, Shunt Active Power Filter modules, Integrated Optimization-based AI Technique and Grid Synchronization Techniques. The review explores the benefits and drawbacks of each technique, providing an in-depth understanding of their respective contributions to improving power quality. Also, it provides a comparative analysis to demonstrate the effectiveness of various techniques for enhancing power quality. The review systematically evaluates how each method addresses challenges such as voltage fluctuations, harmonics, and flicker, thereby contributing to a more stable and reliable power supply. The review also highlights the future research directions and challenges in implementing various techniques for enhancing power quality in grid integration of small-scale photovoltaic systems and provides some suggestions for further improvements to be done in the future for better power quality in grid integration of small-scale photovoltaic system

Keywords: **Logistic Control Methods, Reactive Power Control, Grid Synchronization, small-scale photovoltaic system, Shunt Active Power Filter**

1. INTRODUCTION

Because of the depletion of fossil fuels and the need to reduce their negative impact on the environment, the use of renewable energy is constantly evolving today. Photovoltaic energy generation is becoming more popular in both urban and rural areas due to its low cost, low noise, and easy availability. Microgrids are commonly used to distribute electrical energy in rural communities [1]. There are two types of microgrids: standalone and grid-connected. The solar power plant is disconnected from the grid in standalone photovoltaic microgrids. In this case, the plant is designed for a low voltage distribution network and is subject to voltage imbalance as load imbalance increases, which can be dangerous for some equipment such as 3-phase motors [2]. Furthermore, due to bad weather conditions, a standalone PV system cannot supply load at night and at times during the day; thus, an energy storage system is typically used to stabilize the level of produced energy [3]. When power converters are used, harmonics are introduced into the system. In contrast, the increased use of sensitive electronic circuits in industries and households, as well as privatization and rivalry in electric energy systems, pose power quality improvement as one of the key problems in the electrical industry. Harmonics cause source voltage distortion and addition loss due to unwanted current flowing in the source. It may also lead to the malfunctioning of relays, mains, and other control units. As a result, it is necessary to reduce the harmonics. There are numerous techniques for reducing the effect of harmonics [4, 5]. One of these methods is to use SAPF, which generates a harmonic current of

equal magnitude and polarity to the harmonic current produced in the system, canceling the harmonic current in the system. Because it contains power electronic devices, it has a fast response time and flexibility in operation.
Shunt Active Power Filter (SAPF) is capable of compensating harmonics, and current distortion, and injecting power generated by unconventional resources [6]. The SAPF is a load-related voltage source inverter (VSI). For various load conditions, the Shunt Active Power Filter can keep the current balanced and sinusoidal after remuneration. Power switching devices are used to convert DC to AC power. As a result, the output waveforms are composed of distinct values, yielding output that is more oscillatory rather than filtered. When and how long the power values can become active, the capacity to deliver close sine waveforms around the key recurrence is directed by the tyrannical regulation technique. Additionally, Static Volt-Ampere Reactive Compensators (SVC) play a role in controlling system voltages, enhancing transient stability, and increasing grid capacity [7, 8]. The integration of PV cells involves the challenge of efficiently converting electromagnetic waves into electricity.

The MPPT technique employed in the PV system plays a crucial role in maximizing the utilization of the PV array output power and efficiently tracking the Maximum Power Point (MPP) from the PV array input. Detecting the voltage or current MPP automatically poses a significant challenge in MPPT techniques [9]. This challenge is further compounded by the impact of changes in output voltage on MPPT output characteristics [10]. Despite the advantages of MPPT techniques, existing inverter levels exhibit some inaccuracy due to the additional functionalities required. This inaccuracy is particularly relevant when considering the time required to predict the Global Maximum Power Point (GMPP), which is directly proportional to the number of PV arrays and the complexity of the system design [11].

To address power quality issues, Distributed Flexible AC Transmission System (DFACTS) devices with control algorithms are deployed at the point of common coupling (PCC). DSTATCOM and UPQC, for example, adjust voltage, impedances, and power to improve system dynamics. Devices are classified as series, shunt, series-series, or shunt-series [12, 13]. Traditional control algorithms based on synchronous reference frame theory (SRFT) and instantaneous reactive power theory (IRPT) have drawbacks such as slow response and poor stability. Overcoming these, AI-based algorithms based on deep learning and machine learning provide precise PQ issue mitigation via data modeling. However, these models face challenges such as a lack of creativity and increased system costs. The least mean square (LMS) and least mean fourth (LMF) adaptive control algorithms address intermittency in solar PV generation by improving dynamic responses, adaptivity, computational efficiency, and enhanced dynamic responses in grid-connected solar PV systems [13-15]. Many researchers have introduced various techniques for power quality enhancement in grid integration of small-scale photovoltaic systems but the directions of analyzing the approaches have very rarely been summarized. The main contribution of the review paper is to study enhanced power quality which is given below:

- To reduce the voltage fluctuations, harmonics, and flicker in power quality enhancement in grid integration of small-scale photovoltaic systems, various power quality improvement methods are reviewed with their significance and limitations.
- Various power quality improvement methods such as PI-Based Reactive Power Control Systems, Flicker Logistic Control Methods, Automated Filtering Mechanism, Shunt Active Power Filter modules, Grid Synchronization Techniques, and Integrated Optimization-based AI Techniques are used to enhance the power quality, and these techniques are analyzed with their significance and limitations

The content of the paper is organized as follows: Section 2 presents the literature survey of various approaches for load frequency control in an interconnected power system, section 3 provides comparative analysis; Section 4 discusses the result, section 5 concludes the paper, and finally, section 6 provides the future perspective.

2. LITERATURE SURVEY

In this section, the review has been provided by discussing various technologies for power quality in grid integration of small-scale photovoltaic systems. Also, the significance and limitations of these techniques are described. The directions for power quality techniques are shown in Figure 1.

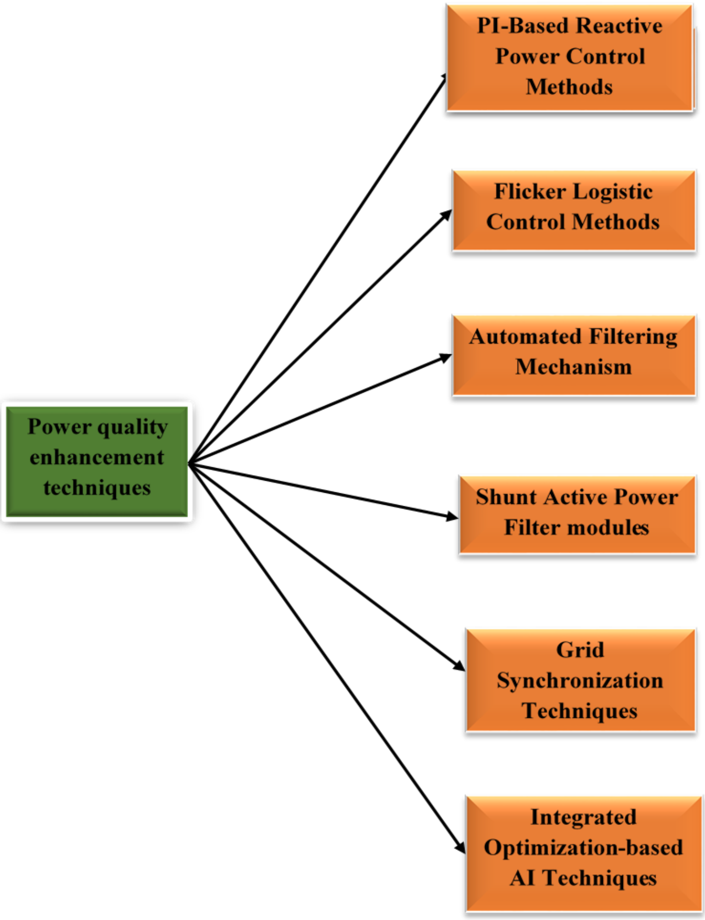

Figure 1: The directions for power quality enhancement techniques

This review has been made in six different phases of power quality enhancement in grid integration of small-scale photovoltaic systems namely, PI-Based Reactive Power Control System, Flicker Logistic Control Methods, Automated Filtering Mechanism, Shunt Active Power Filter module, Grid Synchronization Techniques, and Integrated Optimization-based AI Techniques.

2.1 Review on PI-Based Reactive Power Control System in Grid Integration

In this review of power quality enhancement using various PI-Based Reactive Power Control Systems in grid integration of small-scale photovoltaic systems, Many PI-based reactive Power Controls are used in power quality enhancement such as optimal fractional order PID controller, Fuzzy PID controller, Fuzzy adaptive PI controller, Multi-stage fuzzy-based flexible controller, and Distributed power flow controller. However, there were some limitations, such as the computational burden and testing is a challenge for real-time applications, as well as the limited adaptability to a wide range of scenarios. Therefore, controllers must be developed to properly enhance the power quality in grid integration of small-scale photovoltaic systems[16-25].

Table 1: Review on PI-Based Reactive Power Control System in Grid Integration

Ref no	Techniques/method	Significance	Limitations
[16]	Optimal fractional order PID controller	Reduce settling time and overshoot	The controller's ability is affected by the errors in the probabilistic models.
[17]	Fuzzy-PI and fuzzy-PID	Reduced voltage fluctuation, and reduced overshooting.	Fuzzy controllers have a computational burden in real-time applications.
[18]	Fuzzy adaptive PI controller	Solve power quality problems and mitigate voltage sags, voltage swells, and load harmonic.	Environmental conditions affect the controller's robustness.
[19]	Multi-stage fuzzy-based flexible controller	Achieved voltage stabilization and ensured the lowest harmonic distortion.	Fuzzy controllers have a computational burden in real-time applications.
[20]	Distributed power flow controller	Mitigate the power quality issues and current harmonics.	The controller needs to be adopted.
[21]	Fuzzy Logic Controller	Ensured voltage recovery, increased accuracy, and negligible voltage dip	Environmental conditions affect the controller's robustness and testing is a challenge for real-time applications
[22]	Fuzzy logic-based modified real-reactive power control	Limiting grid overcurrent by reducing active power flow.	Risk of changes in the operating environment.
[23]	Double second-order generalized integrator phase-locked loop	PI controller's gain to obtain a fast response and improve the system's power quality.	The controllers are required to be adaptable.
[24]	Highly Reduced Fuzzy Logic Controller	This simplifies the implementation process and also results in significant time and cost savings.	Adaptability to a wide range of scenarios is limited.
[25]	Cascaded H-bridge inverter	Improve the system's power quality, flexibility, and efficiency of the photovoltaic system.	Unwanted oscillation happens in rapid changes.

Table 1 gives the power quality enhancement using various PI-Based Reactive Power Control Systems in grid integration of small-scale photovoltaic systems. From the table, it is observed that the power quality enhancement in an in-grid integration of a small-scale photovoltaic system is reviewed and the advantages as well as the disadvantages of using various PI-Based Reactive Power Controls are also reviewed. Many PI-based reactive Power Controls are used in power quality enhancement such as optimal fractional order PID controller, Fuzzy PID controller, Fuzzy adaptive PI controller, Multi-stage fuzzy-based flexible controller, and Distributed power flow controller. However, there were some limitations, such as the computational burden and testing is a challenge for real-time applications, as well as the limited adaptability to a wide range of scenarios. Therefore, controllers must be developed to properly enhance the power quality in grid integration of small-scale photovoltaic systems.

2.2 Review on Flicker Logistic Control Methods in Grid Integration

This review gives the various flicker logistic control methods using power quality enhancement in grid integration of small-scale photovoltaic systems. it is observed that the logistic control methods are reviewed and the advantages as well as the disadvantages of the various secure data transmission in network security are also reviewed. Many logistic control methods such as Unified Power Quality Conditioner, Dynamic voltage restorer, Static Var compensator, Static synchronous compensator, and Distribution static compensator were analyzed. However, all these approaches have some limitations such as reactive power imbalances caused by solar power's fluctuating nature, power consumption increases and the cost of batteries and associated power electronics make this approach too costly. Hence, there is a need for logistic control methods to improve the power quality in grid integration of small-scale photovoltaic systems[26-35].

Table 2: Review on Flicker Logistic Control Methods in Grid Integration

Ref no	Techniques/method	Significance	Limitations
[26]	Distribution static compensator	Achieving unity power factor and keeping the power quality stable.	Adapting the system to different scales and configurations necessitates additional considerations
[27]	Static compensator integration in distribution networks	Reduce active and reactive power demand and reliance	Cost-effective and power consumption increases.
[28]	Static Var compensator	Provides well-enhanced voltage stability, the smallest voltage deviation, and active power loss	Reactive power imbalances are caused by solar power's fluctuating nature.
[29]	Dynamic voltage restorer	Supply power to sensitive loads.	The cost of batteries and associated power electronics make this approach too costly.
[30]	Dynamic voltage restorer	Mitigation of voltage sags, improving the overall power quality.	The combination of various technologies makes the system more complex.
[31]	Static synchronous compensator	Improving voltage regulation, improving the performance and reliability of these systems	Introduce additional system disturbances in the form of current unbalanced and harmonic injections.
[32]	Unified Power Quality Conditioner	Integrating power quality improvement and clean energy generation.	Local loads experience some disruption during the switch.
[33]	Quasi Z-source inverter-based UPQC	Reducing current and voltage instabilities, and	Scalability across different scales of solar PV

		harmonic content.	installations poses a challenge.
[34]	Transformerless dynamic voltage restorer	The converter achieved high voltage gain through its soft-switching capability.	This affects the consistent performance of the DVR system.
[35]	Integrated distribution static synchronous compensator	Voltage fluctuation was negligible.	Reactive power imbalances are caused by solar power's fluctuating nature.

Table 2 gives the various flicker logistic control methods using power quality enhancement in grid integration of small-scale photovoltaic systems. From the table, it is observed that the logistic control methods are reviewed and the advantages as well as the disadvantages of the various secure data transmission in network security are also reviewed. Many logistic control methods such as Unified Power Quality Conditioner, Dynamic voltage restorer, Static Var compensator, Static synchronous compensator, and Distribution static compensator were analyzed. However, all these approaches have some limitations such as reactive power imbalances caused by solar power's fluctuating nature, power consumption increases and the cost of batteries and associated power electronics make this approach too costly. Hence, there is a need for logistic control methods to improve the power quality in grid integration of small-scale photovoltaic systems.

2.3 Review on automated filtering mechanism in grid integration

The review gives the various automated filtering mechanisms using power quality enhancement in grid integration of small-scale photovoltaic systems. It is observed that the power quality enhancement in grid integration of small-scale photovoltaic systems using various automated filters is reviewed and the advantages as well as the disadvantages of the various are also provided. Various automated filtering mechanisms are used for power quality enhancement in grid integration of small-scale photovoltaic systems such as LCL filter, Shunt hybrid active filter, Hybrid series active power filter, Fractional order notch filter-based control, LC passive filters Recursive Digital Filter, Hybrid harmonic filter. However, some limitations include its inability to adapt to dynamic real-world conditions, variations in frequency and voltage that cause grid instability, and voltage spikes that occur across the filter components. To effectively improve the power quality in grid integration of small-scale photovoltaic systems, the filters' performance must be improved [35-45].

Table 3: Review on automated filtering mechanism in grid integration

Ref no	Techniques/method	Significance	Limitations
[36]	LCL filter	Filters out harmonics and increases power quality.	Voltage spikes occur across the filter components
[37]	Shunt hybrid active filter	PV systems to improve performance under different operating conditions.	Solar irradiation caused fluctuations in the generated power.
[38]	Hybrid series active power filter	To minimize the usage of energy from the utility grid.	Variations in frequency and voltage cause grid instability.
[39]	Fractional order notch filter-based control	Designed control system handled harmonic distortion in grid current, reactive power demand of the load, and unbalanced load currents.	Filters exhibit overshoot and ringing behavior in sudden changes.

[40]	LC passive filters	The grid system significantly reduced the inverter output current.	Distortions of voltage and current waveform, decreased system efficiency, and increased losses in the system.
[41]	Recursive Digital Filter	Improving power quality and ensuring power transfer between the utility grid and connected loads.	Performance reduces due to the slow response of variable insolation conditions.
[42]	Shunt active power filter	Provide a smooth DC-link voltage and reduce total harmonic distortion.	Inefficient for dynamic load changes, and high computational burden.
[43]	Hybrid shunt active power filter	Improve power quality by compensating harmonics and regulating reactive power.	When renewable energy generation is low and load demands are high, this harms the power supply's dependability and stability.
[44]	Hybrid harmonic filter	Optimized the size and number of passive filters, and hysteresis bandwidth.	Power quality needs to be improved by using different hybrid filter topologies.
[45]	LC filters	Enhancing dynamic stability and power quality under any conditions.	Lack of adaptability to dynamic real-world conditions.

Table 3 gives the various automated filtering mechanisms using power quality enhancement in grid integration of small-scale photovoltaic systems. It is observed that the power quality enhancement in grid integration of small-scale photovoltaic systems using various automated filters is reviewed and the advantages as well as the disadvantages of the various are also provided. Various automated filtering mechanisms are used for power quality enhancement in grid integration of small-scale photovoltaic systems such as LCL filter, Shunt hybrid active filter, Hybrid series active power filter, Fractional order notch filter-based control, LC passive filters Recursive Digital Filter, Hybrid harmonic filter. However, some limitations include its inability to adapt to dynamic real-world conditions, variations in frequency and voltage that cause grid instability, and voltage spikes that occur across the filter components. To effectively improve the power quality in grid integration of small-scale photovoltaic systems, the filters' performance must be improved.

2.4 Review on Shunt Active Power Filter Module in Grid Integration

The review gives the various shunt active power filter modules for power quality in grid integration of small-scale photovoltaic systems, it is observed that the detection of power quality in grid integration are reviewed and the advantages as well as the disadvantages of the various shunt active power filter module are also reviewed. Many shunt active power filter modules such as Hybrid active power filter, Shunt Active Power Filter, switched power filter compensator, and Three-phase half-bridge interleaved buck shunt active power filter are presented to reduce settling time and total harmony distortion and improve power quality in grid integration of small-scale photovoltaic systems. However, all these approaches have some limitations such as low reactive power levels leading to voltage instability, and the ability to address voltage fluctuations is limited. Hence, there is a need to develop a shunt active power filter module to effectively improve the power quality[46-55].

Table 4: Review on shunt active power filter module in grid integration

Ref no	Techniques/method	Significance	Limitations
[46]	Shunt active power filter based on a PLL	SAPF mitigation suppressed non-sinusoidal harmonic current and increased active power.	Low reactive power levels lead to voltage instability.
[47]	Three-phase half-bridge interleaved buck shunt active power filter	Achieve a high degree of compensation for current harmonics and reactive power	Low reactive power levels lead to voltage instability
[48]	Solar PV-integrated universal active power filter	The proposed system combines the advantages of clean energy generation with improved power quality.	Voltage and frequency fluctuations are caused.
[49]	Shunt active power filter	The proposed controller reduced the harmonics.	Processing power and memory of digital signal processors are limited, affecting the controller's efficiency and performance.
[50]	SRF theory-based Shunt active power filter	Reduced settling time and total harmony distortion.	Affected the system's real-time performance.
[51]	Shunt Active Power Filter	LME provided a significant steady-state response and power quality improvement.	The computational complexity of the system has an impact on its real-time performance.
[52]	Grid-tied Shunt Active Power Filter	Estimates the harmonic current.	Affected the system's real-time performance.
[53]	Hybrid active power filter	Hysteresis current control eliminates harmonic.	Their ability to address voltage fluctuations is limited.
[54]	A switched power filter compensator and a switched active power filter	Eliminate the harmonic amplitude of the current and voltage and controller error.	Voltage and frequency fluctuations are caused.
[55]	Single-phase active power filter	Ensure high grid current quality and minimize switching frequency.	Implementing a modified PUC converter requires the use of additional components.

Table 4 gives the various shunt active power filter modules for power quality in grid integration of small-scale photovoltaic systems. From the table, it is observed that the detection of power quality in grid integration are reviewed and the advantages as well as the disadvantages of the various shunt active power filter module are also reviewed. Many shunt active power filter modules such as Hybrid active power filter, Shunt Active Power Filter, switched power filter compensator, and Three-phase half-bridge interleaved buck shunt active power filter are presented to reduce settling time and total harmony distortion and improve power quality in grid integration of small-scale photovoltaic systems. However, all these approaches have some limitations such as low reactive power levels leading to voltage instability, and the ability to address voltage fluctuations is limited. Hence, there is a need to develop a shunt active power filter module to effectively improve the power quality.

2.5 Review on Grid Synchronization Techniques in Grid Integration

The review gives the power quality improvement using grid synchronization techniques in grid integration of small-scale photovoltaic systems, it is observed that the power quality improvement in grid integration of small-scale photovoltaic systems is reviewed and the advantages as well as the disadvantages of using various grid synchronization techniques are also reviewed. Many synchronization techniques are used in power quality improvement such as Phase Locked Loop, DQ current control theory, Mixed third and fourth-order complex filter, Vector-based synchronization, Adaptive feed-forward PLL, and lightweight inertial PLL. However, there were some limitations such as PLLs exhibiting transient responses during sudden grid changes, lack of robustness resulting in instability and it requires rapid and accurate synchronization. Therefore, synchronization techniques must be developed to properly improve the power quality in in grid integration of small-scale photovoltaic systems[56-65]

Table 5: Review on Grid Synchronization Techniques in Grid Integration

Ref no	Techniques/method	Significance	Limitations
[56]	Adaptive feed-forward PLL	Increased the stability region, reduced the effect of voltage variation, and provided high harmonic attenuation.	Practical implementation of adaptive algorithms is difficult, and lack stability.
[57]	Vector-based synchronization	The battery charges and discharges to manage excess and deficient power.	System stability requires rapid and accurate synchronization.
[58]	Iterated Extended Kalman Filtering	Achieving unity power factor, reducing mean square error, and increasing convergence speed	The accuracy of KF prediction is not very good
[59]	Mixed third and fourth-order complex filter	Reduced computation time, addressed the poor power quality issue, eliminated harmonics, and reduced burden and noise rejection.	Lack of robustness results in instability.
[60]	Phase-locked loop	Improve power quality, and reduce harmonics. less distorted power output	Voltage and frequency fluctuations are caused.
[61]	Phase Locked Loop	Total harmonic distortion was reduced and improved synchronization accuracy	PLLs exhibit transient responses during sudden grid changes.
[62]	Improved PLL	Provided a great dynamic response	Sudden changes in grid voltage quality impair current extraction accuracy.
[63]	PLL synchronization	Improve power quality and high harmonic attenuation.	Communication delays impact synchronization accuracy

			and speed
[64]	lightweight inertial PLL	Provides the desired inertial response and damping capacity, resulting in the lowest frequency drop at the system.	IPLL encounters challenges in dynamic grid conditions.
[65]	DQ current control theory	Computational burden reduced, and steady-state performance was improved.	Mismatches in frequency have an impact on the reliability of power control and tracking.

Table 5 gives the power quality improvement using grid synchronization techniques in grid integration of small-scale photovoltaic systems. From the table, it is observed that the power quality improvement in grid integration of small-scale photovoltaic systems is reviewed and the advantages as well as the disadvantages of using various grid synchronization techniques are also reviewed. Many synchronization techniques are used in power quality improvement such as Phase Locked Loop, DQ current control theory, Mixed third and fourth-order complex filter, Vector-based synchronization, Adaptive feed-forward PLL, and lightweight inertial PLL. However, there were some limitations such as PLLs exhibiting transient responses during sudden grid changes, lack of robustness resulting in instability and it requires rapid and accurate synchronization. Therefore, synchronization techniques must be developed to properly improve the power quality in in grid integration of small-scale photovoltaic systems.

2.6 Review on Integrated Optimization-Based AI Techniques in Grid Integration

The review gives the power quality enhancement using various Integrated Optimization-Based AI techniques, it is observed that the power quality enhancement in a grid integration of a small-scale photovoltaic system is reviewed and the advantages as well as the disadvantages of the various are also reviewed. Various Integrated Optimization-Based AI techniques such as Tunable Q-factor wavelet transform and an Artificial neural network, Grey wolf-optimized Artificial neural network, Decision-tree-based fuzzy logic controller, Multi-Feature-attention-LSTM, Statistical feature-based Deep neural network, Deep-learning classifier based on LSTM, Adaboost algorithm, and convolutional neural network are used for power quality enhancement in an interconnected power system. However, all these approaches have some limitations such as effective decision-making is needed, the reliable detection of islanding is difficult in dynamic response, real-time use is computationally complex and threshold-setting is difficult. Hence, there is a need to develop Optimization-Based AI techniques for effectively controlling the power quality enhancement in grid integration of a small-scale photovoltaic system[66-75].

Table: Review on Integrated Optimization-Based AI Techniques in Grid Integration

Ref no	Techniques/method	Significance	Limitations
[66]	MPPT-based AI controllers	Improved power quality for the grid-connected PV system.	AI controllers lack robustness in the face of rapidly changing operating conditions.
[67]	Tunable Q-factor wavelet transform and an Artificial neural network	Highly accurate islanding condition and insensitive to external grid disturbances.	Changes in environmental conditions, load variations, and other factors that affect photovoltaic system performance.

[68]	Grey wolf-optimized Artificial neural network	More accurate and dependable islanding detection, and improving efficiency, reliability, and sustainability.	Difficult to ensure reliable and precise islanding detection under various conditions.
[69]	Decision-tree-based fuzzy logic controller	Effective islanding detection, improved transient response, and reduced settling time.	Total harmonic distortion exceeds the limits.
[70]	Continuous Wavelet Transforms and convolutional neural network	Improves the model's robustness to frequency and amplitude variations.	Real-time is extremely computational and poses difficulties for execution in control systems.
[71]	Multi-Feature-attention-LSTM	Higher accuracy reduces noise interference, ensures safe operation, and shorter detection time	The issue of the active method affects the microgrid power quality.
[72]	Statistical feature-based Deep neural network	Performed well under noisy conditions and detected islanding conditions accurately.	Effective decision-making is required.
[73]	Deep-learning classifier based on LSTM	Detecting islanding effectively and using less detection time	Careful hyperparameter selection is required.
[74]	Adaboost algorithm	Effectively reducing the complexity of the island classification and accurate detection.	There is a difficulty in threshold-setting.
[75]	convolutional neural network	Process large amounts of imagery rapidly while also ensuring the power system's safety.	Careful hyperparameter selection is required.

The table gives the power quality enhancement using various Integrated Optimization-Based AI techniques. From the table, it is observed that the power quality enhancement in a grid integration of a small-scale photovoltaic system is reviewed and the advantages as well as the disadvantages of the various are also reviewed. Various Integrated Optimization-Based AI techniques such as Tunable Q-factor wavelet transform and an Artificial neural network, Grey wolf-optimized Artificial neural network, Decision-tree-based fuzzy logic controller, Multi-Feature-attention-LSTM, Statistical feature-based Deep neural network, Deep-learning classifier based on LSTM, Adaboost algorithm, and convolutional neural network are used for power quality enhancement in an interconnected power system. However, all these approaches have some limitations such as effective decision-making is needed, the reliable detection of islanding is difficult in dynamic response, real-time use is computationally complex and threshold-setting is difficult. Hence, there is a need to develop Optimization-Based AI techniques for effectively controlling the power quality enhancement in grid integration of a small-scale photovoltaic system.

3. Comparison of performance of various Power quality improvement techniques for grid integrated small-scale photovoltaic system

The comparison analysis of various approaches for power quality improvement is discussed in this section.

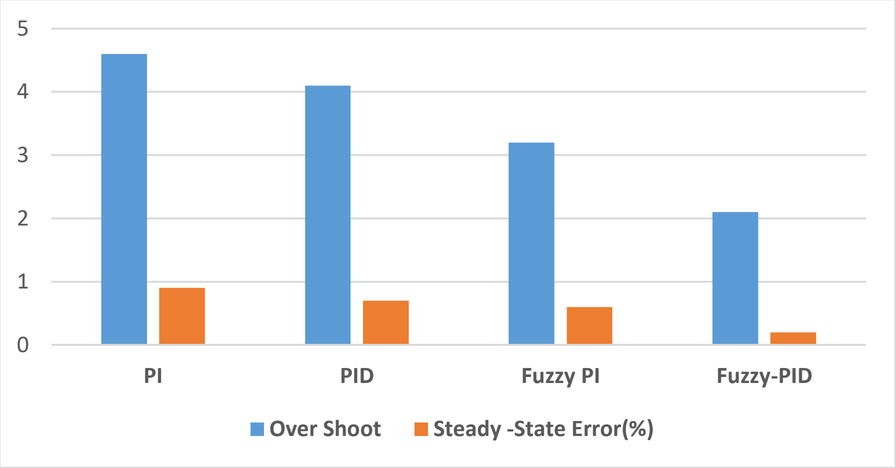

Figure 2: Comparison of overshoot and steady-state error of various PI-Based Reactive Power Control

Figure 2 depicts the comparison overshoot and steady-state error of various PI-Based Reactive Power Controls such as the PI [17], PID [17], Fuzzy-PI [17], and Fuzzy-PID [17]. From the comparison, the PI, PID, Fuzzy-PI, and Fuzzy-PID controllers achieve an overshoot of 4.6, 4.1, 3.2%, and 2.1% respectively. The steady-state error PI, PID, Fuzzy-PI, and Fuzzy-PID controllers are 0.9%, 0.7%, 0.6%, and 0.2%. Compared with all the existing models Fuzzy-PID achieves less steady-state error and overshoot.

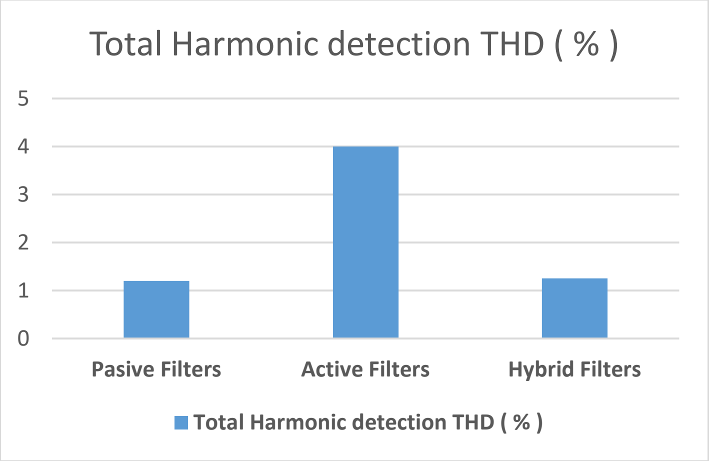

Figure 3: Comparison of total harmonic detection with various automated filters

Figure 3 shows the comparison of the total harmonic detection of various automated filters such as passive filter [44], active filter [44], and hybrid filter [44] which have a frequency deviation value of 1.2%, 4%, and 1.25% respectively. Compared with all the existing techniques hybrid filters have a low total harmonic detection value of 1.2%.

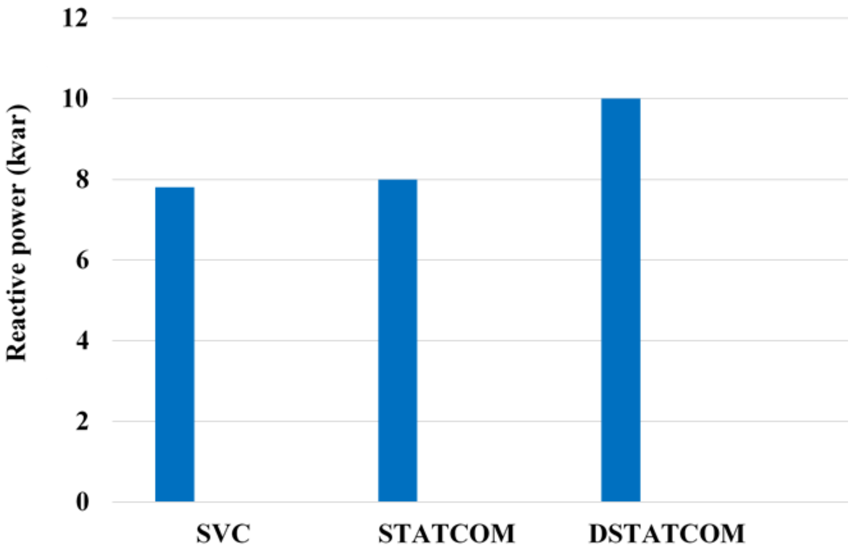

Figure 4: Comparison of reactive power with various flicker logistic control methods

Figure 4 illustrates the comparison of the reactive power of various flicker logistic control methods such as SVC [26], STATCOM [27], and DSTATCOM [28]. The existing techniques such as SVC, STATCOM, and DSTATCOM have a reactive power value of 7.8, 8, and 10 kvar respectively. DSTATCOM has a high reactive power value of 10kvar and SVC has a low settling time value of 7.8 kvar.

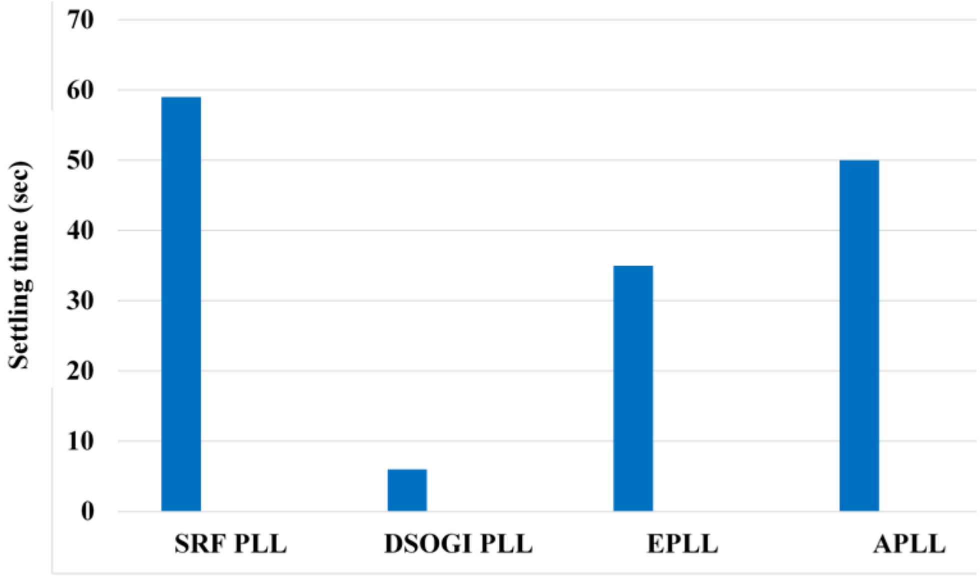

Figure 5: Comparison of settling time with various grid synchronization techniques

Figure 5 shows the comparison of settling time with various existing grid synchronization techniques such as SRF PLL [56], DSOGI PLL [23], EPLL [61], and APLL [56]. The existing techniques such as SRF PLL, DSOGI PLL, EPLL, and APLL have a settling time value of 58 sec, 6 sec, 30 sec, and 52 sec respectively. SRF PLL has a high settling time value of 58 and DSOGI PLL has a low settling time value of 6 sec.

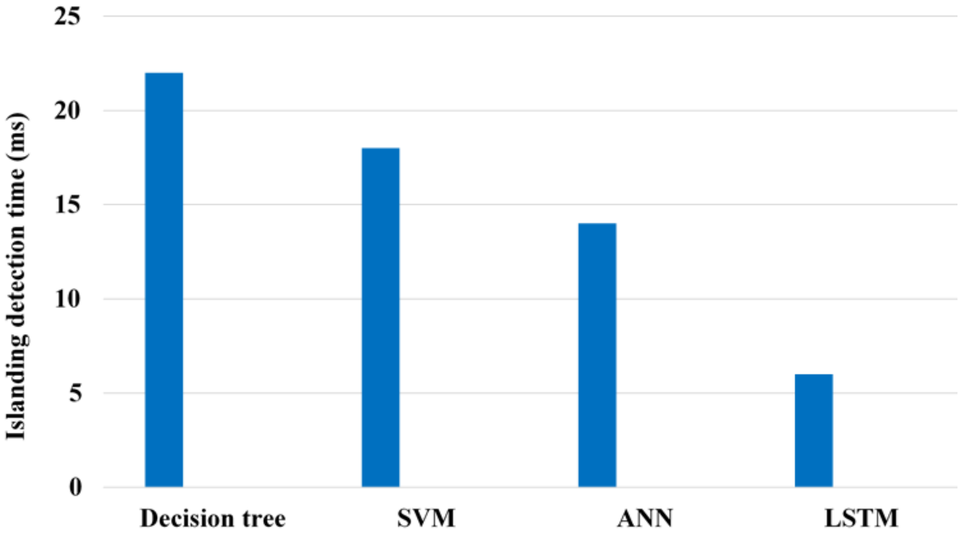

Figure 6: Comparison of Islanding detection time with various Integrated Optimization-Based AI techniques

Figure 6 demonstrates the comparison of Islanding detection time with various Integrated Optimization-Based AI techniques such as decision tree [73], SVM [73], ANN [73], and LSTM [73] attaining an Islanding detection time of 22ms, 18ms, 14ms, and 6ms respectively. Compared with all the existing techniques LSTM has a less Islanding detection time of 6ms.

Overall, the comparison analysis of various power quality improvement techniques for power quality enhancement in grid integration of a small-scale photovoltaic system is presented. Here, the overshoot and steady-state error are compared with some methods such as PI, PID, Fuzzy-PI, and Fuzzy-PID controllers, in this Fuzzy-PID achieves less steady-state error and overshoot. LSTM has a less Islanding detection time compared with a decision tree, SVM, and ANN. Settling time is compared with various grid synchronization techniques, in this SRF PLL, achieves a high settling time. Compared with various automated filters, Hybrid filters attain a low total harmonic detection. DSTATCOM achieves a high reactive power. However, some errors occurred while navigating complicated harmonics in grid integration of a small-scale photovoltaic system. Hence these techniques require further improvement to perform efficient power quality enhancement without harmonics, less settling time, overshoot, and steady-state error and detection time.

4. Result and Summary

The various techniques for power quality enhancement in grid integration of a small-scale photovoltaic system have been analyzed in various directions such as PI-Based Reactive Power Control Systems, Flicker Logistic Control Methods, Automated Filtering Mechanisms, Shunt Active Power Filter modules, Integrated Optimization-based AI Technique and Grid Synchronization Techniques. The analyzed summary is given as follows:

- PI-Based Reactive Power Control Systems optimal fractional order PID controller, Fuzzy PID controller, Fuzzy adaptive PI controller, Multi-stage fuzzy-based flexible controller, and Distributed power flow controller were found to be helpful and effective in power quality enhancement, mitigating voltage sags, voltage swells and ensured the lowest harmonic distortion. However, these approaches were found with some limitations such as the Fuzzy controller's computational burden and testing being a challenge for real-time applications, unwanted oscillation happening in rapid changes also limited adaptability to a wide range of scenarios.

- The flicker logistic control methods such as Unified Power Quality Conditioner, Dynamic voltage restorer, Static Var compensator, Static synchronous compensator, and Distribution static compensator helped reduce current and voltage instabilities and harmonic content of grid integration of small-scale photovoltaic systems. However, some drawbacks such as power consumption increases and the cost of batteries and associated power electronics make this approach too costly.
- The automated filters such as an LCL filter, Shunt hybrid active filter, Hybrid series active power filter, Fractional order notch filter-based control, LC passive filters Recursive Digital Filter, and Hybrid harmonic filter helped to reduce the total harmonic distortion and improve the power quality in grid integrated small-scale photovoltaic systems. However, drawbacks such as its inability to adapt to dynamic real-world conditions, poor stability, and voltage spikes that occur across the filter components.
- The various shunt active power filter modules such as Hybrid active power filter, Shunt Active Power Filter, switched power filter compensator, and Three-phase half-bridge interleaved buck shunt active power filters were studied to help improve power quality, reduce settling time, and effectively provide better accuracy. However, some drawbacks such as low reactive power levels lead to voltage instability and the ability to address voltage fluctuations is limited.
- The grid synchronization techniques such as Phase Locked Loop, DQ current control theory, Mixed third and fourth-order complex filter, Vector-based synchronization, Adaptive feed-forward PLL, and lightweight inertial PLL were studied to help improve quality to effectively increase the performance. However, these approaches have some drawbacks, PLLs exhibit transient responses during sudden grid changes, lack of robustness results in instability, and it requires rapid and accurate synchronization.
- Various Integrated Optimization-Based AI techniques such as Tunable Q-factor wavelet transform and an Artificial neural network, Grey wolf-optimized Artificial neural network, Decision-tree-based fuzzy logic controller, Multi-Feature-attention-LSTM, Statistical feature-based Deep neural network, Deep-learning classifier based on LSTM, Adaboost algorithm, and convolutional neural network were found to be efficient and reliable operations of the modern power network. However, these strategies had some limitations such as in real-world scenarios complexity, effective decision-making is needed and reliable detection is difficult for dynamic operation.

5. Conclusion

This review paper presented a comprehensive overview of the recent developments in various techniques for power quality enhancement, including PI-Based Reactive Power Control Systems, Flicker Logistic Control Methods, Automated Filtering Mechanisms, Shunt Active Power Filter modules, Integrated Optimization-based AI Technique and Grid Synchronization Techniques. The review highlighted that power quality improvement methods can significantly improve the performance of power quality enhancement in in grid integration of a small-scale photovoltaic system. Overall, this review paper provides valuable insights into the recent developments in power quality improvement methods for power quality enhancement. A comparison of the performance of various power quality improvement methods in terms of harmonics, less settling time, overshoot, and steady-state error and detection time for power quality enhancement in grid integration of a small-scale photovoltaic system has been provided. The paper concludes that the integration of power quality improvement methods can enhance the performance of power quality and ensure the stability and reliability of grid integration of a small-scale photovoltaic system. The future research directions include addressing the challenges in implementing power quality improvement methods and exploring new techniques to further improve the performance of power quality enhancement in grid integration of a small-scale photovoltaic system.

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