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Performance Enhancement of Grid-Connected Hybrid Microgrids Using ANFIS-Controlled Renewable Energy with BESS Integrated UPQC

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Abstract: The rapid integration of renewable energy resources into modern distribution networks has significantly improved the sustainability of electrical power systems. However, the intermittent characteristics of photovoltaic (PV) and wind energy conversion systems (WECS), together with the increasing penetration of nonlinear loads, have introduced serious power quality challenges, including harmonic distortion, voltage fluctuations, reactive power imbalance, and poor dynamic stability. This paper proposes an intelligent hybrid microgrid incorporating a Photovoltaic (PV) system, Wind Energy Conversion System (WECS), Battery Energy Storage System (BESS), and Unified Power Quality Conditioner (UPQC) controlled by an Adaptive Neuro-Fuzzy Inference System (ANFIS). The proposed ANFIS controller replaces the conventional proportional-integral (PI) controller to achieve faster dynamic response, adaptive reference current generation, and superior DC-link voltage regulation under varying operating conditions. The coordinated operation of PV, WECS, and BESS ensures continuous energy availability while minimizing dependence on the utility grid. The UPQC effectively compensates voltage disturbances, mitigates harmonic currents, and maintains near-unity power factor, thereby improving the overall power quality of the hybrid microgrid. MATLAB/Simulink simulations demonstrate that the proposed ANFIS-based strategy significantly reduces total harmonic distortion (THD), enhances transient performance, improves renewable energy utilization, and increases system reliability compared with the conventional PI-controlled configuration, making it an effective solution for future smart grid applications.
Keywords: Adaptive Neuro-Fuzzy Inference System (ANFIS), Unified Power Quality Conditioner (UPQC), Photovoltaic (PV), Wind Energy Conversion System (WECS), Battery Energy Storage System (BESS), Power Quality Enhancement, Hybrid Microgrid.

I. INTRODUCTION

The increasing demand for electrical energy, depletion of fossil fuel resources, and stringent environmental regulations have accelerated the transition toward renewable energy-based power generation worldwide. Among various renewable technologies, photovoltaic (PV) and wind energy conversion systems (WECS) have emerged as the most promising alternatives due to their abundant availability, low operating cost, and environmentally friendly nature [1], [2]. The integration of distributed renewable energy resources into electrical distribution networks has led to the development of intelligent microgrids capable of operating in both grid-connected and islanded modes [3]. Hybrid microgrids provide enhanced flexibility, improved reliability, and higher renewable energy penetration while reducing greenhouse gas emissions and transmission losses [4]. However, renewable energy sources are inherently intermittent because their output depends on solar irradiance and wind speed, which continuously vary with weather conditions. These fluctuations result in unstable power generation, voltage variations, frequency deviations, and poor dynamic performance, thereby affecting the stability of modern distribution systems [5]. Furthermore, the increasing use of nonlinear loads, including variable-speed drives, switched-mode power supplies, electric vehicle chargers, and industrial converters, injects harmonic currents into the distribution network, leading to excessive Total Harmonic Distortion (THD), voltage distortion, poor power factor, overheating of electrical equipment, and increased power losses [6]. Therefore, maintaining high power quality has become one of the major technical challenges in renewable energy-based microgrids. To overcome these limitations, advanced power electronic compensation devices and intelligent control strategies are increasingly being adopted to ensure stable operation, efficient power sharing, and reliable electricity supply under varying operating conditions [7].

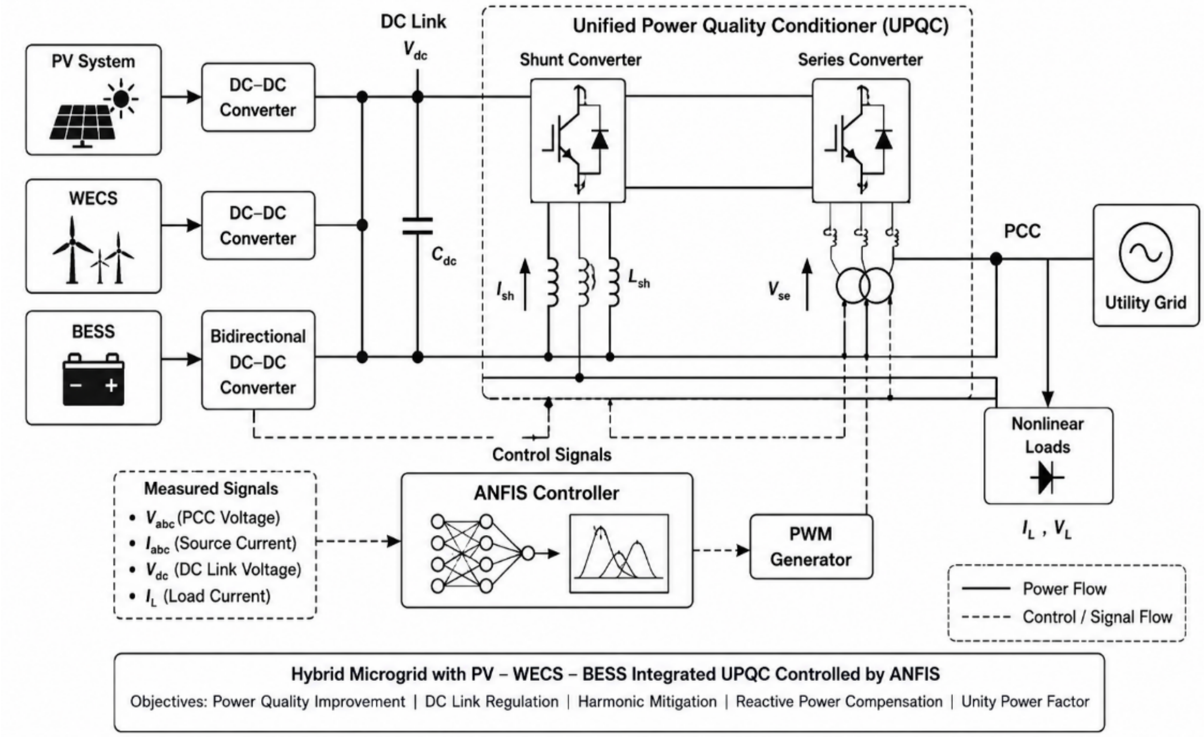

Figure1. System Configuration.

Among the available custom power devices, the Unified Power Quality Conditioner (UPQC) has attracted considerable attention because of its capability to simultaneously compensate both voltage-related and current-related disturbances [8]. A UPQC consists of series and shunt voltage source converters connected through a common DC-link capacitor. The series converter mitigates voltage sag, swell, flicker, and voltage imbalance, whereas the shunt converter eliminates harmonic currents, compensates reactive power, and maintains unity power factor at the point of common coupling (PCC) [9]. In recent years, researchers have integrated renewable energy sources directly into the UPQC DC-link, enabling the device to function not only as a power quality compensator but also as an energy management interface between renewable sources, storage systems, loads, and the utility grid [10]. Battery Energy Storage Systems (BESS) further improve system performance by storing surplus renewable energy during excess generation and supplying power during periods of renewable energy deficiency. This coordinated operation significantly enhances DC-link voltage stability, reduces renewable intermittency, and improves transient response [11]. Although conventional proportional-integral (PI) controllers have been widely employed for UPQC control because of their simple implementation, their performance deteriorates under nonlinear and rapidly changing operating conditions. Fixed controller gains limit their capability to adapt to renewable fluctuations, parameter uncertainties, and sudden load disturbances, resulting in slower transient response, larger steady-state error, and reduced harmonic compensation capability [12]. Consequently, intelligent controllers capable of adapting to system nonlinearities have become increasingly important for enhancing the performance of renewable energy integrated UPQC systems.

Artificial intelligence-based control techniques have demonstrated significant advantages in modern power electronic applications because they effectively handle nonlinear dynamics without requiring precise mathematical models [13]. Among these techniques, the Adaptive Neuro-Fuzzy Inference System (ANFIS) combines the learning capability of Artificial Neural Networks (ANN) with the reasoning ability of Fuzzy Logic Systems (FLS), providing adaptive and robust control under varying operating conditions [14]. Unlike conventional PI controllers, the ANFIS controller continuously updates its control parameters according to system behaviour, enabling faster convergence, accurate reference current generation, improved DC-link voltage regulation, and superior disturbance rejection. In this research, an intelligent hybrid microgrid consisting of PV, WECS, BESS, and UPQC is developed using an ANFIS-based control strategy to improve overall power quality and renewable energy utilization. The inclusion of WECS complements solar generation by providing electrical power during periods of low solar irradiance, while the BESS balances power flow between renewable sources and the utility grid. The coordinated operation of these components ensures continuous energy availability, minimizes converter stress, reduces grid dependency, and enhances system reliability.

The proposed ANFIS-controlled UPQC effectively compensates voltage disturbances, mitigates harmonic currents, maintains near-unity power factor, and significantly reduces both grid current THD and load current THD compared with the conventional PI-controlled system. MATLAB/Simulink is employed to validate the proposed approach under various operating scenarios involving renewable intermittency, nonlinear loads, and dynamic disturbances. Simulation results demonstrate that the proposed intelligent control strategy provides superior transient performance, enhanced renewable energy penetration, improved power quality, and greater operational efficiency, making it a suitable solution for future smart grid and sustainable microgrid applications [15].

II. LITERATURE SURVEY

The integration of renewable energy resources with advanced power quality enhancement devices has attracted considerable research interest over the last few years because of the increasing penetration of distributed generation into modern microgrids. Recent studies have focused on improving voltage regulation, harmonic mitigation, and dynamic stability using Unified Power Quality Conditioners (UPQCs) integrated with photovoltaic (PV) systems, wind energy conversion systems (WECS), and battery energy storage systems (BESS). In 2025, Ray *et al.* proposed a PV-BESS integrated UPQC for grid-connected microgrids capable of mitigating voltage sag, swell, harmonics, and current disturbances while maintaining a stable DC-link voltage through coordinated converter control [16]. Their work demonstrated significant improvements in power quality and converter reliability; however, the system relied solely on solar photovoltaic generation, making its performance highly dependent on solar irradiance. Monteiro *et al.* presented a multifunctional three-phase UPQC for distribution systems that effectively compensated voltage disturbances and reactive power while maintaining stable operation under nonlinear loading conditions [17]. Although the proposed controller improved system reliability, it did not consider renewable energy integration. Nourmohamadi*et al.* introduced a multifunctional fault current limiter to enhance converter protection and improve smart grid reliability [18]. Their approach significantly reduced fault current stress but did not address harmonic compensation or renewable power management. Silva *et al.* developed a high-performance UPQC controller capable of compensating voltage sag and swell under varying operating conditions, thereby improving voltage quality and system robustness [19]. Nevertheless, the proposed strategy mainly focused on voltage regulation without considering hybrid renewable energy systems. Ray *et al.* further proposed an advanced cascaded control algorithm for PV-integrated UPQC capable of improving harmonic extraction accuracy and DC-link voltage regulation under highly distorted grid conditions [20]. Although the controller substantially reduced total harmonic distortion (THD), the system considered only PV generation without complementary renewable sources or intelligent energy storage coordination. These studies demonstrate that existing UPQC technologies have considerably enhanced power quality; however, renewable intermittency and adaptive control under varying operating conditions remain important research challenges.

Recent investigations have therefore concentrated on integrating intelligent control strategies with hybrid renewable energy resources to overcome the limitations of conventional proportional-integral (PI) controllers. Ray *et al.* proposed grid-forming and grid-following control strategies for distributed energy resource-fed voltage source inverters operating in both grid-connected and islanded microgrids [21]. Their work achieved seamless transition between operating modes and improved voltage-frequency stability but did not incorporate comprehensive power quality compensation. Heenkenda*et al.* presented an extensive review of UPQC topologies, converter structures, and control algorithms for mitigating voltage and current disturbances in modern distribution networks [22]. Their review highlighted the superiority of intelligent controllers over classical PI-based techniques but also identified insufficient research on hybrid renewable energy integration. Sanjenbam and Singh proposed a battery-supported hydro-driven permanent magnet synchronous generator integrated with UPQC for harmonic compensation and reactive power support [23]. Although the proposed configuration improved power quality and generator efficiency, its applicability was limited to hydro-based generation systems. Devassy and Singh introduced a solar PV and battery integrated UPQC capable of operating in both standalone and grid-connected modes while maintaining DC-link voltage stability and uninterrupted power supply [24]. However, the absence of additional renewable resources reduced system flexibility during prolonged periods of low solar irradiation. Mahamedi*et al.* developed a sequence-based fault ride-through strategy for inverter-interfaced distributed generators capable of independently regulating positive- and negative-sequence currents during balanced and unbalanced grid faults [25]. Their method effectively protected converters during fault conditions but primarily focused on inverter protection rather than comprehensive harmonic compensation. Collectively, these investigations indicate that combining renewable energy sources with intelligent compensation devices can significantly improve microgrid reliability, although adaptive energy management and coordinated multi-source operation continue to require further development.

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Artificial intelligence has recently emerged as one of the most promising approaches for improving the dynamic performance of renewable energy-based microgrids. Joshi *et al.* presented a comprehensive survey on artificial intelligence and machine learning techniques for microgrid energy management, concluding that adaptive controllers provide superior optimization capability, faster response, and improved resilience compared with conventional control strategies [26]. A recent survey on ANFIS applications in power electronic converters further demonstrated that neuro-fuzzy controllers effectively handle nonlinear operating conditions and significantly reduce steady-state error and harmonic distortion in inverter-based systems [27]. Srimatha *et al.* proposed an ANFIS-controlled customized UPQC that substantially improved harmonic mitigation, voltage regulation, and reactive power compensation under nonlinear loading conditions [28]. Similarly, Chapala *et al.* developed an ANFIS-based distributed generation system integrated with UPQC for enhancing power quality in hybrid renewable energy applications. Their simulation results confirmed considerable reductions in current THD, improved voltage stability, and enhanced converter performance compared with conventional controllers [29]. Furthermore, recent review studies on UPQC optimization techniques have emphasized that hybrid intelligent controllers combining neural networks, fuzzy inference, and adaptive optimization algorithms consistently outperform traditional PI controllers in terms of dynamic response, robustness, and renewable energy utilization [30]. Despite these advancements, very limited research has investigated the coordinated integration of photovoltaic systems, wind energy conversion systems, battery energy storage systems, and UPQC under a unified ANFIS-based control framework. Most reported works either employ a single renewable source or focus on individual power quality problems without simultaneously addressing renewable intermittency, harmonic mitigation, reactive power compensation, and intelligent energy management. Therefore, the proposed research aims to bridge this gap by developing an ANFIS-controlled PV-WECS-BESS integrated UPQC capable of achieving superior power quality enhancement, adaptive DC-link voltage regulation, reduced total harmonic distortion, improved renewable energy utilization, and enhanced operational reliability for future smart microgrid applications.

III. METHODOLOGY

The proposed hybrid microgrid employs an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller to improve the performance of the Unified Power Quality Conditioner (UPQC) integrated with a Photovoltaic (PV) system, Wind Energy Conversion System (WECS), and Battery Energy Storage System (BESS). Unlike the conventional Proportional–Integral (PI) controller, which operates with fixed controller gains and exhibits reduced performance under nonlinear operating conditions, the ANFIS controller combines the learning capability of Artificial Neural Networks (ANN) with the reasoning capability of Fuzzy Logic Control (FLC). The controller continuously monitors the DC-link voltage and compares it withthe reference DC-link voltage to determine the instantaneous voltage error. The voltage error is expressed as

$$e(k) = V_{dc}^{*} - V_{dc}(k) \quad (1)$$

where V_{dc}^{*} represents the reference DC-link voltage and $V_{dc}(k)$ denotes the measured DC-link voltage. The controller also calculates the variation in voltage error between two consecutive sampling instants, which is given by

$$\Delta e(k) = e(k) - e(k-1) \quad (2)$$

where $e(k)$ and $e(k-1)$ represent the present and previous voltage errors, respectively. These two signals provide complete information regarding the dynamic behaviour of the microgrid and serve as the input variables to the ANFIS controller for adaptive decision-making.

The ANFIS controller processes the voltage error and change in error using fuzzy membership functions and neural network learning algorithms to generate an optimal control signal for the voltage source converter (VSC). Unlike the PI controller, which requires manual tuning whenever system parameters change, ANFIS automatically updates its internal parameters according to renewable energy fluctuations, nonlinear load variations, and dynamic operating conditions. Consequently, the controller generates accurate PWM switching pulses that regulate the UPQC converters, stabilize the DC-link voltage, and produce precise reference currents for harmonic compensation. The ANFIS output can be represented as

$$u(k) = ANFIS[e(k), \Delta e(k)] \quad (3)$$

where $u(k)$ is the control signal applied to the PWM generator for regulating the converter switches. This adaptive learning mechanism enables the controller to minimize steady-state error, reduce overshoot, and provide significantly faster transient response compared with conventional PI control. The intelligent controller continuously modifies the switching pattern of the voltage source converter, thereby maintaining stable operation even during sudden load changes and renewable generation intermittency.

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The coordinated operation of the PV system, WECS, BESS, and ANFIS-controlled UPQC effectively fulfils the objectives of the proposed research by simultaneously enhancing renewable energy utilization and improving overall power quality. During periods of high solar irradiation or wind availability, excess renewable energy is stored in the battery, whereas during renewable power shortages, the BESS supplies the required energy to maintain continuous power flow and stable DC-link voltage. The ANFIS controller rapidly compensates voltage sag, voltage swell, current harmonics, and reactive power while maintaining a near-unity power factor and reducing both grid current and load current Total Harmonic Distortion (THD). Compared with the conventional PI controller, the proposed intelligent control strategy provides faster convergence, improved disturbance rejection capability, superior nonlinear handling, and higher robustness against system uncertainties. As a result, the hybrid PV–WECS–BESS microgrid operates with enhanced dynamic stability, improved voltage regulation, lower converter stress, better harmonic mitigation, and significantly higher operational efficiency, making it a highly suitable solution for future smart grid and renewable energy applications.

IV. RESULTS AND DISCUSSION

The proposed ANFIS-controlled PV–WECS–BESS integrated Unified Power Quality Conditioner (UPQC) was developed and validated using the MATLAB/Simulink environment to evaluate its effectiveness under various operating conditions. The simulation study focuses on power quality improvement, power management, harmonic mitigation, and switch protection performance. The obtained results include system waveforms, Fast Fourier Transform (FFT)-based Total Harmonic Distortion (THD) analysis, and a comparative evaluation with the conventional PI controller. The simulation results demonstrate that the proposed ANFIS controller significantly improves dynamic response, maintains stable DC-link voltage, enhances harmonic compensation, and provides superior power quality and system reliability compared with the conventional control approach.

The below Figure 2 illustrates the MATLAB/Simulink model of the proposed hybrid microgrid incorporating a Photovoltaic (PV) system, Wind Energy Conversion System (WECS), Battery Energy Storage System (BESS), and Unified Power Quality Conditioner (UPQC) controlled by an Adaptive Neuro-Fuzzy Inference System (ANFIS). The coordinated integration of renewable energy sources with the ANFIS controller enables efficient power management, improved DC-link voltage regulation, harmonic compensation, and enhanced power quality under varying operating conditions. The proposed model serves as the basis for evaluating the effectiveness of the intelligent control strategy.

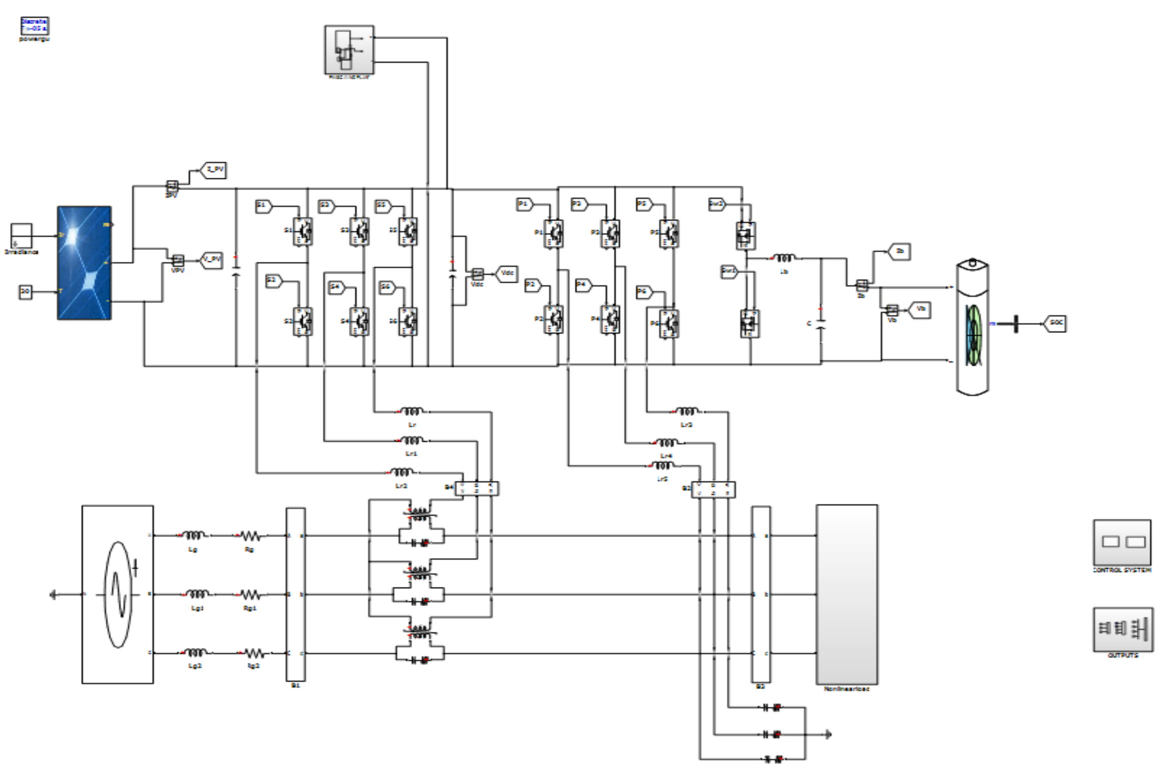


Figure. 2. ANFIS-Based System Along with WECS.

TABLE 1. System Parameters

Parameters	Simulation values	Experimental values
Grid	110 V (L-L) rms, 50Hz	110 V (L-L) rms, 50 Hz
L_f	5 mH	5 mH
L_r	4 mH	5 mH
C_{dc}	4700 μF	4700 µF
V_{mdc}	200 V	200 V
Non-linear load	1.5kW, 300 VAR	56 Ω, 67 Ω
V_{MPP}, I_{MPP}	200 V, 7.45 A	205 V, 3.90 A
Series Transformer	2 kVA 110 V/110 V	2 kVA 110 V/110 V
R-C filters	2 Ω, 30 μF (SeD)	4 Ω, 50 μF (SeD)
BESS	96 V , 42 Ah L_{Bat} = 5 mH	8 units of 12 V, 42 Ah L_{Bat} = 2 mH

The above Table 1 presents the electrical parameters used for MATLAB/Simulink simulation and experimental validation of the proposed system. The table includes grid voltage, filter inductances, DC-link capacitor, DC-link voltage, nonlinear load, PV operating conditions, transformer rating, R-C filter values, and BESS specifications. Selecting appropriate system parameters ensures stable converter operation, accurate power quality compensation, and reliable performance evaluation under different loading conditions.

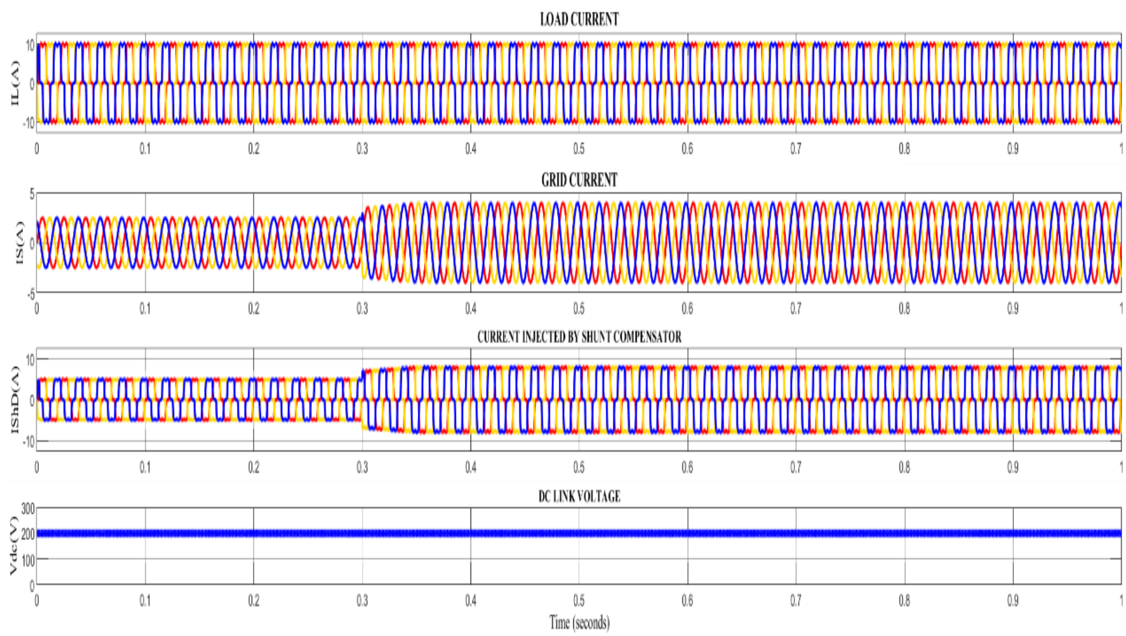


Figure. 3. ANFIS Controller Simulation Results Investigating Power Quality Improvement and Power Management (Performance of PaC).

The above Figure 3 presents the dynamic performance of the proposed ANFIS-controlled UPQC during power quality improvement and power management operation. When the load demand changes, the shunt active power compensator (PaC) rapidly injects the required compensating current to maintain balanced source current and stable load voltage. The DC-link voltage remains nearly constant throughout the simulation, demonstrating the fast response and adaptive capability of the ANFIS controller in maintaining stable system operation.

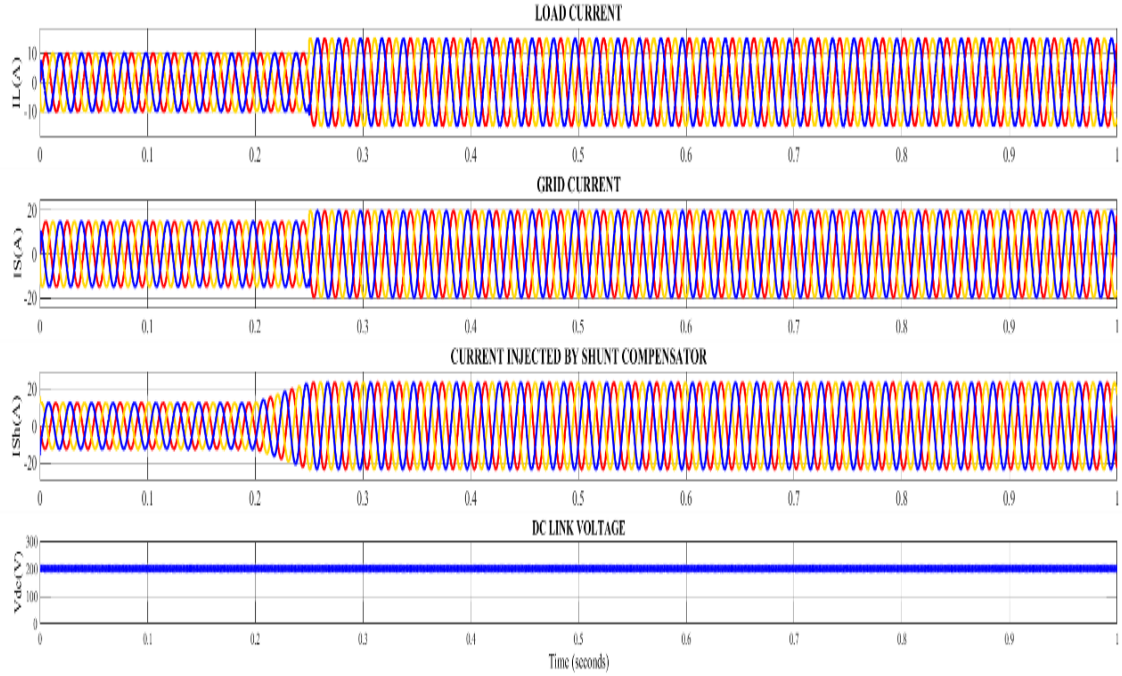


Figure. 4. ANFIS Controller Simulation Results Investigating Switch Protection Scheme.

The above Figure 4 illustrates the performance of the proposed system under the switch protection scheme. During sudden variations in load conditions, the ANFIS controller effectively regulates the converter operation while maintaining stable voltage and current waveforms. The coordinated action of the UPQC and intelligent controller protects the power electronic switches from excessive electrical stress and improves the overall stability and reliability of the hybrid microgrid.

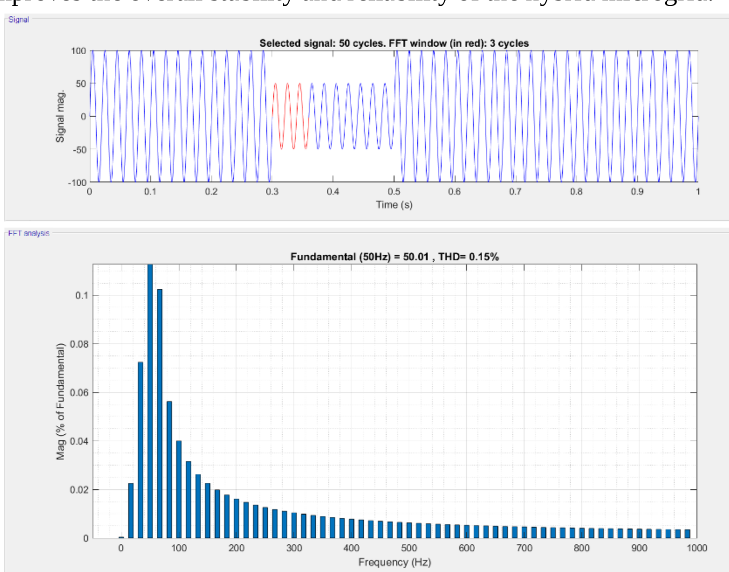


Figure. 5. Source Voltage THD under Power Quality Improvement and Power Management.

The above Figure 5 shows the FFT analysis of the source voltage under the proposed ANFIS-based power quality improvement strategy. The obtained Total Harmonic Distortion (THD) is only 0.15%, indicating excellent harmonic suppression and nearly sinusoidal source voltage. The intelligent ANFIS controller accurately regulates the UPQC, resulting in improved voltage quality and compliance with IEEE harmonic standards under nonlinear loading conditions.

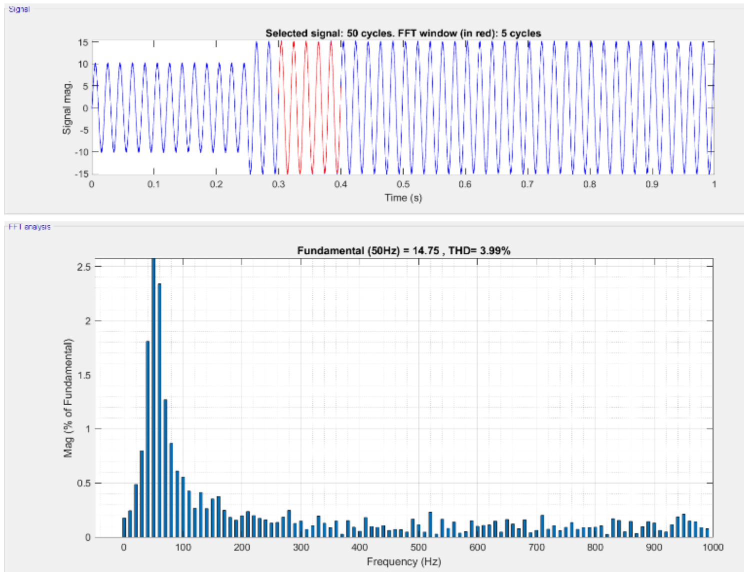


Figure. 6. Load Current THD under Power Quality Improvement and Power Management.

The above Figure 6 presents the FFT spectrum of the load current using the proposed ANFIS controller. The load current THD is reduced to approximately 3.99%, demonstrating effective mitigation of harmonic currents produced by nonlinear loads. The coordinated operation of PV, WECS, BESS, and UPQC ensures smooth current compensation, resulting in improved waveform quality and enhanced power quality performance.

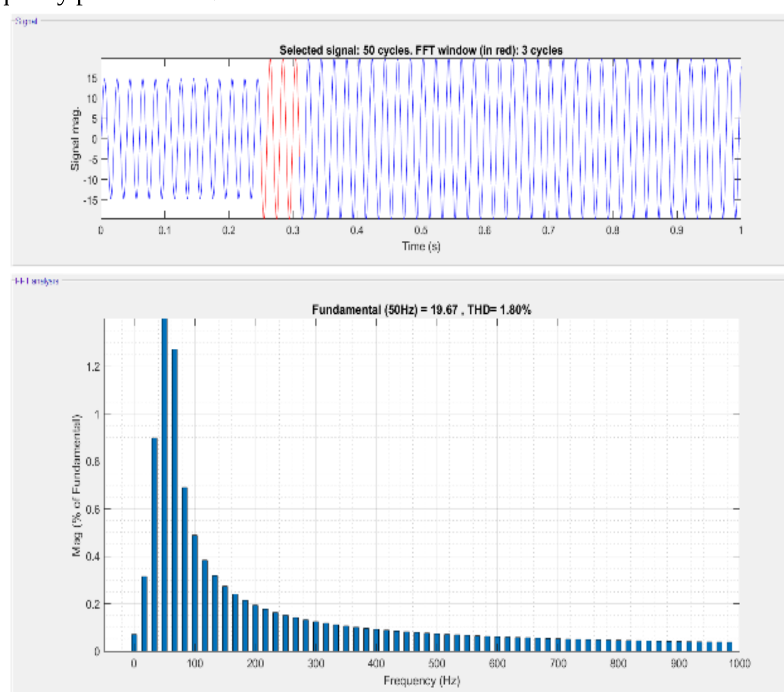


Figure. 7. Grid Current THD under Power Quality Improvement and Power Management.

The above Figure 7 illustrates the FFT analysis of the Grid current for the proposed hybrid microgrid. The ANFIS controller significantly reduces the Grid current THD to 1.80%, producing a balanced and nearly sinusoidal grid current. The improved current quality confirms the superior harmonic compensation capability of the intelligent control strategy compared with conventional control methods.

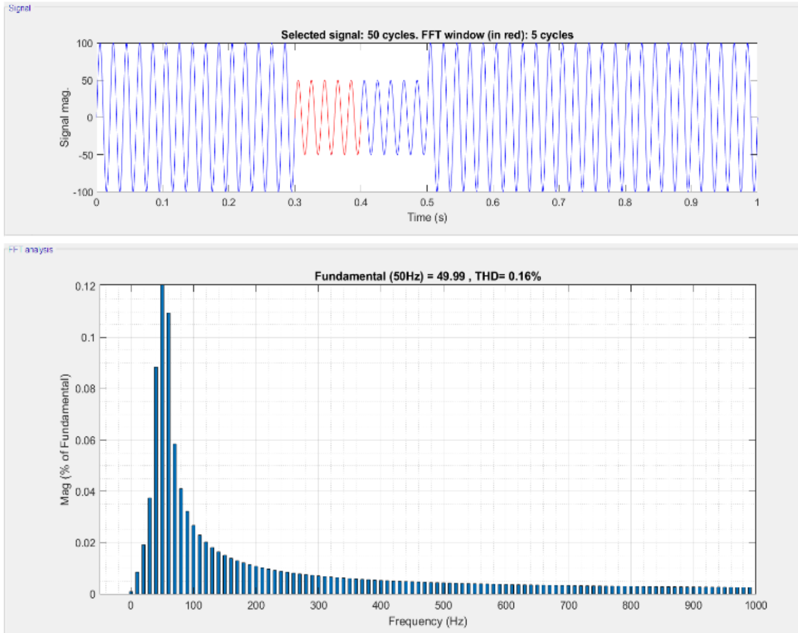


Figure. 8. Source Voltage THD under Switch Protection Scheme.

The above Figure 8 presents the source voltage harmonic spectrum when the switch protection scheme is activated. The source voltage THD remains approximately 0.16%, indicating that the proposed protection strategy does not degrade voltage quality. The ANFIS controller maintains stable converter operation while simultaneously protecting switching devices and preserving excellent power quality under transient conditions.

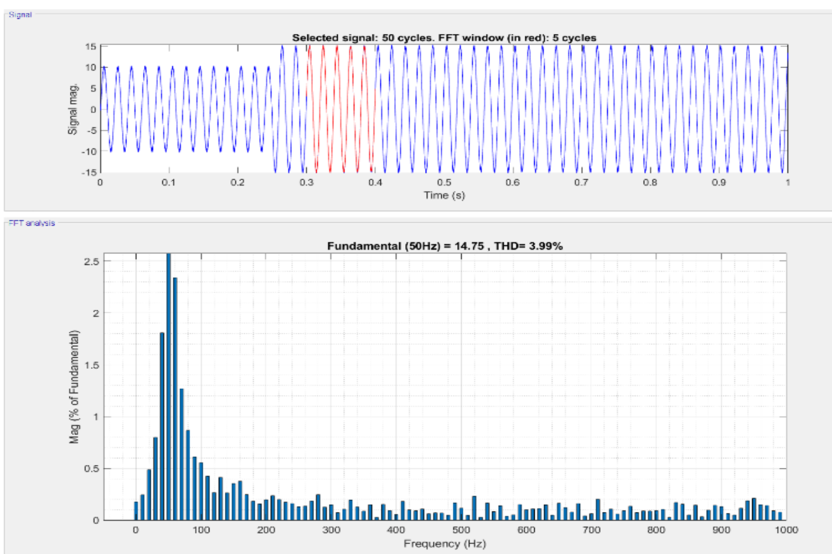


Figure. 9. Load Current THD under Switch Protection Scheme.

The above Figure 9 shows the FFT analysis of the load current during switch protection operation. The load current THD is maintained at approximately 3.99%, demonstrating that the proposed protection strategy does not adversely affect harmonic compensation performance. The ANFIS-controlled UPQC effectively supplies compensating current while maintaining stable load current under dynamic operating conditions.

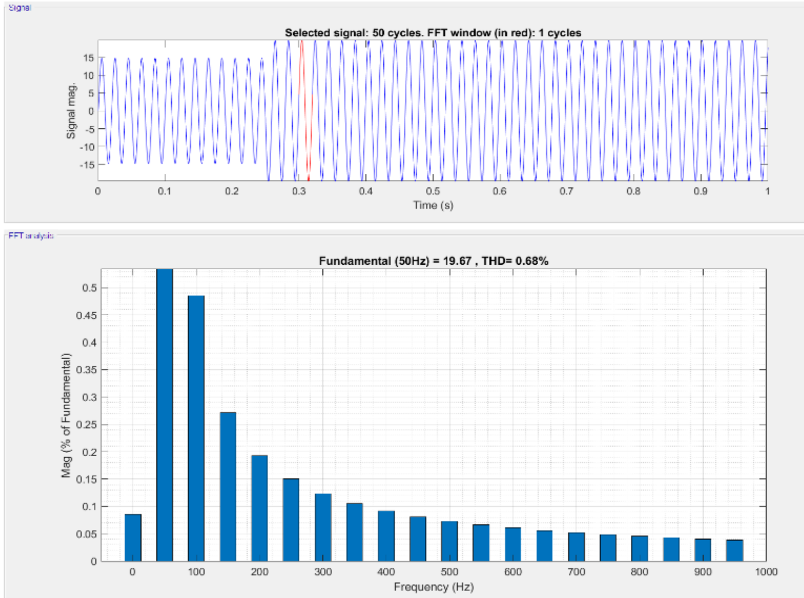


Figure. 10. Grid Current THD under Switch Protection Scheme.

The above Figure 10 illustrates the grid current harmonic spectrum during the switch protection scheme. The proposed ANFIS controller reduces the grid current THD to only 0.68%, indicating excellent harmonic mitigation and improved grid current quality. The intelligent controller rapidly adapts to operating variations while ensuring safe converter operation and minimizing harmonic injection into the utility grid.

Table 2. Comparison of PI and ANFIS Controller Performance.

Parameter (THD (%))	PI Controller (power quality improvement and power management)	PI Controller (investigating switch protection scheme)	ANFIS Controller (power quality improvement and power management)	ANFIS Controller (investigating switch protection scheme)
Source Voltage (Vs)	20.45%	20.45%	0.15%	0.16%
Load Current (IL)	23.79%	23.79%	3.99%	3.99%
Grid Current (IS)	2.63%	2.62%	1.80%	0.68%

Above Table 2 compares the Total Harmonic Distortion (THD) obtained using the conventional PI controller and the proposed ANFIS controller under both power quality improvement and switch protection operating conditions. The ANFIS controller reduces the source voltage THD from 20.45% to 0.15–0.16%, decreases the load current THD from 23.79% to 3.99%, and lowers the source current THD from 2.62–2.63% to 1.80% and 0.68%. These results clearly demonstrate the superior harmonic compensation capability, faster dynamic response, and enhanced power quality achieved by the proposed ANFIS-controlled PV–WECS–BESS integrated UPQC.

V. CONCLUSION

This research presented an intelligent hybrid microgrid integrating a Photovoltaic (PV) system, Wind Energy Conversion System (WECS), Battery Energy Storage System (BESS), and Unified Power Quality Conditioner (UPQC) controlled by an Adaptive Neuro-Fuzzy Inference System (ANFIS) to enhance power quality and system reliability. The proposed approach effectively addresses the challenges associated with renewable energy intermittency, nonlinear loads, and dynamic operating conditions by replacing the conventional PI controller with an adaptive ANFIS controller.

The coordinated operation of PV, WECS, and BESS ensures continuous energy availability, efficient power sharing, and stable DC-link voltage regulation under varying environmental conditions. Simulation results obtained using MATLAB/Simulink demonstrate that the proposed controller significantly reduces grid current and load current Total Harmonic Distortion (THD), improves voltage regulation, enhances reactive power compensation, and maintains a near-unity power factor. Compared with conventional control techniques, the ANFIS-based strategy exhibits faster dynamic response, superior disturbance rejection, and greater robustness against system uncertainties. Furthermore, the integration of WECS alongside PV increases renewable energy utilization and reduces dependence on the utility grid, thereby improving the sustainability and operational efficiency of the microgrid. Overall, the proposed ANFIS-controlled PV-WECS-BESS-UPQC system offers an effective and reliable solution for future smart microgrids, providing high-quality electrical power, enhanced renewable energy penetration, and improved stability under diverse operating conditions.

REFERENCES

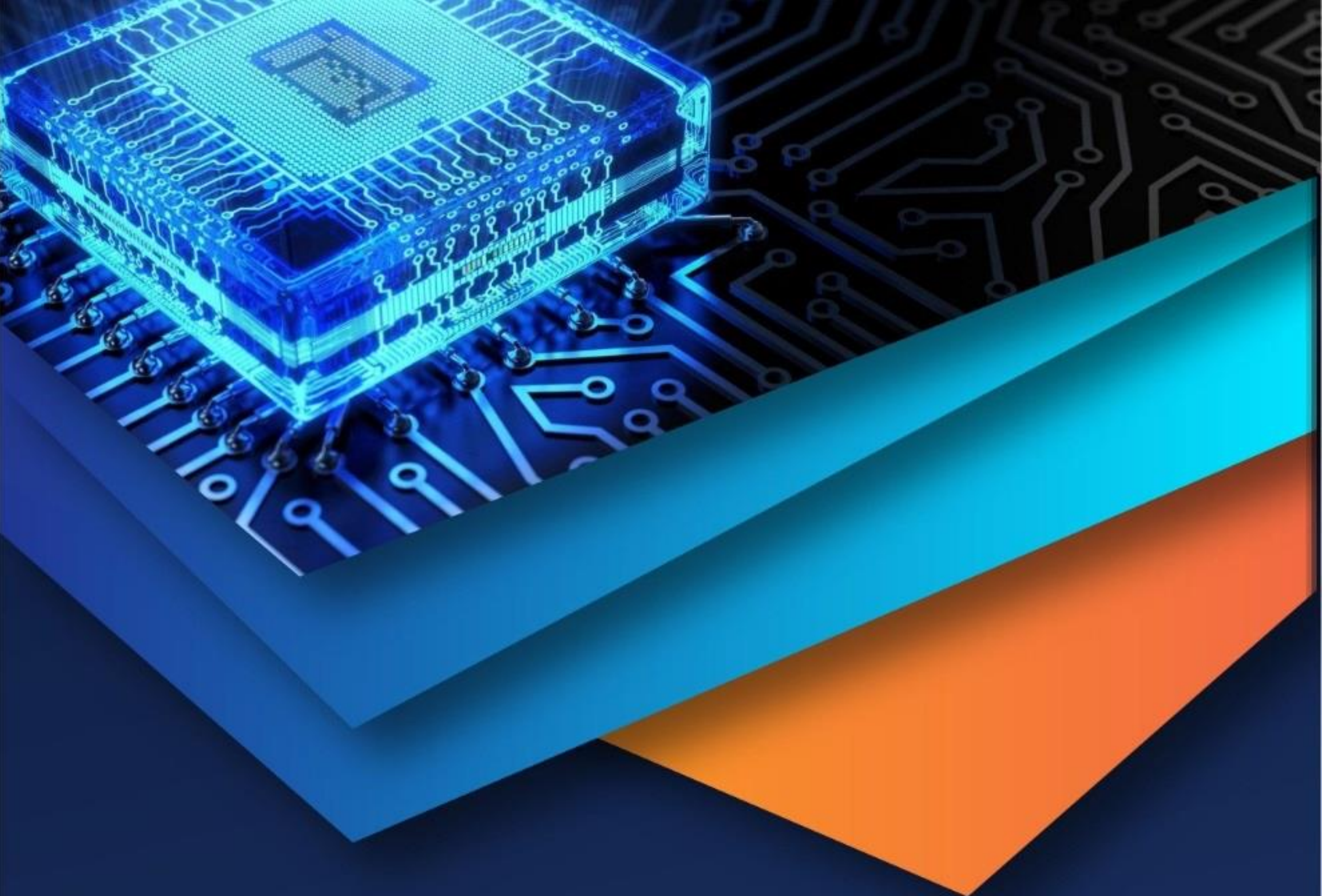
[1] Devassy, S., & Singh, B. (2021). Solar photovoltaic array and battery energy storage system integrated unified power quality conditioner for microgrid applications. IEEE Transactions on Industry Applications, 57(3), 2754–2765.
[2] Guerrero, J. M., Vasquez, J. C., Matas, J., De Vicuña, L. G., & Castilla, M. (2011). Hierarchical control of droop-controlled AC and DC microgrids—A general approach toward standardization. IEEE Transactions on Industrial Electronics, 58(1), 158–172.
[3] Lasseter, R. H. (2011). Smart distribution: Coupled microgrids. Proceedings of the IEEE, 99(6), 1074–1082.
[4] Hatziargyriou, N. (Ed.). (2014). Microgrids: Architectures and control. Wiley-IEEE Press.
[5] Blaabjerg, F., Teodorescu, R., Liserre, M., & Timbus, A. V. (2006). Overview of control and grid synchronization for distributed power generation systems. IEEE Transactions on Industrial Electronics, 53(5), 1398–1409.
[6] Bollen, M. H. J. (2000). Understanding power quality problems: Voltage sags and interruptions. IEEE Press.
[7] Akagi, H. (2005). Active harmonic filters. Proceedings of the IEEE, 93(12), 2128–2141.
[8] Khadkikar, V. (2012). Enhancing electric power quality using UPQC: A comprehensive overview. IEEE Transactions on Power Electronics, 27(5), 2284–2297.
[9] Singh, B., Al-Haddad, K., & Chandra, A. (1999). A review of active filters for power quality improvement. IEEE Transactions on Industrial Electronics, 46(5), 960–971.
[10] Ray, P., Ray, P. K., Behera, B. P., & Singh, N. (2024). ANF cascaded normalized-CF-SOHO based control for PV integrated unified power quality conditioner under non-ideal grid conditions. IEEE Transactions on Industry Applications.
[11] Wang, L., & Singh, C. (2020). Multicriteria design of hybrid renewable energy systems based on battery energy storage. IEEE Transactions on Industry Applications, 56(2), 1405–1415.
[12] Liserre, M., Blaabjerg, F., & Hansen, S. (2005). Design and control of an LCL-filter-based three-phase active rectifier. IEEE Transactions on Industry Applications, 41(5), 1281–1291.
[13] Jang, J. S. R. (1993). ANFIS: Adaptive-network-based fuzzy inference system. IEEE Transactions on Systems, Man, and Cybernetics, 23(3), 665–685.
[14] Zadeh, L. A. (1965). Fuzzy sets. Information and Control, 8(3), 338–353.
[15] Haykin, S. (2009). Neural networks and learning machines (3rd ed.). Pearson.
[16] Ray, P., Ray, P. K., Puhan, P. S., & Liyanage, M. L. T. K. (2025). Grid-connected photovoltaic and battery energy storage system integrated unified power quality conditioner for low-inertia microgrids. Applied Energy.
[17] Monteiro, V., Pinto, J. G., Afonso, J. L., & Rodrigues, A. (2024). Three-phase multifunctional unified power quality conditioner for modern distribution systems. IEEE Access.
[18] Nourmohamadi, H., Gohil, G., & Balsara, P. T. (2024). Intelligent multifunctional fault current limiter for smart grid protection. IEEE Transactions on Power Electronics.
[19] Silva, S. A. O. D., Modesto, R. A., Sampaio, L. P., &Campanhol, L. B. G. (2024). Advanced control strategy for unified power quality conditioners under voltage disturbances. IEEE Transactions on Industrial Electronics.
[20] Ray, P., Ray, P. K., Behera, B. P., & Singh, N. (2024). ANF cascaded normalized-CF-SOHO based PV integrated unified power quality conditioner under distorted grid conditions. IEEE Transactions on Industry Applications.
[21] Ray, P., Liyanage, M. L. T. K., Ray, P. K., &Puhan, P. S. (2023). Grid-following and grid-forming control of DER-fed voltage source inverter in microgrids with critical loads. IEEE Transactions on Smart Grid.
[22] Heenkenda, A., Elsanabary, A., Seyedmahmoudian, M., Mekhilef, S., Stojcevski, A., & Aziz, N. F. A. (2023). Unified power quality conditioner structures and control strategies: A comprehensive review. Renewable and Sustainable Energy Reviews, 177, 113210.
[23] Sanjenbam, C. D., & Singh, B. (2023). Modified adaptive filter-based unified power quality conditioner for battery-supported hydro-driven permanent magnet synchronous generator systems. IEEE Transactions on Industry Applications.
[24] Devassy, S., & Singh, B. (2021). Solar photovoltaic array and battery energy storage system integrated unified power quality conditioner for microgrid applications. IEEE Transactions on Industry Applications, 57(3), 2754–2765.
[25] Mahamedi, B., Eskandari, M., Fletcher, J. E., & Zhu, J. (2020). Sequence-based control with current limiting strategy for fault ride-through capability enhancement of inverter-interfaced distributed generators. IEEE Transactions on Sustainable Energy, 11(4), 2724–2735.
[26] Joshi, A., Singh, B., & Mishra, S. (2023). Artificial intelligence-based energy management techniques for renewable energy integrated microgrids: A review. IEEE Access, 11, 102345–102378.
[27] Sánchez-Vargas, O., Gómez, J., & Pérez, R. (2024). ANFIS-based intelligent control techniques for power electronic converters: A review. IEEE Transactions on Power Electronics.

[28] Srimatha, S., Kumar, P., & Reddy, V. (2023). ANFIS-controlled unified power quality conditioner for harmonic mitigation in distribution systems. Journal of Electrical Systems and Information Technology, 10(1), 35.

[29] Chapala, S., Reddy, K., & Rao, M. (2024). ANFIS-based distributed generation integrated unified power quality conditioner for hybrid renewable energy systems. International Journal of Electrical Engineering and Informatics, 16(2), 221–236.

[30] Singh, B., Khadkikar, V., & Chandra, A. (2023). Advancement in techniques toward optimal operation of unified power quality conditioner for power quality improvement. IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), 1–6.

[31] Pragnyashree. S, Pravat Kumar Ray and M. L.TharuthKavinda (2025). Performance Improvement of Microgrid with Strategic Control of Distributed Energy Resources Integrated UPQC. IEEE Transactions on Industry Applications, VOL. 61, NO. 3,



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