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ANN-Assisted Soccer-League Optimization for Enhanced Power Quality in Solar-Battery Integrated UPQC

Mr. R Nitish
PG Scholar
Department of Electrical and Electronics Engineering,
Kuppam Engineering College,
KES Nagar, Kuppam, Andhra Pradesh 517425 India
Email: nitishnitish4940@gmail.com

Dr.Velappagari Sekhar
Associate Professor & HOD
Department of Electrical and Electronics Engineering,
Kuppam Engineering College,
KES Nagar, Kuppam, Andhra Pradesh 517425 India
Email: velappagarisekhar@gmail.com

Mr. B Theja
PG Scholar
Department of Electrical and Electronics Engineering,
Kuppam Engineering College,
KES Nagar, Kuppam, Andhra Pradesh 517425 India
Email:thejutheju026@gmail.com

Mr. V.Niranjan
Lecturer
Department of Electrical and Electronics Engineering,
Dr.Y.C. James Yen Government Polytechnic,
Kuppam, Andhra Pradesh 517425 India
***Email:** niranjan.vaidhyam@gmail.com*

Abstract— **In order to satisfy demand and minimize losses, the grid is rapidly encouraging the integration of renewable energy sources like wind and solar power. However, power quality problems are frequently caused by this integration in addition to power electronic devices and non-linear loads. This work addresses this issue by introducing a novel method that uses Boost and Buck-Boost converters to create an optimal tuned hybrid controller for the Unified Power Quality Conditioner (UPQC) that is based on a soccer league algorithm and integrated with solar power and battery storage systems. The UPQC is an active power filter that can be used as a series or shunt filter. The suggested controller combines the advantages of proportional-integral controllers tuned by the SOL method with ANN-based controllers. This methodology treats the Kp and Ki values of shunt and series controllers as control variables, optimized by the SOL algorithm to satisfy predetermined objectives, in contrast to prior methods that use fuzzy controllers. Important contributions include lowering the overall harmonics in current waveforms, improving power factor, preventing voltage sag, swell, and disturbances, preserving constant DC-Link capacitor voltage during variations in solar irradiation, and correcting for unbalanced loads and networks. The efficacy of the Soccer-League Optimization Hybrid Controller (SLOHC) is demonstrated by performance evaluation conducted through four test studies on various load and supply voltage combinations. Superior performance is revealed by comparison with conventional techniques including proportional-integral controllers, biogeography-based optimization, and evolutionary algorithms. This is especially true when compared to approaches found in the literature, as it reduces total harmonic distortion. MATLAB/Simulink software is used for the design and evaluation, demonstrating the usefulness of the suggested strategy in improving power quality in integrated solar-battery systems.**

Keywords—Artificial Neural Network (ANN) Controller, SLOHC Controller, UPFC,UPQC etc.

I. Introduction

The integration of renewable energy sources, particularly solar power, into traditional grids presents a promising avenue for reducing carbon emissions and enhancing energy sustainability. However, this integration introduces challenges related to power quality, as renewable sources are inherently intermittent and fluctuating. These challenges are further compounded by the presence of power electronic devices, non-linear loads, and unbalanced network conditions.

In response to these issues, the Unified Power Quality Conditioner (UPQC) has emerged as a crucial technology for mitigating power quality disturbances. By simultaneously acting as both a Shunt and Series active power filter, the UPQC can address a wide range of power quality issues, including harmonics, voltage fluctuations, and unbalanced loads.

In recent years, researchers have focused on developing advanced control strategies to enhance the performance of UPQC systems. Traditional methods, such as fuzzy controllers, have shown effectiveness in certain scenarios but may lack robustness and adaptability in complex and dynamic environments.

To address these limitations, this paper proposes a novel approach: the ANN-Guided Soccer-League Optimization Hybrid Controller (SLOHC) for UPQC systems integrated with solar power and battery storage. This hybrid controller combines the advantages of Artificial Neural Network (ANN) controllers and the Soccer-League Optimization (SOL) algorithm to achieve superior performance in power quality enhancement.

The ANN component of the controller offers learning capabilities and adaptability, allowing the system to dynamically adjust to changing operating conditions. Meanwhile, the SOL algorithm optimizes the controller parameters, specifically the proportional and integral gains of the Shunt and Series controllers, to achieve predefined objectives such as minimizing total harmonic distortion and maintaining voltage stability.

The integration of solar power and battery storage further enhances the functionality of the UPQC system, enabling it to respond effectively to variations in solar irradiation and demand fluctuations. By leveraging the complementary capabilities of renewable energy and energy storage, the proposed method aims to improve grid stability and reliability while maximizing the utilization of clean energy resources.

In this project, we present the design and implementation of the ANN-Guided SLOHC for solar-battery integrated UPQC systems. We evaluate the performance of the proposed method through simulation studies conducted in MATLAB/Simulink, comparing it with existing control strategies such as fuzzy controllers and conventional optimization techniques. Our results demonstrate the effectiveness and superiority of the proposed approach in enhancing power quality and grid stability in renewable energy-integrated systems.

The organizational framework of this study divides the research work in the different sections. The Literature survey is presented in section 2. In section 3 &4 discussed about Existing & proposed system methodologies. Further, in section 5 shown Results is discussed and. Conclusion and future work are presented by last sections 6.

II. Literature Survey

In order to increase power quality, Wang, Y.-W., Wong, M.-C., & Lam, C.-S. present a historical review of parallel hybrid active power filters, providing an understanding of earlier methods and strategies in this field.[1]
Hingorani, N. G. - The author explains Flexible AC Transmission (FACTS) technologies, providing background information for comprehending the larger picture of grid stability enhancement and power quality improvement.In [2]
Devassy, S., & Singh, B. - This study offers an integrated three-phase solar PV integrated Unified Power Quality Conditioner (UPQC) design and performance analysis, offering important insights into the combination of power quality improvement methods and renewable energy sources. In [3]

Xu, J. X., Lee, T. H., Panda, S. K., Dash, P. K., & Routray, A. - To help readers comprehend advanced control strategies used in power quality enhancement, the authors give an overview of fuzzy and neural controllers for dynamic systems.[4]
S. Mikkili and A. K. Panda This study provides practical insights into control strategy implementation by focusing on the hardware development and simulation of a Shunt Active Harmonic Filter (SHAF) for harmonics mitigation using the Real-Time Digital Simulator (RTDS).[5]
Lin, H. C. - The author highlights the significance of sophisticated control strategies in power quality enhancement by discussing a quick power system harmonic detection approach based on intelligent neural networks.[6]

In this research, Dheeban, S. S., and Selvan, N. B. M. demonstrate the efficacy of hybrid intelligent control techniques by presenting an approach to power quality enhancement based on an Adaptive Neuro-Fuzzy Inference System (ANFIS) and a photovoltaic integrated UPQC.[7]
Gopal, B., Sreenivas, G. N., and Murthy, P. K. - The authors highlight the function of UPQC in boosting grid stability in the presence of distributed energy resources as they explore power quality improvement utilizing UPQC integrated with distributed generating networks.[8]
In order to show the efficacy of fuzzy-based control strategies in power quality enhancement, Mohankumar, G.

B., and Manoharan, S. examine the performance of a multi-converter Unified Power Quality Conditioner (UPQC) with dual feeder systems utilizing fuzzy logic control.[9]

The authors, Mahaboob, Ajithan, and Jayaraman, demonstrate the use of nature-inspired optimization approaches in control design by presenting an optimal design of a shunt active power filter for power quality enhancement through predator-prey based firefly optimization.[10]

Wang, Y.-W., Lam, C.-S., and Wong, M.-C. In order to improve power quality, this study provides a historical perspective on the creation and growth of parallel hybrid active power filters. It offers important insights on the trajectory of research in this area by examining earlier approaches and developments and noting significant obstacles, breakthroughs, and potential paths for future work.[11]

Hingorani, N. G. - In this seminal work, Hingorani discusses Flexible AC Transmission Systems (FACTS), providing a comprehensive overview of the principles, applications, and benefits of FACTS technologies in enhancing power system control and stability. The paper serves as a foundational reference for understanding the broader context of power quality improvement and grid optimization.[12]

The design and performance study of a three-phase solar PV integrated Unified Power Quality Conditioner (UPQC) are the main topics of this paper by Devassy, S., and Singh, B. The research provides important insights into the integration of power quality enhancement techniques with renewable energy sources by assessing the efficacy of UPQC in minimizing power quality issues in solar PV-integrated systems.[13]

Xu, J. X., Lee, T. H., Panda, S. K., Dash, P. K., & Routray, A. - By giving a general review of fuzzy and neural controllers for dynamic systems, the authors set the foundation for comprehension of sophisticated control techniques used in power quality enhancement. The study is a useful resource for researchers investigating novel control methodologies by providing an overview of the fundamentals and practical applications of fuzzy and neural control systems.[14]

The hardware implementation and modeling of a Shunt Active Harmonic Filter (SHAF) for harmonic mitigation employing a p-q control approach with PI and fuzzy logic controllers are presented in this paper by Mikkili, S., and Panda, A. K. The research provides insights into the performance and efficacy of harmonic mitigation techniques in real-world applications by comparing various control schemes and illustrating the practical implementation of SHAF.[15]

H. C. Lin The author highlights the significance of sophisticated signal processing techniques in power quality monitoring and control by discussing a quick power system harmonic detection method based on artificial neural networks. The research makes a contribution to the advancement of accurate and efficient harmonic detection approaches by putting forth an intelligent neural network methodology for fast harmonic detection.[16]

The authors of this research, Dheeban, S. S., and Selvan, N. B. M., suggest using the Adaptive Neuro-Fuzzy Inference System (ANFIS) to enhance power quality in photovoltaic integrated distribution systems. The study illustrates how hybrid intelligence approaches can improve power quality in renewable energy-integrated systems by utilizing ANFIS's intelligent control capabilities.[17]

Gopal, B., Sreenivas, G. N., and Murthy, P. K. - The authors talk about how distributed generating networks can be combined with Unified Power Quality Conditioners (UPQC) to improve power quality. The research investigates the potential of UPQC to improve grid stability and power quality in the presence of distributed energy resources by looking at how it integrates with distributed generation.[18]

In this study, Mohankumar, G. B., and Manoharan, S. use fuzzy logic control to examine the performance of a multi-converter Unified Power Quality Conditioner (UPQC) with dual feeder systems. The research offers insights into the efficacy of fuzzy-based control strategies in minimizing power quality issues by assessing the performance of UPQC with fuzzy logic control in dual feeder systems.[19]

Mahaboob, S., Jayaraman, S., and Ajithan, S. K. - The authors use predator-prey based firefly optimization to offer an ideal design of a shunt active power filter for improving power quality. The research provides a novel methodology for optimizing power quality enhancement in distribution systems by putting forth an optimization-based strategy for the design of shunt active power filters.[20]

These papers collectively contribute to the body of knowledge on power quality improvement techniques, providing insights into the development, implementation, and performance evaluation of various methodologies in both conventional and renewable energy-integrated systems.

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III. EXISTING SYSTEM

The paper describes the current strategy, which offers a thorough way to deal with power quality issues in electrical distribution networks. Regarding the integration of renewable energy, specifically solar photovoltaic (PV) systems, the current approach suggests using a Unified Power Quality Conditioner (UPQC) in conjunction with a Battery System (BS) and related converters for extra assistance.

The current method's introduction highlights how crucial it is becoming to include renewable energy sources into the grid in order to achieve sustainability objectives. However, because of the intermittent nature of renewable energy supply and the existence of non-linear loads, this integration poses power quality difficulties. In order to address these issues, the UPQC is suggested as a way to improve power quality, with assistance from the battery system and converters.

Each series and shunt converter in the UPQC has a distinct purpose and is interconnected by a DC-link. The UPQC's Shunt Active Power Filter (SAPF) and Series Hybrid Active Power Filter (SHAPF) are essential for removing harmonics, imbalances, and voltage distortions from the distribution system. Furthermore, the system's flexibility and resilience are increased by the external assistance provided by the battery system, solar PV system, and related converters. This enables the system to adapt to changing renewable energy generation patterns and dynamic grid conditions.

Fig. 1. In general, the explanation of the current approach lays the groundwork for comprehending the goals and driving forces behind the suggested strategy. It establishes the foundation for future discussion on the suggested improvements made possible by the Soccer-League Optimization Hybrid Controller (SLOHC) by highlighting the necessity of sophisticated power quality enhancement techniques in the context of renewable energy integration and giving an outline of the UPQC system architecture and its constituent parts.

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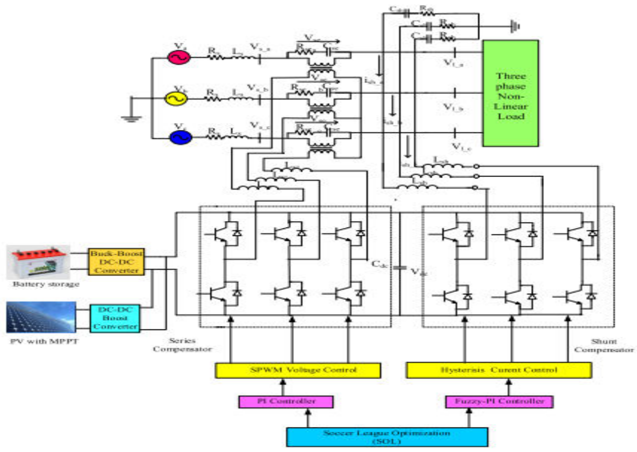

Fig. 2. Existing system Architecture

The current system, shown in Figure 1, is made up of a solar photovoltaic (PV) system with a Boost Converter (BC) connected to the DC-link and a battery system (BS) with a Buck Boost Converter (BBC) integrated with external assistance. In order to take use of the advantages of both the optimally adjusted Proportional-Integral Controller (PI-C) and the Fuzzy Logic Controller (FL-C), this work presents the Soccer-League Optimization Hybrid Controller (SLOHC).

The source phase voltages are indicated by VS_a, VS_b, and VS_c in the system configuration, whereas the grid voltages are represented by Va, Vb, and Vc. The source-side resistance is represented by Rs, and the inductance by LS. Series and shunt converters connected by a DC-Link make up the UPQC. Two essential parts of the UPQC are the Series Hybrid Active Power Filter (SHAPF) and Shunt Active Power Filter (SAPF).

By injecting compensatory voltage (Vse) through an isolating transformer, the SAPF—which consists of a series resistor (Rse), series inductor (Lse), and series capacitor (Cse)—is able to eliminate distortions and unbalances due to supply voltage. Conversely, the SHAPF is made up of a shunt capacitance (Csh), a shunt resistor (Rsh), and a shunt-interfacing inductor (Lsh). Its function is to inject compensatory shunt current (ish) to eliminate harmonics in the current waveform and maintain the stability of the DC-link capacitor voltage (Vdc) during variations in load and irradiation.

Overall, the existing system aims to address power quality issues such as voltage distortions, unbalances, and harmonics through the coordinated operation of the UPQC components and external support from the battery system and solar PV system. The proposed SLOHC method aims to enhance the performance of the system by optimizing control strategies to achieve better power quality and grid stability

IV. Proposed Method

The Unified Power Quality Conditioner (UPQC) system's layout is shown in the figure. It is combined with external support from a solar photovoltaic (PV) system with a BC-connected Boost Converter and a battery system (BS) with a BC-connected Buck Boost Converter. In order to maximize control techniques, this research suggests using the Soccer-League Optimization Hybrid Controller (SLOHC), which combines the powers of the Fuzzy Logic Controller (FL-C) and the Artificial Neural Network Controller (ANN-C).
The source phase voltages are indicated by VS_a, VS_b, and VS_c in the system configuration, whereas the grid voltages are represented by Va, Vb, and Vc. The source-side resistance is denoted by Rs, and the inductance by LS. A DC-Link connects the series and shunt converters that make up the UPQC. In order to mitigate power quality difficulties, the UPQC's Shunt Active Power Filter (SHAPF) and Series Active Power Filter (SAPF) components are crucial.

The SAPF, which consists of a series resistor (Rse), series inductor (Lse), and series capacitor (Cse), injects compensating voltage (Vse) through an isolating transformer to remove distortions and unbalances due to supply voltage. However, by injecting compensating shunt current (ish), the SHAPF, which is made up of a shunt resistor (Rsh), shunt-interfacing inductor (Lsh), and shunt capacitance (Csh), lowers harmonics in the current waveform and maintains the DC-link capacitor voltage (Vdc) stable during variations in load and irradiation.

Overall, the figure illustrates the configuration of the UPQC system along with its supporting components and highlights the proposed utilization of the SLOHC to optimize control strategies and enhance power quality performance in the integrated system.

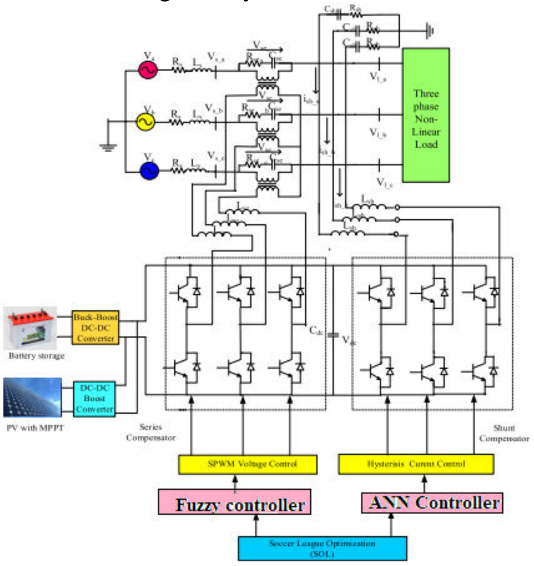

Fig. 3. Proposed method Architecture

A. UPFC

In the proposed strategy, the Brought together Power Stream Regulator (UPFC) assumes a urgent part in overseeing power quality and improving the steadiness of the electrical circulation framework. The UPFC is a high level power gadgets gadget that coordinates both series and shunt compensators to direct voltage, control power stream, and alleviate power quality issues, for example, voltage droops, grows, sounds, and unbalances. The UPFC achieves superior adaptive control and optimization by incorporating the Soccer-League Optimization Hybrid Controller (SLOHC), which combines the capabilities of the Artificial Neural Network Controller (ANN-C) and the Fuzzy Logic Controller (FL-C). The ANN-C gives prescient control in view of authentic and ongoing information, while the FL-C handles nonlinearities and vulnerabilities through fluffy rationale rules. These controllers are optimally tuned by the SLOHC to guarantee that the UPFC can dynamically respond to shifting grid conditions and disturbances, preserving a reliable and high-quality power supply. This joining is especially gainful in situations including environmentally friendly power sources, where variances and discontinuity can essentially affect power quality. By utilizing the joined qualities of ANN-C and FL-C inside the UPFC structure, the proposed technique guarantees strong and effective power quality administration, adding to the general dependability and execution of the electrical appropriation framework.

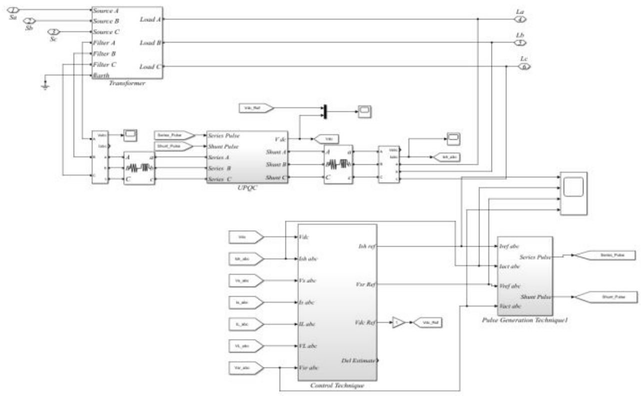

Fig. 4. UPFC Architecture

B. UPQC

In this venture, the Bound together Power Quality Conditioner (UPQC) is a vital part intended to upgrade the power quality in electrical conveyance frameworks fundamentally. The UPQC incorporates both series and shunt dynamic power channels to at the same time address an extensive variety of force quality issues, including voltage lists, grows, sounds, and unbalances. The proposed technique consolidates a Soccer-Association Enhancement Half and half Regulator (SLOHC) into the UPQC framework to upgrade its presentation. The SLOHC use the qualities of both a Fake Brain Organization Regulator (ANN-C) and a Fluffy Rationale Regulator (FL-C). The ANN-C gives prescient abilities in light of authentic and ongoing information, considering proactive acclimations to drive stream, while the FL-C offers strong treatment of framework nonlinearities and vulnerabilities through its standard based approach. By utilizing the Soccer-Association Enhancement calculation, the SLOHC adjusts the control boundaries to accomplish ideal execution, guaranteeing the UPQC can successfully alleviate power aggravations and keep up with stable activity much under changing burden conditions and sustainable power mix. This exceptional control procedure empowers the UPQC to convey prevalent power quality improvement, making it a fundamental instrument for present day, versatile, and proficient power appropriation organizations.

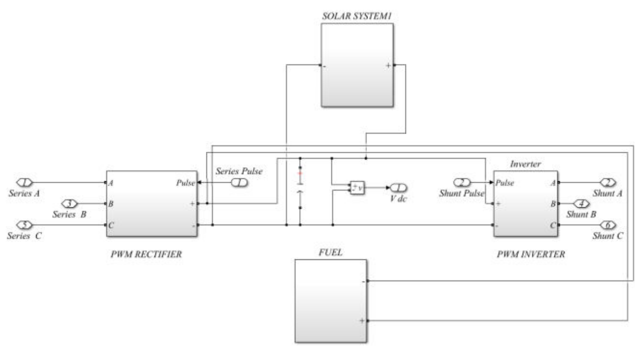

Fig. 5. UPQC Architecture

C. ANN Controller

In this project, the integration of an Artificial Neural Network (ANN) Controller serves as a crucial component to enhance the efficiency, adaptability, and intelligence of the charging system. The need for an ANN Controller arises from the complexity and variability of the charging process, as well as the dynamic nature of grid conditions and user preferences. Traditional control methods, such as Proportional-Integral (PI) controllers, may struggle to effectively manage the diverse and fluctuating parameters involved in electric vehicle (EV) charging, including grid load, battery state-of-charge, and user behavior. By contrast, an ANN Controller offers the ability to learn from data and adjust its parameters in real-time, enabling it to adapt to changing conditions and optimize charging strategies accordingly. This adaptive capability is particularly valuable in scenarios where grid constraints, renewable energy integration, and user demand fluctuate unpredictably. Furthermore, the ANN Controller enhances the system's capability to manage bidirectional power flow, prioritize charging tasks, and maintain grid stability, thereby maximizing efficiency and reliability. Overall, the inclusion of an ANN Controller in this project represents a significant advancement in control technology, providing a versatile and intelligent solution to address the complex challenges of EV charging in a dynamic and evolving energy landscape.

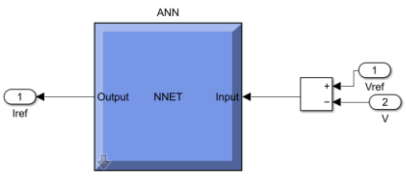

Fig. 6. Neuaral Network

V. RESULTS AND DISCUSSION

A. Existing Method

This figure 6 presents the Simulink model of the existing method for power quality improvement using a standard UPQC setup. It includes the configuration of the series and shunt converters, the control algorithms used, and the overall system layout.

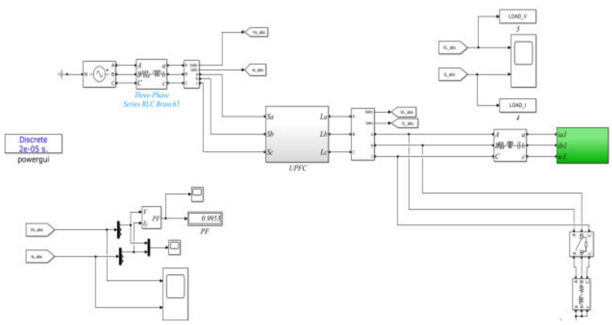

Fig. 7. Existing Method Simulink Model

This figure 7 shows the waveforms of the input AC voltage and current before any conditioning by the UPQC. The waveforms likely exhibit distortions, such as harmonics and unbalances, indicative of poor power quality typically present in an unconditioned system.

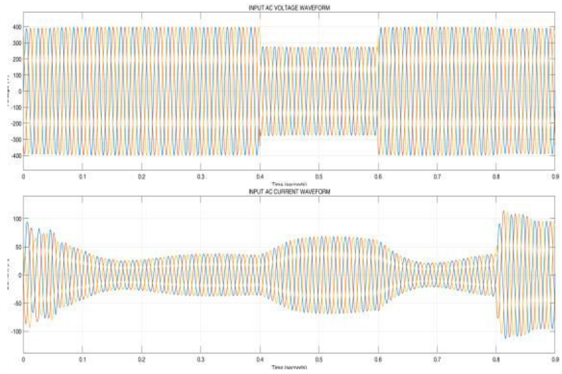

Fig. 8. Input AC Voltage and Current Waveform

This figure 8 illustrates the voltage and current waveforms at the load side. These waveforms show the effects of the UPQC's conditioning, where improvements in power quality can be observed compared to the input waveforms. However, the existing method may still have limitations in fully mitigating all disturbances.

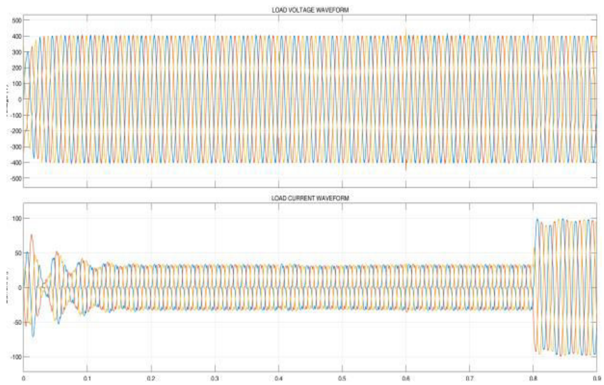

Fig. 9. Load voltage and Current Waveform

This figure 9 depicts the waveform characteristics specifically related to the UPQC's operation. It shows how the series and shunt components of the UPQC work to inject compensating voltages and currents to correct the input distortions and maintain a stable load supply.

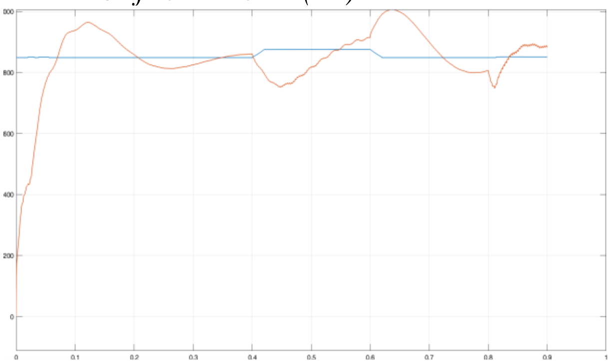

Fig. 10. UPFC Waveform

This figure 10 shows the input and output voltages and currents of the converters within the UPQC. It illustrates the performance of the converters in regulating and transforming the power quality metrics to ensure an optimal supply to the load.

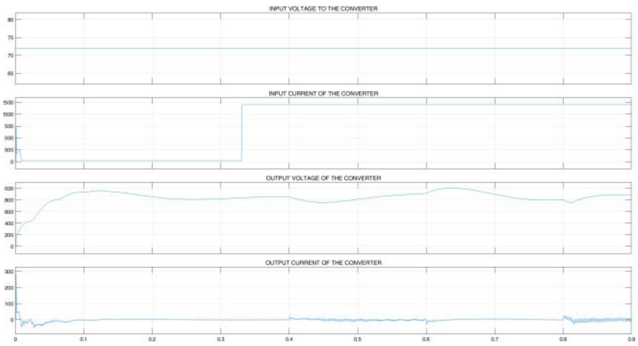

Fig. 11. Converter Input and Output Voltage ,current waveform

B. Proposed System

This figure presents the Simulink model of the proposed method, integrating the Soccer-League Optimization Hybrid Controller (SLOHC) with the UPQC system. It includes the ANN-C and FL-C configurations, their integration into the UPQC, and the overall system architecture.

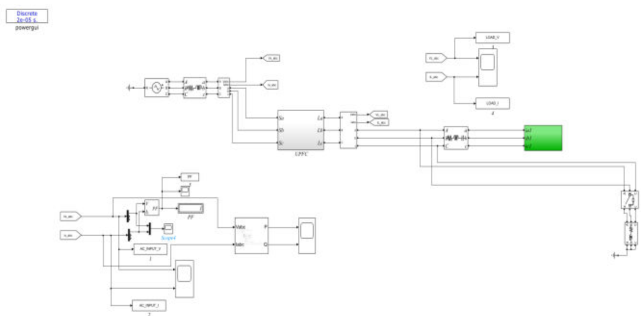

Fig. 12. Proposed system Simulink Model

This figure 12 shows the waveforms of the three-phase input voltage and current before conditioning by the proposed SLOHC-UPQC system. These waveforms may contain distortions similar to those seen in the existing method, representing the initial power quality issues.

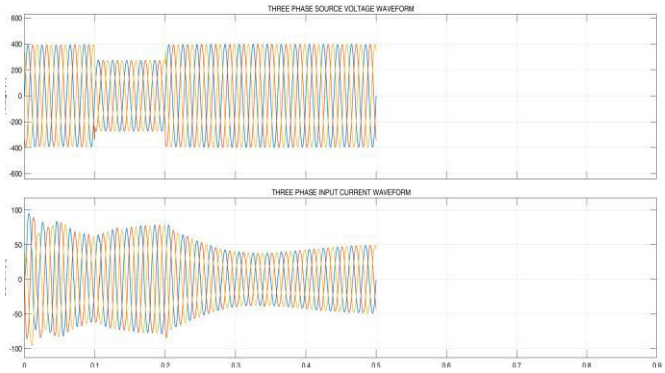

Fig. 13. Three Phase Input Voltage and Current waveform

This figure 13 illustrates the conditioned three-phase load voltage and current waveforms after the application of the proposed method. The improvements in power quality are more pronounced here, with reduced harmonics, balanced phases, and stable voltage levels

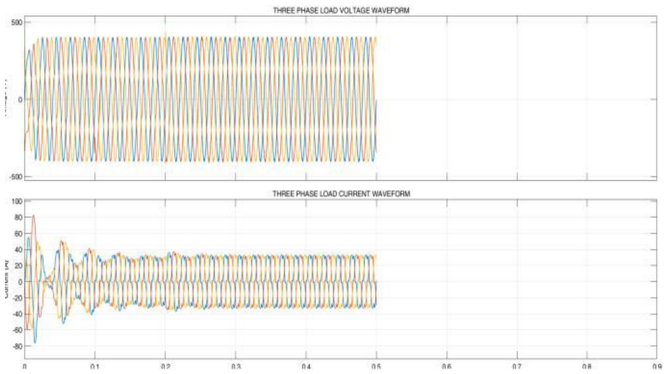

Fig. 14. Three phase Load Voltage and Current waveform

This figure 14 depicts the real and reactive power waveforms managed by the proposed system. The effective control of these power components showcases the system's ability to optimize power flow and enhance the overall efficiency and stability of the power distribution network.

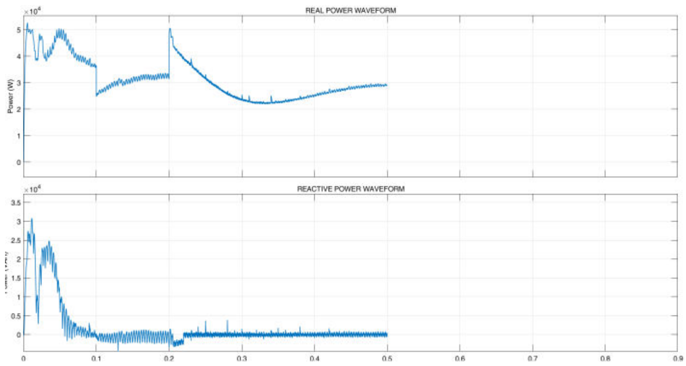

Fig. 15. Real Power and reactive power waveform

These figures 15 show the reference and actual voltage and current waveforms for the shunt and series converters' PWM generators. The close alignment between the reference and actual waveforms indicates the high precision and effectiveness of the SLOHC in controlling the converters, ensuring accurate power quality management.

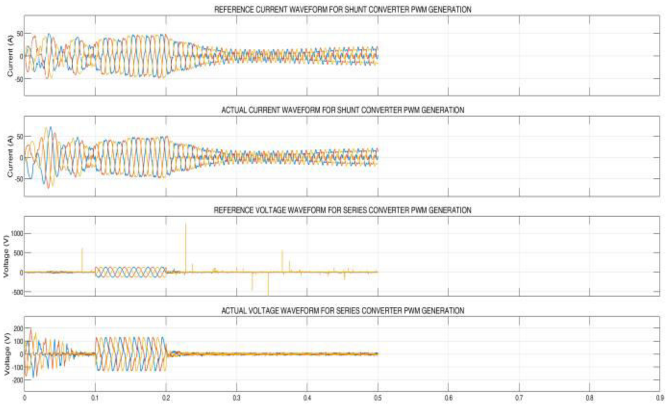

Fig. 16. Reference &Actual voltage & current waveform for shunt converter pwm generator

and

Reference & Actuak voltage & current waveform for series converter pwm Generator

This figure 16 shows the input and output voltages and currents for the inverter within the proposed UPQC system. It highlights the inverter's performance in transforming the power from the input side to the desired output quality, demonstrating the system's capability to maintain stable and high-quality power delivery to the load.

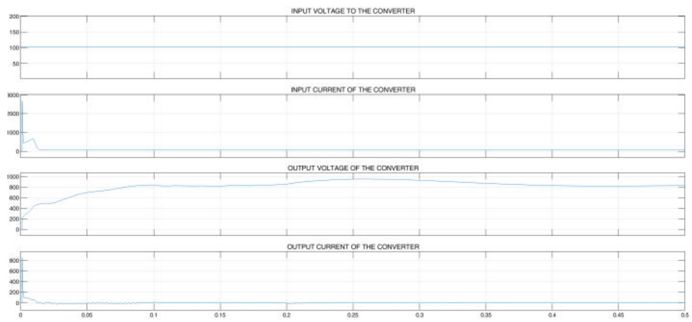

Fig. 17. Input and Output voltage & Current to the inverter

The simulation results illustrate the enhanced performance of the proposed SLOHC-UPQC method over the existing method. The proposed system shows significant improvements in mitigating power quality issues, optimizing real and reactive power management, and providing more accurate and stable control of voltage and current waveforms. These improvements underscore the efficacy of integrating advanced control techniques, such as ANN-C and FL-C, optimized through the Soccer-League Optimization algorithm, into UPQC systems for superior power quality enhancement.

VI. Conclusion

The integration of the Soccer-League Optimization Hybrid Controller (SLOHC) into the Unified Power Quality Conditioner (UPQC) system presents a promising solution for enhancing power quality and grid stability in electrical distribution systems. Through the synergistic combination of the Artificial Neural Network Controller (ANN-C) and Fuzzy Logic Controller (FL-C), the SLOHC framework offers adaptive and robust control strategies to effectively mitigate voltage distortions, harmonics, and unbalances.

The proposed method demonstrates several key advantages, including enhanced power quality, adaptability to changing grid conditions, optimization capability, and complementary control actions. By harnessing advanced control techniques and optimization algorithms, the SLOHC-equipped UPQC system provides reliable and efficient operation across various applications, including renewable energy integration, industrial facilities, smart grids, and electric vehicle charging station.

Future Scope

In future the proposed method can be extended with The proposed method can be extended with the Continued research and development efforts can focus on refining the optimization algorithms used in the SLOHC framework, exploring advanced optimization techniques to further enhance controller performance and efficiency.

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ABOUT AUTHORS

1. Mr. R Nitish studying M.Tech II Year., (PE) in Department of Electrical and Electronics Engineering, Kuppam Engineering College, KES Nagar, Kuppam, Andhra Pradesh 517425 India.

2. Dr. Velappagari Sekhar, Associate Professor & HOD, Department of Electrical and Electronics Engineering, Kuppam Engineering College, KES Nagar, Kuppam, Andhra Pradesh 517425 India
.

3. Mr. B Theja, studying M.Tech II Year., (PE), Department of Electrical and Electronics Engineering, Kuppam Engineering College, KES Nagar, Kuppam, Andhra Pradesh 517425 India.

4. Mr. V.Niranjan, Lecturer, Department of Electrical and Electronics Engineering, Dr. Y.C. James Yen Government Polytechnic, Kuppam, Andhra Pradesh 517425 India