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# **Improving Power Quality with Electrical Energy Systems**

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Article Info	Abstract: - As the proliferation of sensitive electronic devices continues, the
	importance of maintaining high power quality in energy systems has
Accepted : 01 Jan 2025	become increasingly critical. Electrical disturbances within the energy
Published : 03 Jan 2025	system can lead to both technical and financial damages and can degrade
	the quality of power supplied. The Unified Power Quality Conditioner
Publication Issue :	(UPQC) has emerged as a highly effective solution to mitigate these
January-February-2025	dilemmas. Key factors affecting power quality include voltage sags, swells,
Volume 8, Issue 1	harmonics, non-linear loads, unbalanced loads, and voltage stability
	dilemmas.
Page Number : 01-10	Keywords : Power Quality (PQ), Unified power quality conditioner
	(UPQC).

#### I. INTRODUCTION

An electrical energy system is designed to provide reliable and efficient power to ensure that various electrical devices can function properly. As the demand for electrical energy escalates, it is imperative to maintain that the power quality delivered aligns with the increasing power quantity requirements. One of the primary objectives in power grids has always been to uphold the quality of electrical power, which is essential for their effective operation [1].

The power system takes part in a crucial role in providing the electrical energy that is necessary for our everyday activities. However, power quality problems can crop up within the power system. Ensuring that the power transfer system operates efficiently requires meeting the prescribed power quality standards, such as IEEE 519 and IEEE 1159. Meeting these standards is crucial to guarantee the effectiveness and reliability of the power system [2-3]. As the use of testing equipment has become more prevalent, there has been a growing awareness and concern regarding power quality issues in recent years. This is because the proper functioning of these sensitive devices is heavily reliant on consistent and reliable power quality, and any deviations or disturbances can have a significant impact on their performance. The use of advanced electronic equipment has increased as a result of the growth of industrial and technical development. However, the operation of these devices has led to several issues in the electrical grid, such as the appearance of excessive harmonics, which can cause distortion in the supply voltage waves. Power quality

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(PQ) issues have become a significant challenge for modern electric power systems. Power quality issues pose significant challenges to modern electric power systems, with voltage sag, voltage swell, transient frequency deviation, flicker, voltage and current harmonics, and zero sequence currents being the most prevalent concerns. Power quality issues are deviations in voltage, current, or frequency that significantly depart from the ideal sinusoidal waveform and may cause failure or malfunction of customer equipment. Power quality refers to a power system's ability to maintain sinusoidal waveforms of voltages and currents on the distribution bus at their rated magnitude and frequency, with minimal deviation or distortion. Power electronic devices, such as Switch Mode Power Supplies (SMPS), current regulators, frequency converters, and others, can contribute to power quality issues. These devices may introduce harmonic distortions, voltage fluctuations, and other irregularities, impacting the overall stability and reliability of the power system. All power electronic devices are also classified as non- linear loads. Due to usage of nonlinear loads harmonics, voltage sag, voltage swell all kind of distortion generated for which power quality issues generated and the consumer does not get the desired power.

The power quality issues can be mitigated through the implementation of an electronics-based strategy. This equipment is a constructive solution for power quality issues. Conventionally different type of procedures has been taken to control the problem that is related to power quality. We used a static capacitor to compensate the reactive power in the grid. There is also other equipment such as thyristor switched capacitor (TSC), static VAR compensators (STATCOM), and thyristor-controlled reactors (TCR) have been implemented to offer greater flexibility in managing reactive power compensation [4].

In this paper, a unified power quality conditioner which is known as UPQC is used to address above issues. UPQC is the combination of a series active filter and a shunt active filter which are used to discard the high frequency current ripples and voltage distortion. Filters can be categorized into two distinct types: active filters and passive filters. In addition to this, active filtering is also categorized into shunt, series, and hybrid filters. The shunt active filter is specifically linked in parallel and addresses issues such as elevated harmonics [5]. Series active filters are essential for addressing voltage-related power quality disturbances by integrating in series with the power distribution system [6]. The hybrid composition of both series and shunt is capable to remove both types of problems. In UPQC we used a hybrid composition of both series and shunt converter with some noble control strategies. Active power filters (APFs) possess the capability to mitigate a variety of significant power quality issues. Previously, in conjunction with UPQC, PI control strategies were employed to effectively mitigate harmonics, voltage sag, voltage swell, and distortion. However, to enhance the performance of the UPQC and achieve improved results, this work has implemented a TS-fuzzy controller. The proposed controller was investigated under voltage sag, voltage swell and harmonic distortion. The suggested approach can be validated within the MATLAB/Simulink environment.

### STATE OF THE ART:

In terms of custom power devices, it is important to understand that each device offers unique benefits and limitations that should be taken into consideration when selecting a device for a specific power system



application. After extensive research, it can be concluded that the Unified Power Quality Conditioner (UPQC) is a highly efficient and effective remedy for diminishing power quality problems in power systems that have high-capacity loads, which are susceptible to voltage and current fluctuations and imbalances. There are many more reasons that proved why UPQC is preferred over others. In devices, most of the devices either correct current or voltage disruptions but UPQC does both tasks simultaneously and hence multiple tasks can be done by UPQC [7].

The Unified Power Quality Conditioner is a comprehensive solution that integrates two types of Active Power Filters (APFs) – shunt active power filters and series active power filters [8-10]. Shunt APFs are designed to counteract the current harmonics generated by non-linear loads, facilitating reactive power compensation and balancing of imbalance currents. On the other hand, series APFs primarily function as voltage regulators and harmonic isolators, ensuring a stable connection between non-linear loads and the utility grid. In modern-day distribution systems, there is an increasing demand for elevated levels of voltage quality and current stability. The UPQC addresses these requirements, making it a crucial component in today's power generation and distribution systems. The active power filters (APFs) have become increasingly relevant for practical implementation as they can effectively address issues related to voltage regulation and current stability by mitigating harmonic distortion and improving power factor in power systems. But it may not be cost effective if we install two separate devices individually.



Fig.1. Configuration of UPQC

Moran [11] introduced a system configuration in which two separate systems were interconnected using a shared DC reactor. This particular configuration was referred to as a "line voltage regulator/conditioner." Additionally, the back-to-back inverter setup has been identified by several other names in the literature, including: Series-Parallel Converter [12], Unified Active Power Filter (UAPF) [13], Universal Active Power Line Conditioner [14-15], Universal Power Quality Conditioning System (UPQS) [16], Universal Active Filter [17]. These various names highlight the versatility and applicability of the back-to-back inverter arrangement, as it serves as an effective solution for enhancing power quality, voltage regulation, and harmonic mitigation in electrical systems.

In configuration wise it can be said that the construction of UPQC is similar in nature to that of a unified power flow controller (UPFC) as both devices consists of power electronic components such as voltage source inverter (VSI), DC-link capacitors and transformers and utilize algorithms to regulate power flow and improve power quality in electrical power systems. Conversely, UPFC is capable of operating solely under balanced conditions. Due to its unique properties, the power transmission system is suited for the application of UPFC since it normally runs in a counterbalanced and wrapping out environment. Conversely, the power distribution system might encompass DC elements, along with voltage and current anomalies, as well as imbalances in voltage and current. Therefore, in this scenario, the UPQC is employed to address these issues effectively. Fig. 1 provides a visual representation of the UPQC system configuration, illustrating its components and how it is integrated into the power distribution system to lessen power quality problems and ensure stable and reliable operation.

The primary objective of a Unified Power Quality Conditioner (UPQC) is to address various voltage imbalances and power quality issues in electrical systems. These issues include voltage sags, swells, flicker, harmonics, reactive power, negative-sequence currents, and harmonics. To achieve this, the UPQC employs two inverters with specific functions: Shunt Active Power Filter: This inverter is connected across the load and serves as a shunt active power filter. Its purpose is to mitigate current harmonics generated by nonlinear loads, thereby reducing reactive current in the load and improving power factor. Series Active Power Filter: line. It handles as a series voltage source inverter (VSI) and is used for utility supply. The series APF acts as a voltage source to counteract voltage disturbances, such as sags and swells, and helps in voltage regulation. By using both the shunt and series APFs, the UPQC effectively addresses a wide range of power quality issues, providing a more stable and reliable power supply to sensitive loads and improving overall system performance. In the system configuration shown in Figure (1), a common DC bus is formed using either a capacitor or an inductor. This DC-link is used to supply DC voltage to the two connected inverters. An LC filter is utilized as a passive low-pass filter (LPF) to reduce the amount of ripples in the system, thereby providing a smoother output. The shunt coupling inductor, denoted as *Lsh*, is employed to interface the shunt inverter with the power network. During the switching process, the ripples in the system are attenuated by the

*Lsh* filter, contributing to improved performance and reduced harmonic content. A series injection transformer is used to connect the series inverter to the AC power line. This transformer allows the series inverter to interface with the power line effectively. Moreover, through the application of an authenticated turns ratio, there is often the potential to lessen the current or voltage capacity of the series inverter, making it more suitable for the application and enhancing system efficiency.

Due to the above-mentioned feature, the UPQC is used the new intelligent control strategy for decreasing the voltage sag, swell, harmonics, voltage instability etc. of the power system. The main contribution of the work is summarized below:

• To demonstrate that the proposed intelligent control strategy surpasses the traditional PI controller in terms of voltage and current harmonics. This validation provides evidence of the superiority of the



intelligent control approach over the conventional method.

- The proposed intelligent control is tested under unbalanced condition and nonlinear loads. By examining the behavior of the system under such conditions, the paper highlights the robustness and adaptability of the proposed approach.
- To find the efficacy of the proposed controller, a comparative analysis between the FFT (Fast Fourier Transform) results of the suggested intelligent control strategy and the traditional control strategy is accomplished.
- To arbitrate the performance of the DC bus in terms of voltage utilizing both conventional and intelligent control techniques.

# II. PRINCIPLE AND OPERATION OF UPQC SYSTEM

Indeed, the Unified Power Quality Conditioner (UPQC) is based on the principle of combining both shunt and series Active Power Filters (APFs) to create a hybrid solution. The placement of a DC-link between the shunt and series APFs allows these two individual systems to function as one integrated system, making the UPQC a cost- effective solution for power quality improvement. The shunt inverter in the UPQC is operated using a current control mode, where it regulates the load current to match the reference value. The control algorithm ensures that the actual delivered current closely follows the set reference current, thereby achieving the desired performance of the UPQC. Additionally, the shunt APF performs another critical role by preserving the DC bus voltage within the system. By effectively domineering the DC bus voltage, the UPQC ensures the smooth function of the shunt and series APFs and helps to regain the stability and reliability of the entire system. Shunt inverter injects current to mitigate the harmonics that is generated from non-linear load. The detailed is given in Fig. 2.

The injected current can be governed from the below equation.

$$iSh(wt) = i^*(wt) - iL(wt) \tag{1}$$

where, iSh(wt),  $i^{*}(wt)$  and iL (wt) depicts the currents flowing through the shunt inverter, reference source, and load, respectively.

The series inverter of the UPQC is typically operated in voltage control mode. Its primary purpose is to generate and inject voltage in series with the power line to maintain a balanced and sinusoidal point of common coupling (PCC). By inserting the appropriate voltage in series with the line, the UPQC ensures that the power line remains free from distortions and voltage fluctuations, providing a stable and high-quality voltage supply at the load terminal. The equation below can be used to visualize the series inverter of the UPQC.

 $v(wt) = v^*(wt)_L - v_S(wt)$ 



where, respectively,  $v_{Sr}$  (*wt*),  $v^*(wt)$  and  $v_S(wt)$  represents the voltages injected into the series inverter, the reference voltage, and the actual source voltage.

During a voltage sag condition, the series inverter of the UPQC injects voltage to ensure that the voltage at the load terminal remains at the desired value. This injected voltage, denoted as  $v_{Sr}$  is compensates for the reduction in supply voltage caused by the sag. Maintaining the DC bus voltage is crucial for the UPQC to perform effectively. The DC-link feedback controller plays a significant role in this process. It needs to respond rapidly to any changes in the DC bus voltage and work efficiently to restore the DC bus voltage to the predetermined reference value. The controller should minimize any delays and overshooting to ensure the DC bus voltage is stabilized quickly and accurately. By efficiently managing the DC bus voltage and promptly compensating for voltage sags, the UPQC can effectively provide a stable and regulated voltage supply to the load, improving power quality and ensuring smooth operation of sensitive electrical equipment. Dynamic models that use the dq transformation, which converts

sinusoidal signals to constants, are usually quite straightforward. This mapping, however, is precise and doesn't rely on any approximations. dq models represent a natural progression from time-varying phasor models and find widespread application in the study and characterization of rapid transient phenomena within power systems.

A more complex control approach is employed for shunt APFs because the precise regulation of current at the load connection point is critical to ensure the proper functioning and stability of the power system. Shunt APF's control strategy is based on a deviation between the current generated by the reference and the load. The transformation from abc to dq is used to create a reference current. The inputs for this transformation from abc to dq are the magnitude of the load current and the phase of the load voltage. To improve power factor and decrease the phase difference between current and voltage, the voltage phase is used as the reference phase for current. A PLL is placed and it reads the phase of load voltage. To extract the positive sequence current (d), negative sequence current (q), and zero sequence current (0) from the given references, they are multiplied by appropriate factors. The positive sequence current (d) is used to construct the amplitude of the reference current, which is then passed through a low pass filter to remove any signal variations. Subsequently, a dq to abc block is employed to create the desired 3-Ø phase current reference. Another current reference is generated by the shunt Active Power Filter (APF) to maintain the resemblance between the load current and its reference. This difference is then adjusted in the shunt APF's current. The hysteresis controller persistently observes the deviation between the present flow of current through the APF and its reference value, causing the controller's output to activate once the deviation surpasses a specific threshold. This output guides the APF to inject or withdraw current accordingly. To control the inverter's three arms, a complementary gate command is produced at the hysteresis controller's output, as each arm requires two gate commands.





Fig.2. Shunt APF using PI controller and TS-fuzzy controller

### III. PROPOSED ALGORITHM

Implementing a control strategy is crucial for enhancing the operational efficacy of the structure. In this work, the noble control approach and UPQC to address the power quality issue. Employed a control strategy for UPQC for sensing the signals of voltage and current. Compensating commands are used in terms of voltage or current levels. The characteristics and intended operation of a specific system are determined by the control strategy. The sole factor determining a UPQC's effectiveness is its control algorithm. The desired performance like switching instants of inverter switches can be achieved by the control strategy. Control strategy also determines the reference signal. There is different type of control strategy that are applied on UPQC. In this paper, the three-phase d-q theory is used.

Its adaptability to an extensive range of gain variations allows the TS-fuzzy linguistic rules to remain flexible, enabling effective management of intricate control challenges. As a result, it successfully improves the power system's stability in the face of demand fluctuations and weather changes [18-20]. It also monitors system uncertainties. Nevertheless, an exploration is conducted to assess whether the TS-fuzzy controller, across diverse operational scenarios, could potentially surpass the performance of the PI controller in cases characterized by nonlinearity and uncertain system conditions [18-20]. Thus, the goal of this work is to enhance the energetic execution of the system by using the proposed intelligent controller.





Fig.3. Membership used in: (a). Error in voltage ( $e_i$ ) and (b). Voltage error derivative ( $e_i$ )

For the purpose of building the TS-fuzzy controller (Fig. 3), the variations in the voltage error  $(e_i)$  and its derivative  $(e_i)$  are used as the fuzzy control's input variables. Utilizing the information presented in Figure 3, two linguistic membership functions (MFs) are applied to transform the error voltage at input and its derivative into fuzzy representations: one for positive (P) and one for negative (N) values. The mathematical representations of these membership functions are given as follows:

$$\mu_{p}(e_{i}) = \begin{cases} 0, & e_{i} < -M_{1} \\ 2M_{1} & & -M \leq e \leq M \\ 2M_{1} & & i & 1 \end{cases} \text{ and } \mu_{N}(e_{i}) = \begin{cases} \frac{1}{2}, & x_{i} < -M_{1} \\ \frac{-e_{i} + M_{i}}{2}, & -M \leq x \leq M \\ 2M_{1} & & i & 1 \end{cases}$$

$$\mu_{p}(e_{i}') = \begin{cases} 0, & e_{i}' < -L_{2} \\ \frac{e_{i}' + M_{2}}{2M_{2}}, & -M_{2} \leq e_{i}' \leq M_{2} \end{cases} \text{ and } \mu_{N}(e_{i}') = \begin{cases} 1, & e_{i}' < -M_{2} \\ 0, & e_{i} > M_{1} \end{cases}$$

$$(3)$$

The four fuzzy rules below are condensed to represent the TS-fuzzy controller:

**Case-1:** If  $e_i(\kappa)$  is N and  $e_i(\kappa)$  is N, then  $L_1=b_1e_i(\kappa)+b_2e_i(\kappa)$ .

**Case-2:** If  $e_i(\kappa)$  is N and  $e_i(\kappa)$  is P, then  $L_2 = b_3 L_1$ . **Case-3:** If  $e_i(\kappa)$  is P and  $e_i(\kappa)$  is N, then  $L_3 = b_4 L_1$ . **Case-4:** If  $e_i(\kappa)$  is P and  $e_i(\kappa)$  is P, then  $L_4 = b_5 L_1$ .

The above controller's result is represented by L1, L2, L3 and L4 in the rules above, where k is the kth sampling instant. The ambiguous constants are b1, b2, b3, b4 and b5. The fuzzy constants' values as well as parameters of PI-controller are mentioned in Table 1. The coefficients ( $K_p$ ,  $K_i$ ) of the PI-controllers are designed on the integral-square-error (ISE) criterion [19].

The generalized defuzzifier is used to produce the output of the TS-fuzzy controller (Y), which is evaluated as follows:



$${}^{V} \quad \frac{\left(S_1 \times L_1 + S_2 \times L_2 + S_3 \times L_3 + S_4 \times L_4\right)}{\left(L_1 + L_2 + L_3 + L_4\right)}$$
(5)

\_ \_ \_ \_ \_ . . . . .

where, S1= min. { $\mu P(e_i)$ ,  $\mu P(e_i)$ }, S2= min.{ $\mu P(e_i)$ ,  $\mu N(e_i)$ }

$$S_3 = \min \{\mu_N(e_i), \mu_P(e_i)\}, S_4 = \min \{\mu_N(e_i), \mu_N(e_i)\}$$

Through dynamic adaptation of the 'Y' value using the intelligent controller, enhancements are achieved in the power system's stability during various system contingencies.

TS-fuzzy controller uses time series data as input to create predictions. To create models that can represent the dynamic behavior of complex systems, time series analysis techniques are integrated with fuzzy logic in TS-fuzzy systems. A PI controller was also used before TS-fuzzy. A feedback control loop known as a PI controller uses output comparison to identify error signals in systems. The process variable's actual measured value is continuously compared to the desired set point value by the PI controller, which then takes remedial action based on the error signal.

As was previously described, series APF uses a voltage control mechanism. To achieve this control, a  $3-\phi$  sinusoidal wave should be generated with the desired amplitude and phase. Phase locked loops (PLL) read the input voltage's phase. Three nominal voltages are generated with appropriate phase alterations for each of the three phases. The output of the PWM generator provides the necessary control signals to the series APF. These control signals drive the power switches in the series APF to generate an acceptable compensating voltage on the output. The compensating voltage is designed to counteract voltage variations and harmonics present in the system, effectively improving the overall power quality. By following this voltage control mechanism, the series APF can effectively mitigate voltage fluctuations and harmonic distortions, contributing to a more stable and reliable power supply and enhancing the performance of the connected loads.

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