Fuzzy Type-II Controller Based UPQC For Power Quality Enhancement

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Abstract—Power quality (PQ) has become a critical issue in modern electrical power systems due to the increasing use of nonlinear loads such as power electronic converters, adjustable speed drives, and renewable energy systems. These loads introduce disturbances such as voltage sags, swells, harmonics, and unbalanced conditions, which degrade system performance and reliability. This paper proposes a Fuzzy Type-II Controller-based Unified Power Quality Conditioner (UPQC) for effective mitigation of power quality issues. The UPQC integrates series and shunt active power filters controlled by an Interval Type-II Fuzzy Logic Controller (IT2FLC), which enhances system robustness and adaptability under uncertain conditions.
Simulation results carried out in MATLAB/Simulink demonstrate significant improvement in system performance. The Total Harmonic Distortion (THD) is reduced from 21.6% to below 3%, the power factor improves to 0.99, and voltage regulation exceeds 97%. The proposed system shows superior performance compared to conventional PI and Type-I fuzzy controllers.

***Index Terms*—UPQC, Fuzzy Type-II Controller, Power Quality, Harmonics, THD, MATLAB/Simulink.**

I. INTRODUCTION

Power quality is a measure of how well electrical power conforms to standard voltage, current, and frequency characteristics. With the increasing use of nonlinear loads, power quality disturbances such as harmonics, voltage sag, swell, and flicker have become major challenges in distribution systems.

Nonlinear loads such as rectifiers and converters draw distorted current, which leads to harmonic generation. These harmonics cause overheating, reduced efficiency, and malfunction of sensitive equipment. Additionally, renewable energy integration introduces further instability due to intermittent power generation.

To overcome these issues, devices such as Dynamic Voltage Restorer (DVR), DSTATCOM, and Unified Power Quality Conditioner (UPQC) are used. Among them, UPQC is the most effective as it compensates both voltage and current disturbances simultaneously. However, the performance of UPQC depends on the control strategy. Conventional PI controllers are limited in handling nonlinear and uncertain conditions. Hence, intelligent control techniques such as Fuzzy Logic Controllers are introduced.

Type-II fuzzy controllers provide better handling of uncertainties using the Footprint of Uncertainty (FOU), making them more effective than Type-I controllers. This paper proposes a Fuzzy Type-II Controller-based UPQC for improved power quality.

II. SYSTEM ARCHITECTURE

A. Overall System Description

The proposed system consists of a Unified Power Quality Conditioner (UPQC) integrated with a Fuzzy Type-II controller. The UPQC includes:

- Series Active Power Filter (SAPF)
- Shunt Active Power Filter (SHAPF)
- DC-link capacitor

The series filter compensates voltage disturbances, while the shunt filter eliminates current harmonics and reactive power.

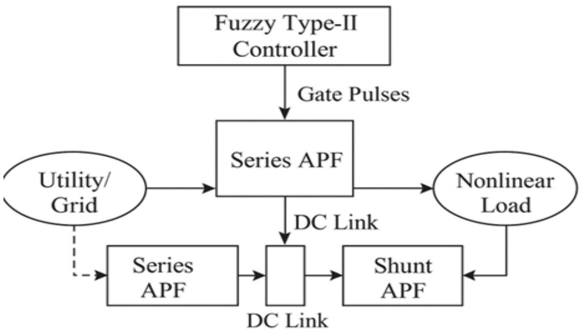

Fig. 1. Block Diagram of UPQC

B. Working Principle

The UPQC is connected between the supply and load. The series converter injects compensating voltage, and the shunt converter injects compensating current.

The DC-link capacitor enables energy exchange between the two converters, ensuring continuous operation.

C. Components Description

- Supply System: Provides three-phase AC voltage
- Nonlinear Load: Generates harmonics
- SAPF: Compensates voltage disturbances
- SHAPF: Compensates current harmonics
- DC-Link: Maintains energy balance

III. SYSTEM MODELING

The proposed UPQC system is modeled using MATLAB/Simulink with the help of SimPowerSystems toolbox. The model consists of a three-phase AC source, nonlinear load, series and shunt converters, and control system.

The nonlinear load is designed to generate harmonic distortion in the system. The UPQC is placed between the source and load to compensate for these disturbances.

The series and shunt converters are implemented using voltage source inverters (VSI), which are controlled using PWM techniques. The Fuzzy Type-II controller generates the reference signals required for switching. The simulation is carried out under various operating conditions such as voltage sag, voltage swell, and harmonic distortion to evaluate system performance.

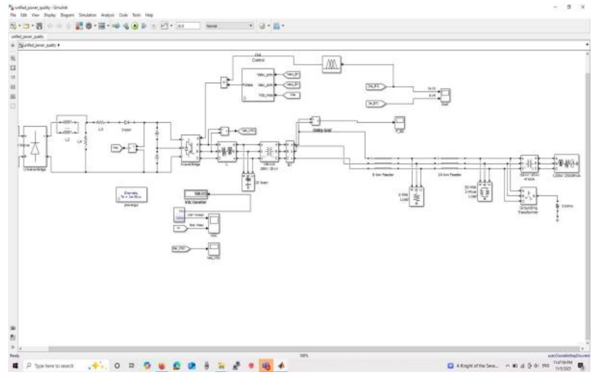

Fig. 2. MATLAB MODEL IMAGE

III. CONTROL STRATEGY

A. Fuzzy Type-II Controller

The control strategy of the proposed UPQC is based on an Interval Type-II Fuzzy Logic Controller (IT2FLC). The controller is designed to handle nonlinearities and uncertainties effectively.

The controller takes two input variables:

- Error (e)
- Change in error (Δe)

The error is defined as: e(t) = Vref − Vactual

The change in error is given by:

Δe(t) = e(t) − e(t−1)

The controller processes these inputs using fuzzification, rule base, inference mechanism, and defuzzification to generate the control output.

The control output is given by:

u(t) = f(e(t), Δe(t))

$$THD = \frac{\sqrt{V_2^2+V_3^2+V_4^2+\cdots+V_n^2}}{V_1} \times 100$$

B. DC-Link Voltage Control

The DC-link voltage is maintained constant to ensure proper operation of the UPQC. The relation governing the DC-link voltage is:

C (dVdc/dt) = Ishunt − Iseries

where C is the DC-link capacitance, Vdc is the DC-link voltage, and Ishunt and Iseries are the currents of shunt and series converters respectively.

C. PWM Control

The output of the fuzzy controller is used to generate reference signals for PWM switching. These signals control the switching of the inverters to inject compensating voltage and current into the system.

D. Advantages of Proposed Controller

- Better handling of uncertainties
- Faster dynamic response
- Reduced harmonic distortion
- Improved power factor
- Stable system operation

IV. SIMULATION RESULTS

The proposed system is simulated in MATLAB/Simulink under different disturbance conditions such as voltage sag, swell, and nonlinear load conditions.

Before compensation, the system exhibits distorted voltage and current waveforms due to harmonic distortion. After applying the UPQC, the waveforms become sinusoidal and stable.

The Total Harmonic Distortion (THD) is reduced from 21.6% to below 2.8%, which satisfies IEEE-519 standards. The power factor is improved to approximately 0.99, and voltage regulation exceeds 97%.

The response time of the system is significantly improved, achieving fast compensation within 14 ms. These results demonstrate the effectiveness of the proposed Fuzzy Type-II controller.

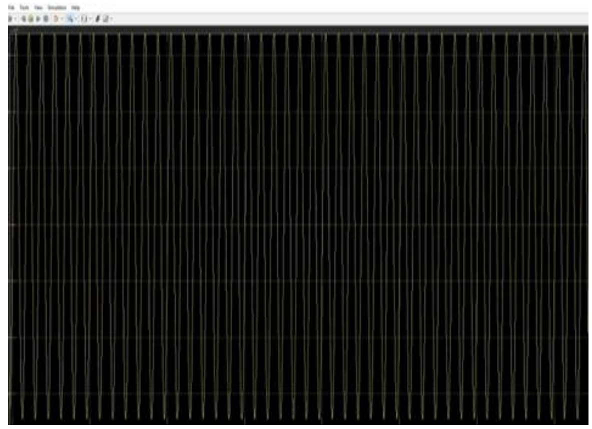

Fig. 3. waveform image

Table. 1. Table

Parameter	Without UPQC	Conventional UPQC (PI/Type-I Fuzzy)	Proposed Fuzzy Type-II UPQC
Supply Voltage (V)	415	415	415
Load Voltage (V)	395	410	415
Source Current THD (%)	21.6	8.5	2.8
Power Factor	0.78	0.92	0.99
DC-Link Voltage (V)	640	670	700
Voltage Sag Compensation (%)	—	80	98
Voltage Swell Compensation (%)	—	82	97
Response Time (ms)	38	26	14
Harmonic Reduction Efficiency (%)	—	58	87

V. DISCUSSION

The simulation results clearly indicate that the proposed Fuzzy Type-II controller-based UPQC performs better than conventional methods.

Compared to PI and Type-I fuzzy controllers, the proposed system achieves lower THD, faster response time, and better voltage regulation.

The ability of the Type-II fuzzy controller to handle uncertainties makes it suitable for dynamic and nonlinear environments. The improved performance makes the system highly suitable for modern power distribution systems.

VI. CONCLUSION

This paper presented a Fuzzy Type-II Controller-based Unified Power Quality Conditioner for improving power quality in electrical distribution systems. The proposed system effectively mitigates voltage and current disturbances, reduces harmonic distortion, and improves power factor.

Simulation results confirm that the system achieves THD below IEEE limits, improved voltage stability, and faster dynamic response. The proposed method is suitable for applications in smart grids, industrial systems, and renewable energy integration.

Future work can focus on hardware implementation and real-time analysis of the system.

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