Power Quality Improvement in Micro Grids by Using Multi-Inverter Based UPQC with Fuzzy Controller

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Abstract:-

This work introduces a Unified Power Quality Controller (UPQC) employing an Artificial Neural Network (ANN) for enhanced performance. The UPQC effectively compensates for unbalanced grid and load voltages within the power system. Specifically designed for grid integration of photovoltaic systems, the UPQC, guided by an ANN controller, addresses issues such as voltage sags/swells, unit power factor correction, and voltage and current harmonic cancellation.In the context of a power distribution network, this UPQC system concurrently rectifies supply voltage and load voltage irregularities. The unit vector template control algorithm incorporates a phase-locked loop (PLL) mechanism to prevent multiple zero crossings during the detection of highly distorted grid voltages. Applied to both shunt and series inverters of the photovoltaic grid-connected UPQC, the unit vector template control with PLL-based algorithm ensures effective regulation of grid and load voltage unbalances. Furthermore, the UPQC, guided by the ANN controller, controls the Total Harmonics Distortion (THD) of both grid and load voltages.

***Keywords**: FLC, PQ,UPQC,*

1. Introduction

The power industry confronts escalating challenges in power quality owing to the growing intricacy of loads, including motor speed drive systems, PLCs, rectifiers, electronic ballasts, and computers. Issues such as low power factor, high total harmonic distortion (THD), excessive reactive power consumption, and phase unbalance in the distribution system have become prevalent. While power flow controls like reactive power compensation can be utilized to mitigate these problems, conventional methods like Static VAR Compensators (SVC) exhibit drawbacks in power rating, response, accuracy, and cost.In recent years, the surge in inverter-based Flexible Alternating Current Transmission Systems (FACTS) has spurred significant research interest [1]. Among these advancements, the Multi-Level Cascaded H-Bridge Inverter (MCHI)-based grid-tied STATCOM emerges as a promising solution, offering numerous advantages over traditional approaches. This study proposes a novel five-level inverter-based multilevel system interconnected in cascade through a three-phase transformer. This topology ensures the maintenance of asymmetric voltages at the DC links of the inverters, resulting in balanced output with an increasing number of input levels. The multi-level STATCOM proves effective in compensating for system imbalances. To dynamically assess the converter's performance, a mathematical model is derived and employed to understand the system behavior under various operating conditions.The prevalence of highly distorted loads in consumer-side power systems has given rise to various power quality issues. In response, researchers concentrate on power quality improvement, particularly with the integration of renewable energy sources. Within power conditioning solutions, the Unified Power Quality Conditioner (UPQC) combines the functionalities of DVR and DSTATCOM, offering comprehensive compensation for both current and voltage quality issues. This work provides a detailed analysis of a PV-UPQC configuration, where solar energy integrates with UPQC through a DC-DC boost converter at the DC-link. The PV-UPQC system employs a modified Synchronous Reference Frame (SRF) control algorithm for enhanced sensitivity under highly distorted conditions [2-3].

2. UPQC System Configuration

The system's configuration block diagram is depicted in Fig. 1. The system consists of both a shunt voltage source converter (VSC) and a series voltage source converter. These two components, the shunt VSC and the series VSC, are linked through a common DC link capacitor. The shunt VSC section of the PV-UPQC is connected on the load side through interfacing inductors, while the series VSC is connected in series with the grid via coupling inductors. The series transformer within the PV-UPQC system serves the purpose of injecting the voltage signal generated by the series VSC [4-5].

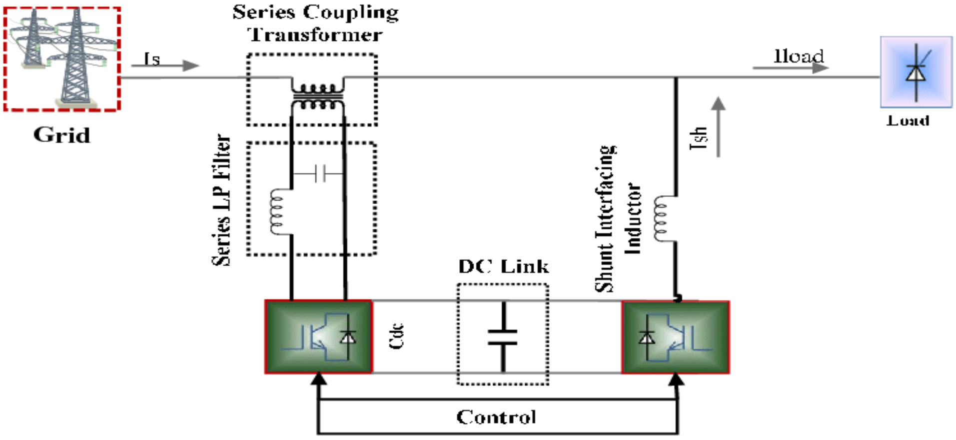


Fig.1. Configuration of unified power quality conditioner

3. Modeling and Case Study of UPQC in Microgid

The Shunt-Series connection, commonly referred to as the Unified Power Quality Conditioner (UPQC) in the realm of power quality conditioners, stands as a robust safeguard for sensitive loads against subpar power sources. Recent advancements in research have led to the development of a universal power quality conditioner designed to tackle a myriad of power quality issues, including voltage drop, voltage swell, voltage outage, excessive power factor correction, and undesirable levels of harmonics in both current and voltage. Figure.2 illustrates the modelling of the UPQC.The UPQC serves a crucial role in compensating for voltage flicker, imbalance, reactive power, negative sequence current, and harmonics. Its application can significantly enhance power quality in the vicinity of utility or industrial power systems [6]. Particularly effective in addressing voltage flicker and imbalance in high-capacity loads, the UPQC emerges as a highly efficient method.Beyond its primary functions, the UPQC also provides nonlinear load control and lends support to voltage-sensitive loads. Moreover, by reducing harmonics in the utility current, it contributes to the overall improvement of the utility current's quality, benefiting nonlinear loads [7].

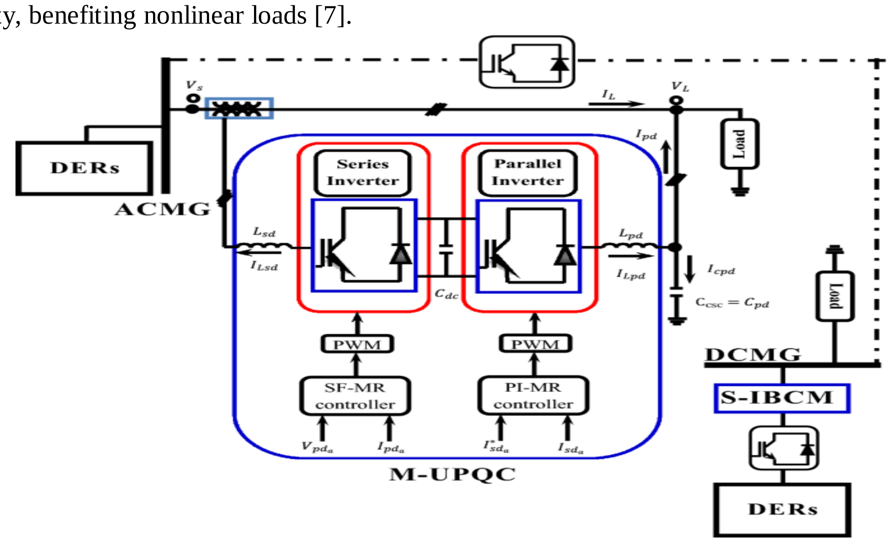


Fig.2. Modelling of unified power quality conditioner

The UPQC's inherent voltage and current synchronization obviate the need for a Power Factor Correction (PFC) unit. Even in the face of supply voltage fluctuations, the UPQC ensures the maintenance of the rated load end voltage. Achieving this without requiring additional voltage support for the DC link is made possible by injecting voltage to uphold the load end voltage at the specified level.The UPQC employs cascaded three-phase inverters connected to the supply voltage through transformers. This configuration aids in reducing harmonics by compensating for the load's reactive power requirements. The shunt compensator serves as a voltage regulator for the common DC link voltage. Operating in voltage-controlled pulse width modulation mode (VCPWM), circuits like the series compensator provide high voltage by supplying a voltage that is in quadrature with the supply voltage to the load [8-9].

4. UPQC with Fuzzy Logic Controller

In contrast to Boolean logic, fuzzy logic addresses problems characterized by uncertainty or vagueness, employing membership functions with values ranging between 0 and 1. In the framework of fuzzy set theory, the transition occurs between membership and non-membership functions [10].

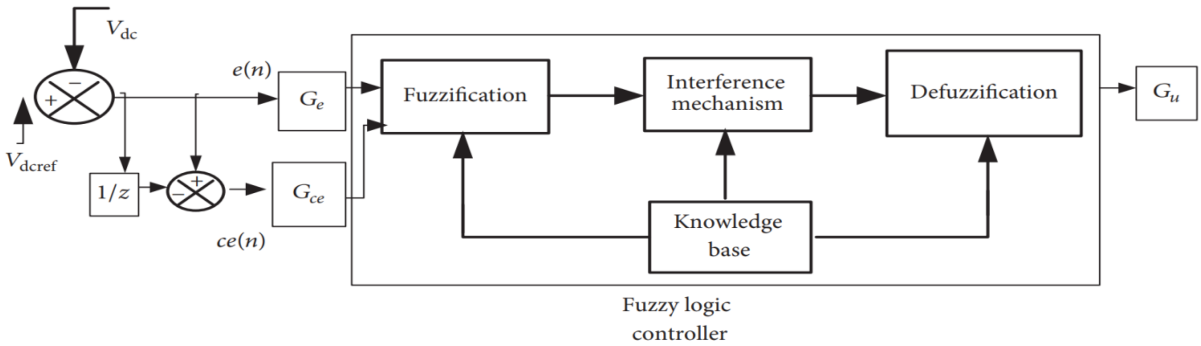


Figure 3: Detailed structure of the fuzzy logic controller.

A Fuzzy Logic Controller (FLC) comprises four fundamental components: fuzzification, knowledge base, interference mechanism, and defuzzification. The detailed structure of the FLC is illustrated in Figure 3. The crisp inputs of the FLC, namely the DC voltage error (e) and the change in error (ce), undergo fuzzification in the first component. This process transforms the input signals into fuzzy values using membership functions expressed through fuzzy linguistic variables, essentially representing fuzzy sets. The knowledge base contains linguistic descriptions formulated in terms of logical implications. The interference mechanism evaluates fuzzy information and applies a set of control rules to convert input signals into fuzzified output. Subsequently, defuzzification employs methods such as center of gravity, maximum, weighted mean, etc., to convert input conditions into control signals, which are then applied to the actual system. Prior to processing by the fuzzy logic controller, the input signals are expressed in fuzzy set notations using linguistic labels characterized by membership grades [11-14].

In the design of this fuzzy controller, a triangular membership function is selected for its simplicity, ease of implementation, and symmetrical characteristics along the axis. Scaling factors denoted as α, β, and γ are utilized to scale the inputs and outputs, aligning with the FLC design principles [15-17]. The error “” and change of error “” at the sampling instant which are used commonly as the inputs of FLC can be written as

$$e = V_{dcref} - V_{dc}$$

$$ce_n = e_n - e_{n-1}$$

5. Simulation Results

In order to study the performance of the proposed control scheme, it was executed in a MATLAB/Simulink environment for the test system,

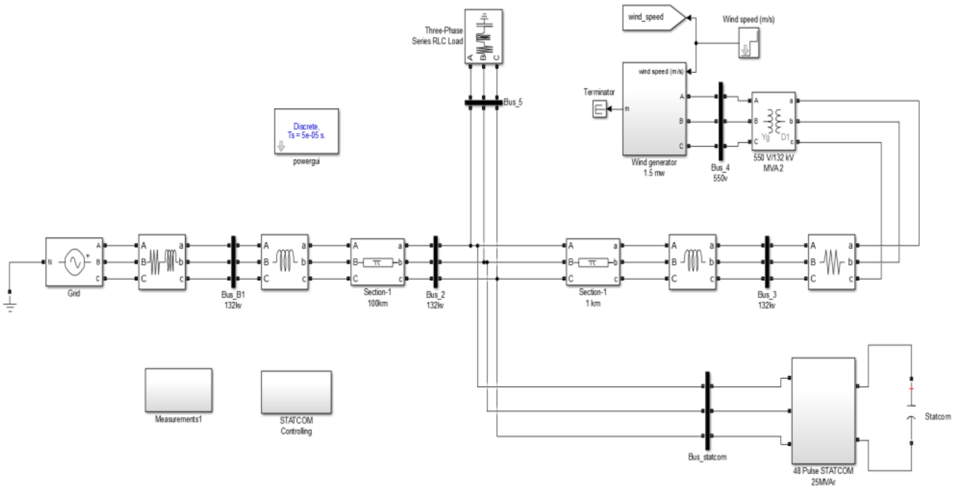
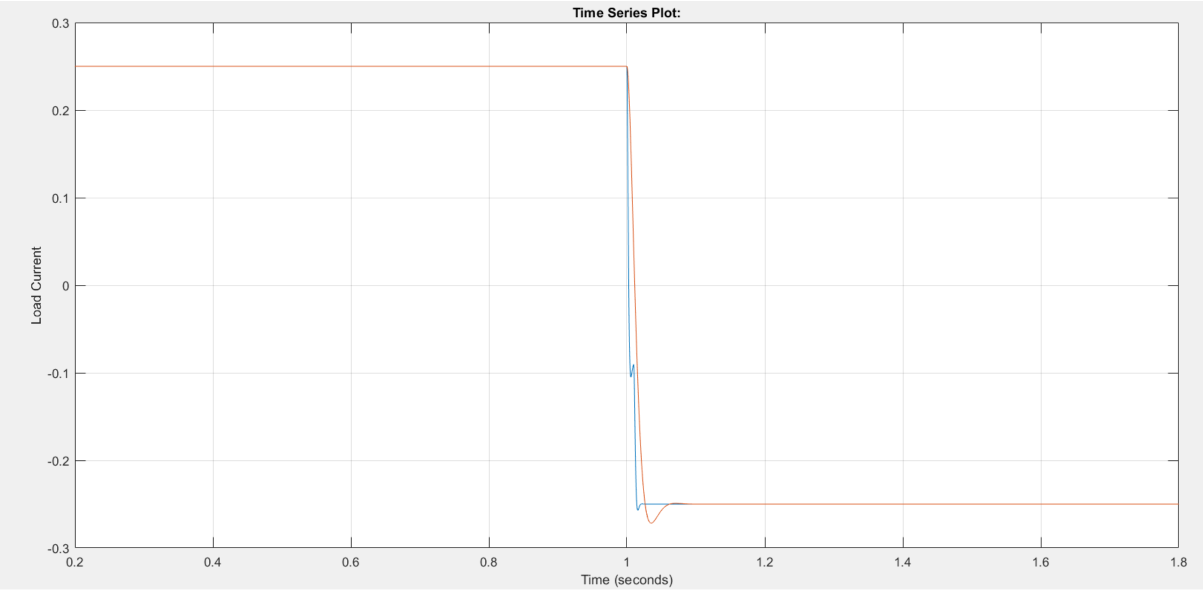


Fig.4.Simulation Diagram of the UPQCSystem

This section focuses on the grid voltage and current waveforms within the interconnected system, elucidating, the distorted voltage waveforms in the main grid, signifying voltage disturbances originating from the source side, and the distorted current waveforms in the microgrid attributed to nonlinear loads. From fig.5 the necessary injection currents by the UPQC, illustrating its impact intended microgrid main grid currents devoid of harmonics.



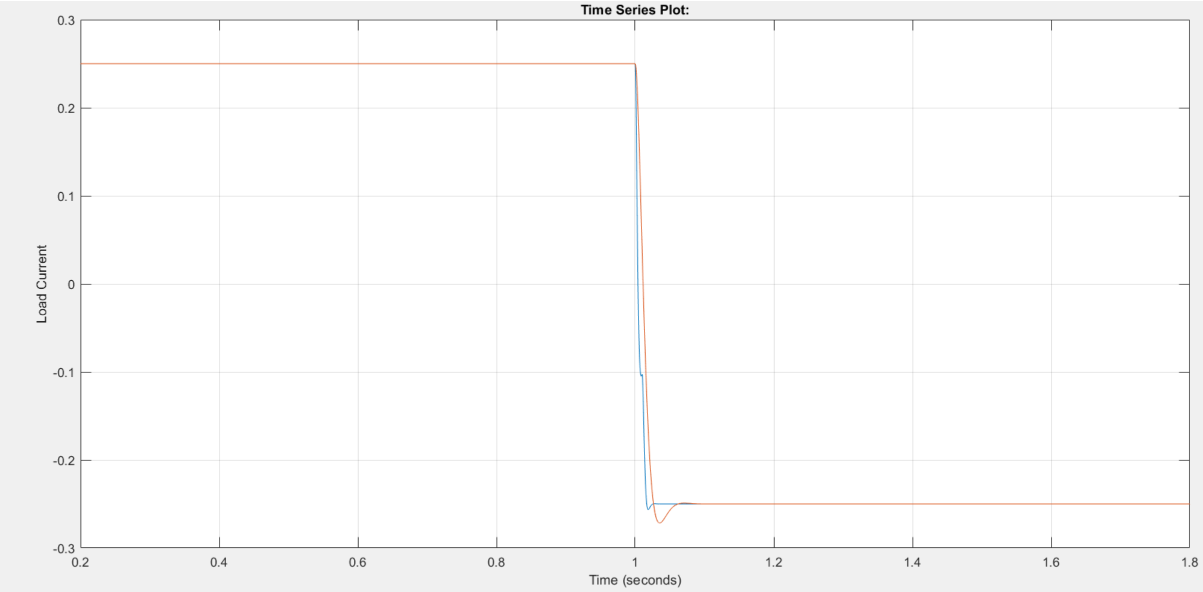
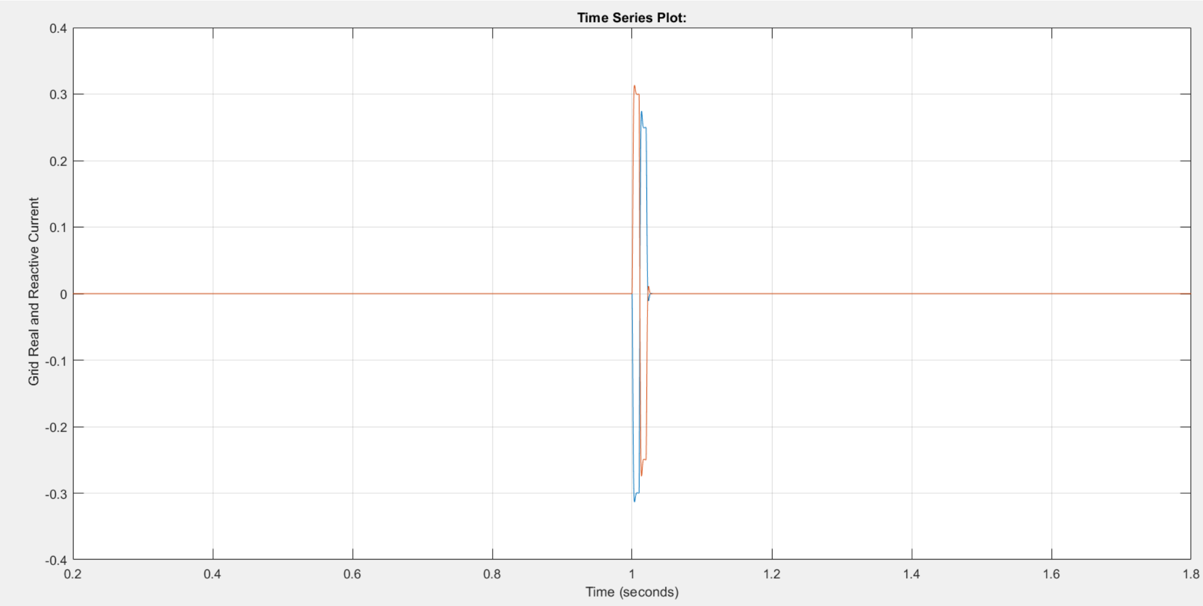


Fig. 5. Simulation result of step change in the load current ilq(a) without and (b) with the designed icq

From fig.6 the necessary injection currents by the UPQC, illustrating its impact intended microgrid main grid grid real and reactive currents.



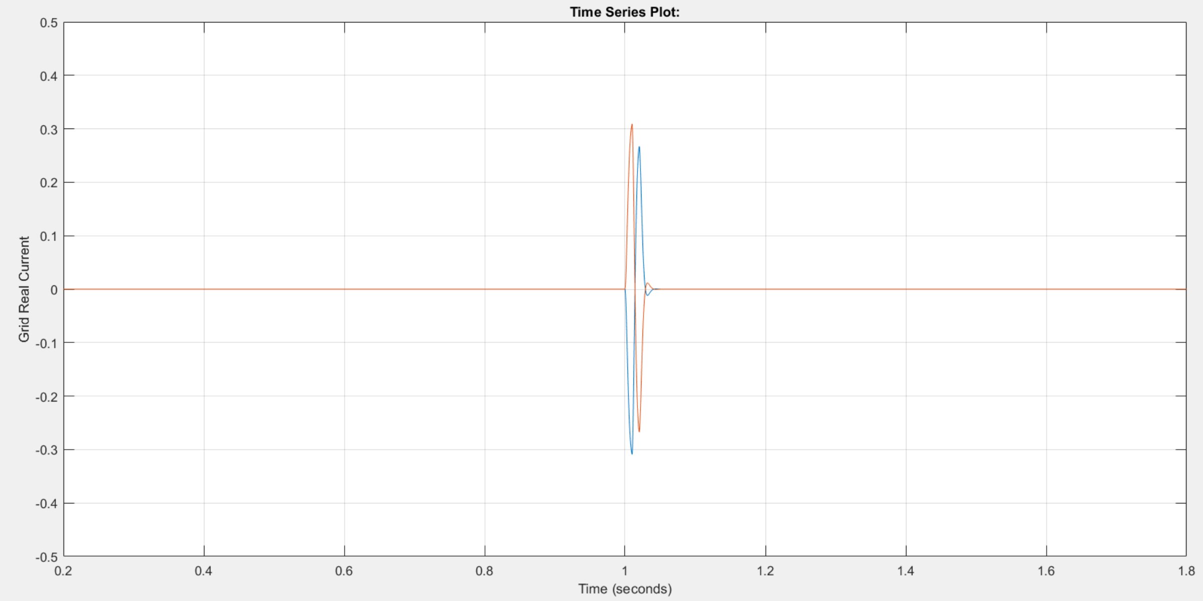


Fig. 6. Simulation result of grid real and reactive currents a) without and (b) with the designed icq"

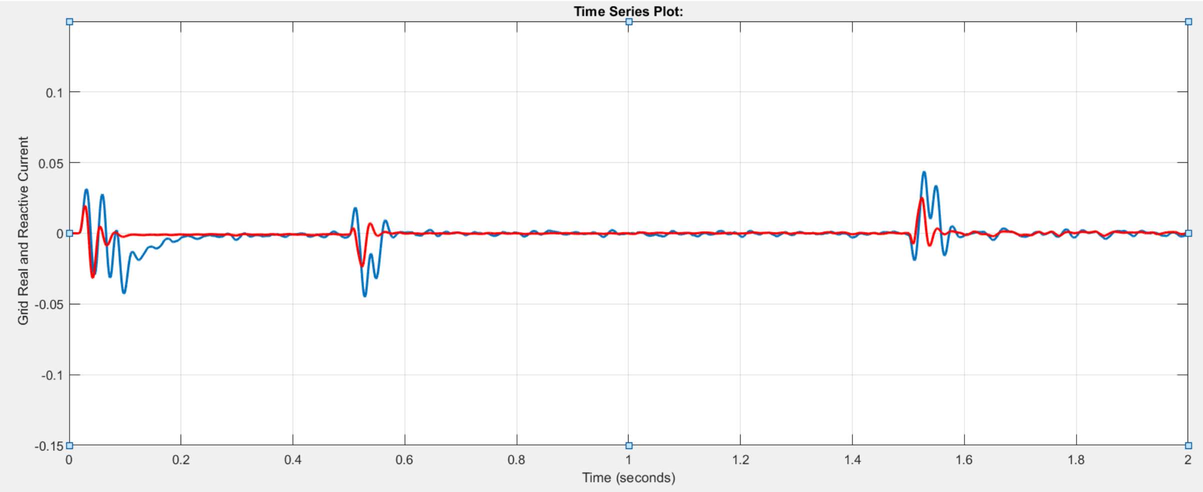


Fig 7. Simulation result of grid real current isreal and reactive current isreactive a) without and (b) with the designed icq" with fuzzy

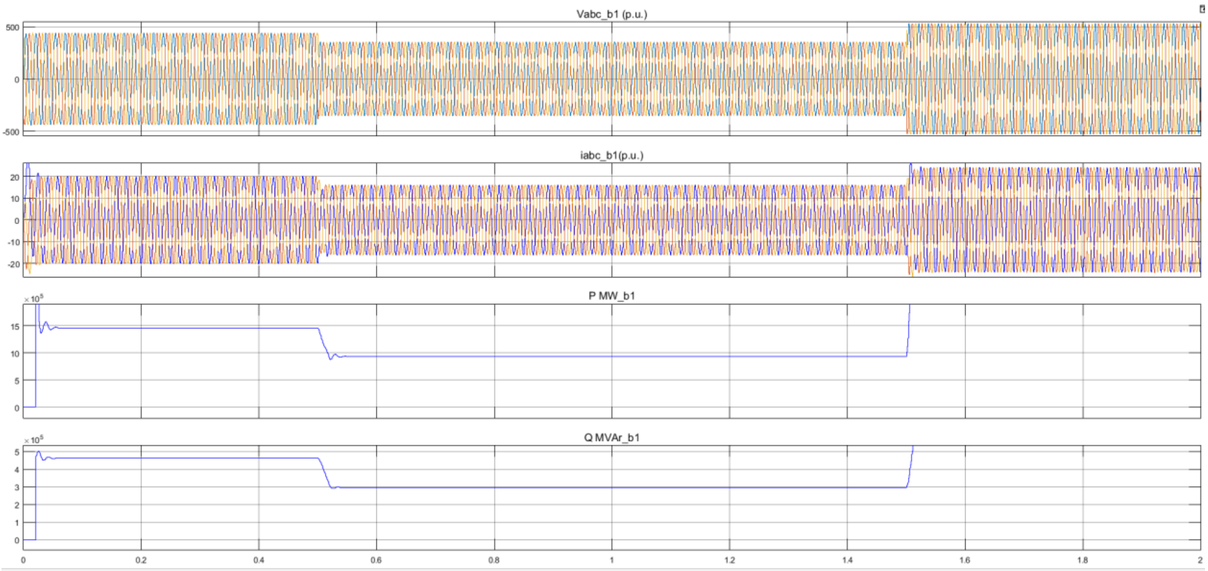


Fig 8. Grid Voltages and Currents with fuzzy system

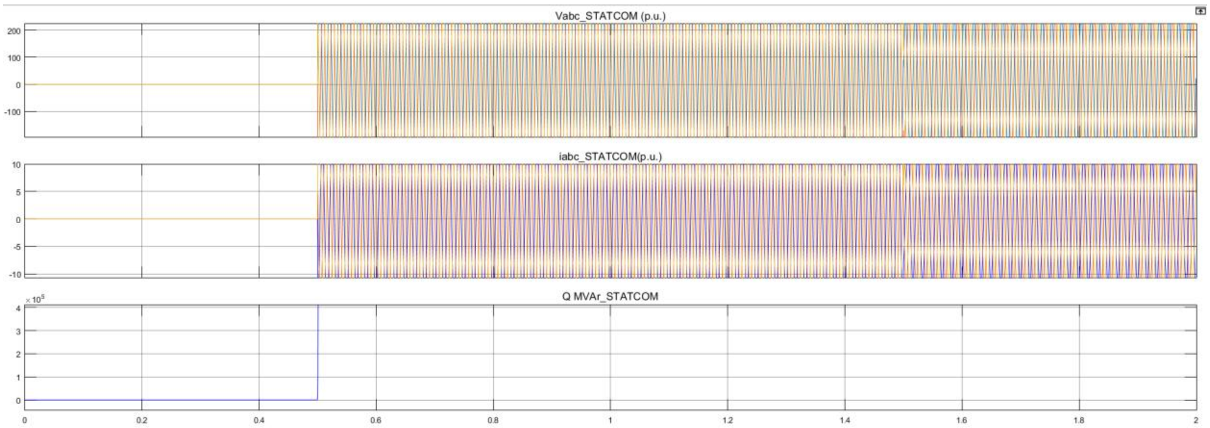


Fig.9 Statcom Voltages, Currents and Reactive Power with fuzzy system

Fig10. Load Voltages, Currents and Active Reactive Power with fuzzy system

6. Conclusion

In conclusion, the comprehensive implementation of a Multi-Inverter Unified Power Quality Conditioner (UPQC) with a fuzzy controller holds significant promise for the improvement of power quality in microgrids. Through careful examination of the interconnected system's voltage and current waveforms, it becomes evident that the proposed UPQC system effectively addresses distorted voltage waveforms from the main grid and mitigates distorted current waveforms in the microgrid caused by nonlinear loads.The injection of both voltage and currents by the UPQC is a crucial aspect that demonstrates its positive influence on the system. The utilization of a fuzzy controller adds an adaptive and intelligent dimension to the control strategy, allowing for efficient compensation and regulation of power quality parameters.By achieving harmonics-free main grid currents and maintaining desired microgrid voltages, the Multi-Inverter UPQC with a fuzzy controller emerges as a robust solution for power quality improvement in microgrids. The presented configuration not only addresses existing challenges, such as low power factor, high total harmonic distortion, and phase unbalance, but also showcases the potential for intelligent control systems, paving the way for more resilient and reliable microgrid operations.

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