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Implementation of ANFIS-based UPQC for Power Quality and Thermal Management Enhancement in the Distribution System

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ABSTRACT

Conventional distribution systems generally operate with voltage and current waveforms being sinusoidal, though they slightly deviate from the ideal sinusoidal waveform, which is measured as distortion. The increase in power demand has led to the local generation and storage of power (Micro Grid systems). For its adoption, we need to implement smart grid architecture. Power electronics is a technologically sound way to limit different kinds of power quality (PQ) disturbances. It can also be used to control power flow, boost energy transmission capacity, enhance dynamic behavior and voltage stability, and ensure better power quality at distribution within established bounds. Unified Power Quality Conditioners (UPQC), one of the well-known Flexible AC Transmission System (FACTS) devices, are typically used to address problems in distribution systems such as voltage surges, flickers, neutral current reduction, and PQ. Additionally, thermal management is crucial for maintaining system stability and preventing overheating. While dealing with sensitive loads, a UPQC injects harmonics into the system, which can compromise system stability. This article describes an artificial neural network with harmonics elimination techniques for a modified UPQC connected with a Smart Grid. The performance of the proposed system is evaluated using MATLAB/Simulink software.

1. Introduction

A microgrid is a localized group of electricity sources, loads, and energy storage systems that can operate either connected to the main power grid or independently as an "island". Microgrids are designed to provide energy resilience, flexibility, and sustainability, often incorporating renewable

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energy sources and advanced technologies to improve efficiency and reduce environmental impact. Besides the protection devices used for the safety operation of the microgrid, the seamless change of the microgrid from island mode is also crucial [1,2].

FACTS controllers play a crucial role in enhancing the stability and resilience of microgrids by providing reactive power support. These controllers, such as SVC and DSTATCOM, are utilized to improve dynamic voltage stability, mitigate fault-induced delay voltage recovery (FIDVR), and enhance operational resilience in microgrid systems [3,4]. Additionally, FACTS devices contribute to enhancing stability and voltage regulation in transmission and distribution systems, improving power quality, power factor, and effective power utilization [5,6]. Moreover, in islanded microgrids, control algorithms for voltage source converters (VSC)-based distributed generators (DGs) emulate synchronous machine behavior, supporting inertia and reducing frequency gradients to stabilize system frequency even during sudden load changes [7-9]. Furthermore, novel controllers like the fractional order cascade controller (FOCC) are proposed to regulate frequency efficiently in islanded microgrids with high renewable energy source integration, demonstrating superior performance compared to traditional controllers [10,11].

By providing numerous paths for the flow of electricity, decreasing outages, and facilitating demand response and load management, a Flexible AC distribution system (FACDS) increases reliability. Additionally, by allowing smart grid technology and encouraging microgrids, this flexibility helps to integrate energy storage and electric vehicles. In the end, FACDS assists utilities in meeting environmental goals, lowering energy losses, and enhancing voltage regulation, which results in a more resilient and long-lasting distribution system. A common DC link capacitor shares the load of a combination of series and shunt converters in this flexible AC distribution system [12,13]. Hence in order to overcome the above limitation, this article focused on a distributed energy source that provides the FACTS device's suggested DC link source in the system. Additionally, to improve the harmonic distortions an ANFIS controller based UPQC is proposed in the system.

2. Purposed System

Figure 1 depicts the entire design of the suggested microgrid structure and FACTS device. Three feeder terminals make up the microgrid's construction, as seen in Figure 1. Moreover, power quality correction is accomplished by flexible AC transmission technology. Additionally, the method compensates for harmonic content in load currents and gird voltage [14]. The operation and construction structure of FACDS is explained in the next section.

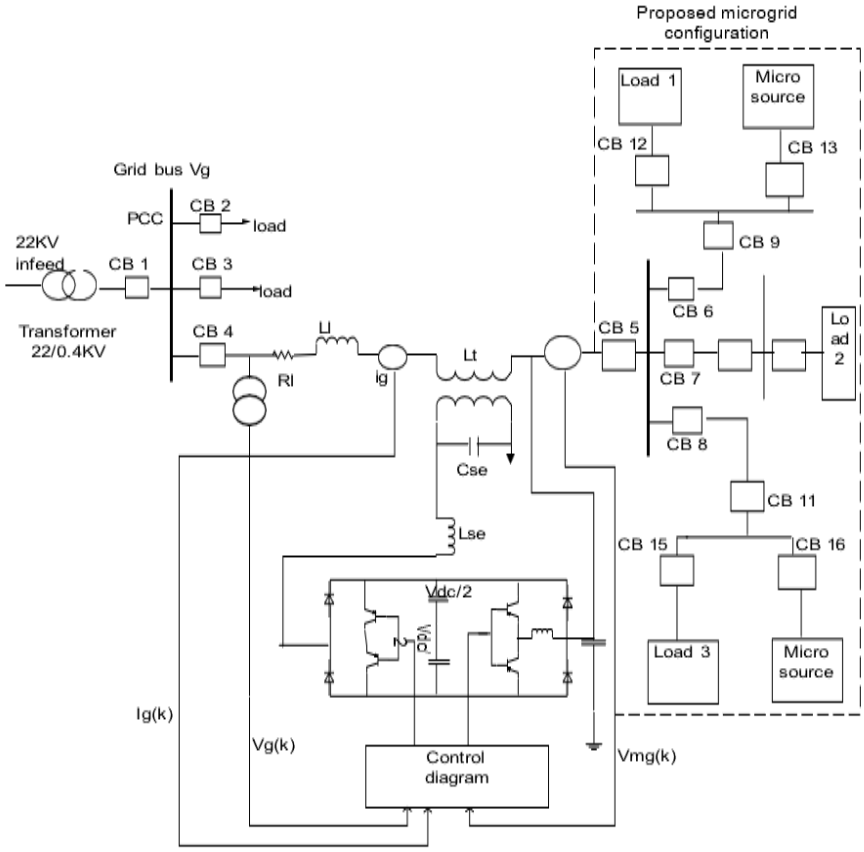

Fig. 1. Configuration of proposed FACTS device-based microgrid system

2.1 Unified Power Quality Controller

Unified Power Quality Controller (UPQC) is a type of advanced power quality device used to enhance the quality of power in electrical distribution systems [15]. The UPQC, to deal with a wide range of power quality challenges, combines the capabilities of a series and a shunt active power filter, divided by dc-link as common between them for exchanging reactive power.

The shunt compensators are essential components that increase power factor, lower harmonic distortion, and improve stability. They function by adding or absorbing reactive power, balancing the total power factor, and boosting system efficiency. They are usually connected in parallel with the system. By lowering transmission losses, this procedure enables the system to provide the load with more active power. Shunt compensators are also employed in voltage control, ensuring a constant voltage level even in the event of variations in the load. They guarantee a dependable and effective power supply for a range of applications by significantly reducing power quality problems like harmonics [16]. A capacitor will be added to the line to lower the line impedance and make up for the inductive voltage drop.

In order to adjust the total impedance of the transmission line and improve power flow control while lowering transmission losses, series compensators are usually put in series with the lines. They can improve system efficiency by increasing the line's capacity for transmitting more power without experiencing noticeable voltage reductions by altering the impedance. Additionally, by lowering the possibility of oscillations and enhancing voltage profiles, they aid in grid stabilization [17]. Figure 2 depicts the UPQC's structural layout.

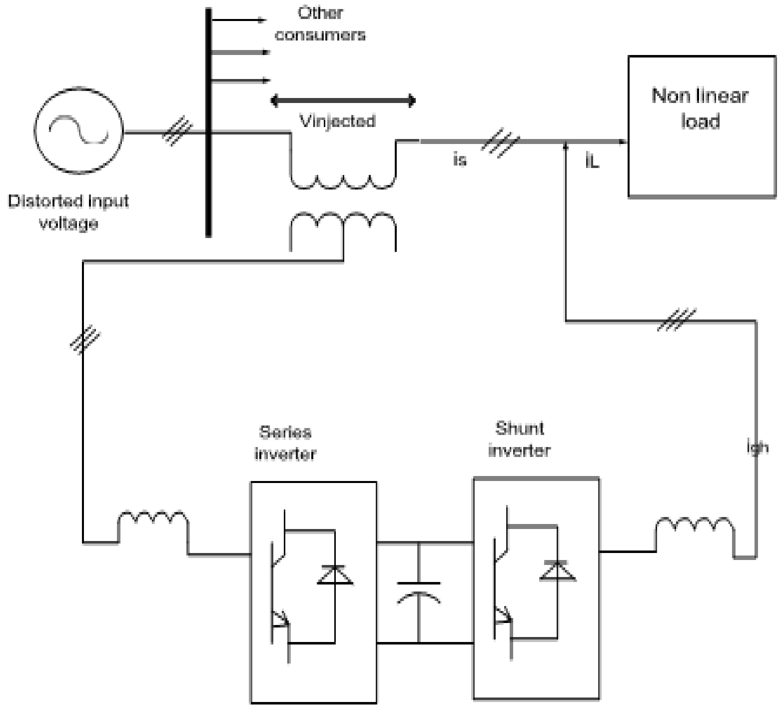

Fig. 2. Structural layout of Unified Power Quality Conditioner

Grid voltage compensation is accomplished by the usage of a series controller, which is covered in the current section. With the use of a three-phase converter, it can be controlled. Figure 3 and Figure 4 display the control schematics of the series and shunt converters, respectively.

The closed closed-loop control schematic of the series converter is illustrated in Figure 3. The series converter is controlled by reference signals such as grid voltages, currents, and active/reactive powers. This produces the reference voltage signals by comparing the grid and load voltages. In the pulse width modulation approach, these carrier signals are compared with the reference signal to produce the required gating pulses for the series voltage source converter.

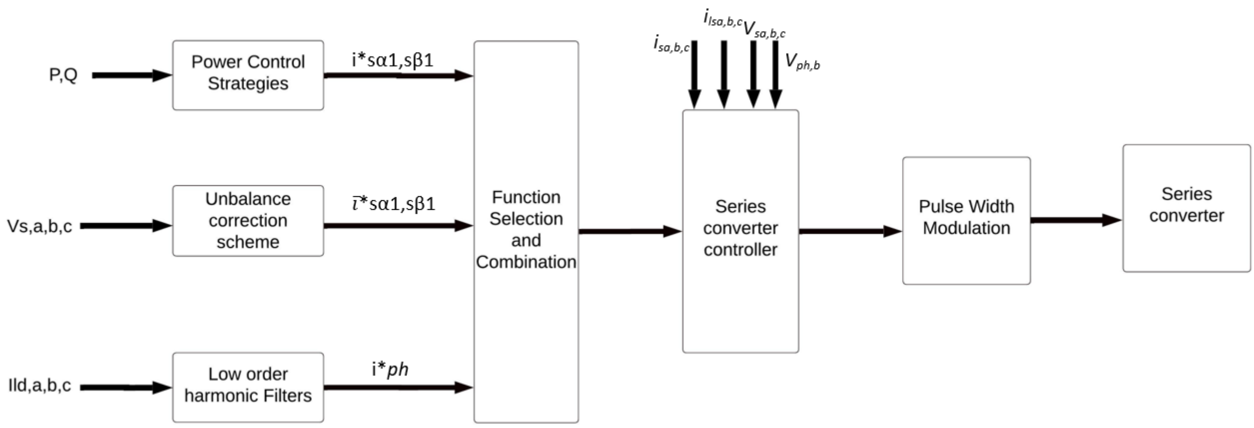

Fig. 3. Control schematic for series converter

Figure 4 depicts the shunt converter's control schematic. In order to calculate the error signals, three-phase current coordinates are converted to two-phase current commands using Park's transformation approach. In the pulse width modulation approach, these reference signals are compared with the carrier signal to produce the gate signals for the shunt voltage source converter [18-20].

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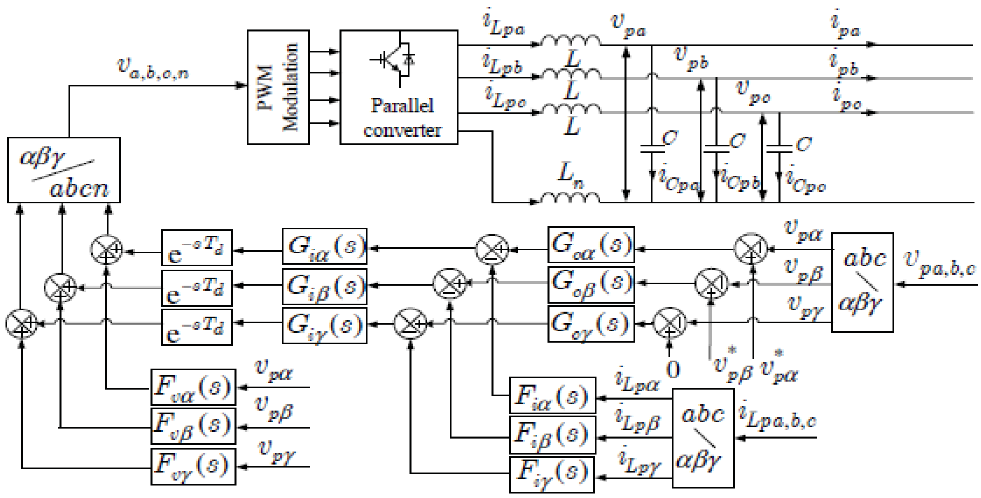


Fig. 4. Control schematic for shunt converter

However, since there is no energy storage, the unified power quality conditioner cannot make up for voltage changes in a system. This paper outlines a UPQC concept that utilizes a rectifier to create a DC-link with the distribution and generation systems [21]. As a result, the distribution generating system provides electricity to the load and grid, the unified power quality conditioner balances out these voltage variations of the grid. There are two ways to operate this suggested DG system. The first, known as the interconnected mode, uses DG to supply power to both the load and the source, and the second, known as the islanding mode, employs DG to provide the load with its own generated power. One of the distribution generation systems in this paper is the photovoltaic generating plant [22,23]. Figure 5 depicts the architecture of the distributed generating system based on the unified power quality conditioner.

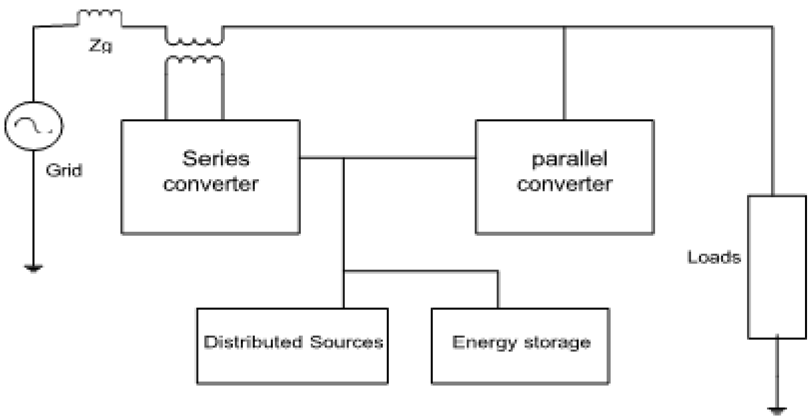


Fig. 5. Schematic layout of UPQC system with DG

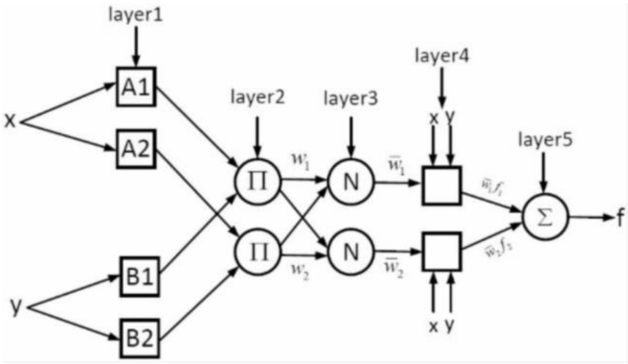
Following the configuration of the membership functions, the fuzzy controller's rules must be.

2.2 Adaptive Neuro-Fuzzy Inference System

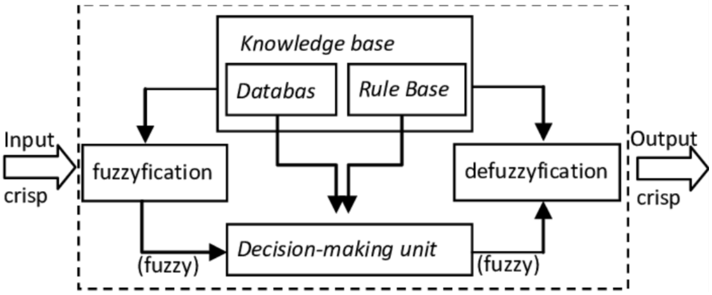
Adaptive Neuro-Fuzzy Inference System (ANFIS) is a hybrid intelligence system that blends fuzzy logic and neural network principles to produce a strong framework for challenging pattern recognition, learning, and data processing tasks. The two inputs of this neural network controller are Δe and Δde, and its single output is f ∈ {Δe, Δde}. There are five membership functions in each input.

The Fuzzy Inference System (FIS) used in this project is a Mamdani-based FIS with one final output and two inputs [24,25].

The mamdani-based fuzzy controller with one output and two inputs is depicted in Figure 6 and it uses a collection of if-then rules to infer output based on input values. These rules consist of antecedents (conditions) and consequents (actions), allowing for complex decision-making. The membership functions of memberships with fuzzy sets are denoted as μAi and μBi, and their respective inputs are associated with the operator logical AND. To determine the values of system parameters, hybrid learning algorithms are put into practice. Both linear and non-linear characteristics influence these learning techniques. MATLAB/Simulink is used to carry out simulations.



(a)



(b)

Fig. 6. (a) ANFIS architecture, (b) Configuration of Fuzzy Inference System

The neuro controller algorithm begins by normalizing inputs and outputs to a uniform scale between 0 and 1, ensuring consistent processing across diverse data. The number of inputs is determined based on dataset characteristics and system requirements, followed by defining the structure with hidden layers and node configurations. A feed-forward network is crafted using activation functions like 'transig' and 'poslin' to govern signal processing between layers. The learning rate is set to regulate the pace of weight and bias adjustments during training, which spans a determined number of iterations. The objective, whether minimizing error rates or achieving specific accuracy levels, guides the training process. Through iterative training, the network refines its parameters, ultimately generating and validating simulation outputs for the application.

3. Results

For both of the cases i.e., for the PI and the ANFIS controllers, the experimental validation of the suggested fuzzy-based UPQC micro-grid system was validated using MATLAB/Simulink. The PI controller has been used to create the suggested grid-interfaced system, and the outcomes are depicted below in Figure 7.

Fig. 7. Simulation result of the feeder currents

The simulation results of the feeder currents of the system under both scenarios i.e., with and without compensation are depicted in Figure 7. It is observed that the gird voltage appears to be distorted without compensation and the voltage is shown as 226 V. Besides, the sinusoidal voltage is shown with compensation and the voltage is measured as 230 V accordingly.

The simulation results for the system microgrid voltage for both scenarios i.e., with and without compensation, are depicted in Figure 8. It is observed that source and load voltages have small distortions using the PI controller and the load-shedding power is obtained as 0.254 kW and can be seen in Figure 9 accordingly.

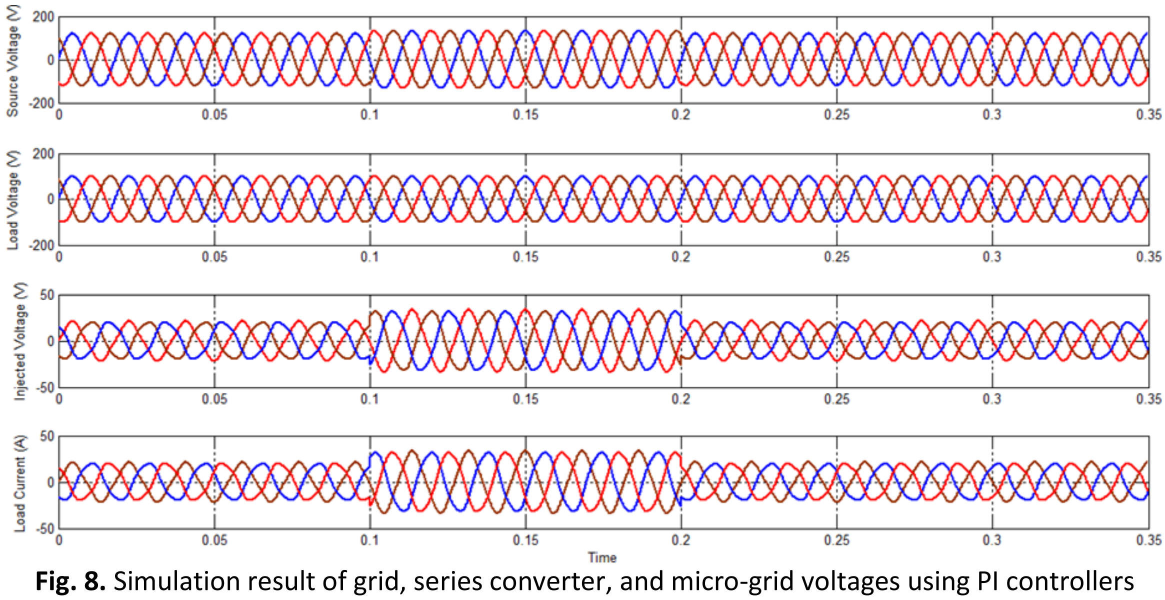


Fig. 8. Simulation result of grid, series converter, and micro-grid voltages using PI controllers

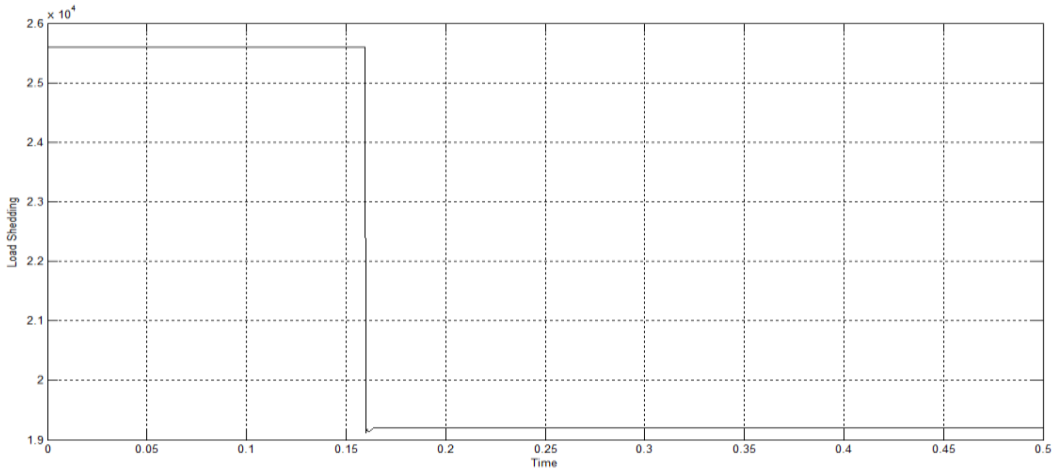


Fig. 9. Simulation result of active power under islanded condition

Figure 10 shows the simulation result for compensation of load voltage under fault conditions using the ANFIS controller. It is observed that there is a small spike in the load current and injected voltage for 0.1 seconds which is due to the thermal conditions of the power electronic switches. Furthermore, the distortions have been reduced in the system using the ANFIS controller.

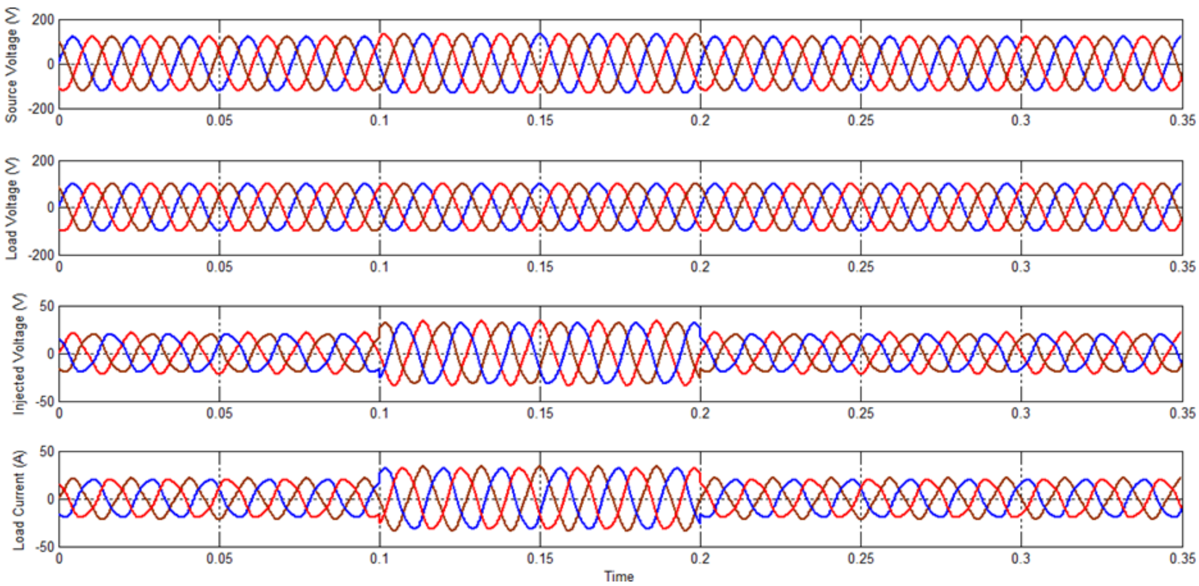
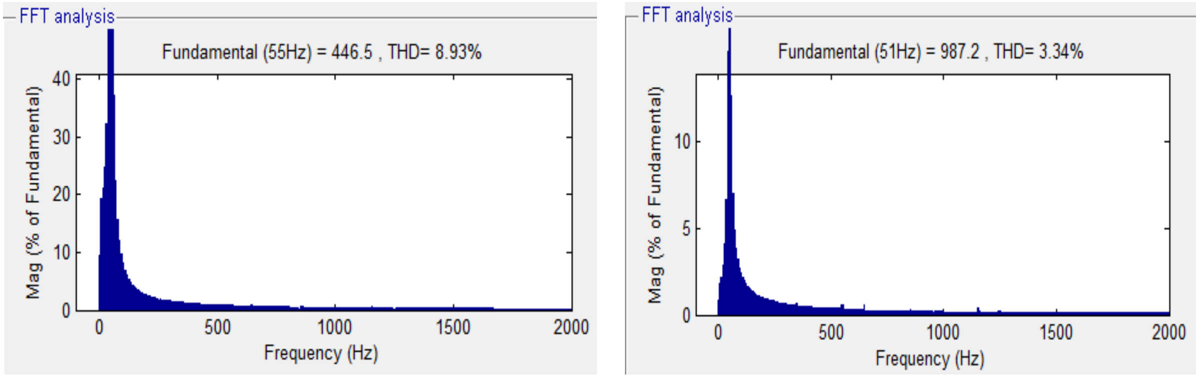


Fig. 10. Simulation result of grid, series converter, and micro-grid voltage using ANFIS controller

The overall total harmonic distortion (THD) analysis of the proposed system using PI and ANFIS controllers is displayed in Figure 11. It is observed that using the PI controller the THD is 8.93 %, whereas it is reduced to 3.34 % using the ANFIS controller. Considering these figures, it could be claimed that the ANFIS control offers a reduced load current harmonic distortion factor than the traditional PI controller.



(a) (b)

Fig. 11. (a) FFT analysis using PI controller (b) FFT analysis using ANFIS controller

4. Conclusions

This paper has demonstrated the use and performance of the controllers on the UPQC-implemented Microgrid. As we know the concept of the microgrid has been introduced to reduce the power quality issues induced in the system due to generation-demand imbalances and other. So Unified Power Quality controllers are generally used to deal with the issues. The ANFIS controller has been observed to be showing better results than the conventional PI controller.

The grid interface employing a converter system with parallel and series architecture with a traditional PI controller and an ANFIS controller is simulated, and the results are achieved. Voltage distortions result from harmonics that are created by the system's non-linearity and thermal properties of the power electronic switches. We could mitigate these distortions in the system by utilizing a traditional PI controller. Nevertheless, the simulation results show that the ANFIS controller can reduce harmonics and enhance the THD more effectively.

In future articles, analysing the thermal properties of the power electronic switches in the proposed system will be essential for enhancing the power quality in the distribution system.

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The authors declare that there is no competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

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