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ENHANCEMENT OF POWER QUALITY USING ANFIS CONTROLLER WITH FUEL CELL INTEGRATED CUSTOM POWER DEVICE IN THE DISTRIBUTION GRID

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Abstract: Electrical and electronic devices are prone to failure when exposed to one or more power quality issues. The purpose of this research is to improve the power quality in a three-phase four-wire distribution grid by using a fuel cell integrated unified power quality conditioner (FCI-UPQC). On the shunt side, the proposed FCI-UPQC has a four-leg converter and a three-leg converter on the series side. The FCI-UPQC reference signals are generated using a combination of synchronous reference frame and instantaneous reactive power theories. In addition, an adaptive neuro-fuzzy inference system (ANFIS) controller is proposed in this study to maintain the DC-link voltage in the FCIUPQC. The ANFIS controller is built in the style of a Sugeno fuzzy architecture and is trained offline with data from the proportional-integral controller. The obtained results demonstrated that the proposed FCI-UPQC compensated power quality problems such as voltage sag, swell, harmonics, neutral current, source current imbalance in the three-phase four-wire distribution grid. The presence of fuel cell in this work makes more effectiveness of the proposed system by providing real power support during supply interruption on the grid side.

Index terms: Active power filter (APF), harmonic compensation, power quality, reactive power compensation, fuel cell integrated unified power quality conditioner (FCI-UPQC), voltage sag and swell compensation, adaptive neuro fuzzy interface system(ANFIS).

I.INTRODUCTION

Power quality is the set of electrical property limits that allow an electrical system to function properly without significant loss [1]. Nonlinearity in the supply is caused by recent inventions of power electronic devices such as variable speed drives, load switching, and so on [2]. Any deviation in current, voltage, or frequency from the reference values causes equipment failure, production loss, and equipment damage [3]. As a result, it is critical to maintain high-quality power. Custom power devices (CPDs) have become smarter in the distribution grid in recent years as a result of their effectiveness in resolving power quality issues [2]. One of the effective

CPD is the unified power quality conditioner (UPQC), whose topology consists of the integration of two active power filters connected in a back-to-back configuration to a common DC-link bus [4]. The UPQC combines the operations of load current and supply voltage imperfections while providing quick response and high reliability [5-8]. The fuel cell integrated UPQC (FCI-UPQC) is a fuel cell combined with series and shunt connected active power filters. The series active power filter [9] is used for voltage regulation and voltage harmonic compensation, while the shunt active filter [11] absorbs current harmonics and compensates for negative sequence currents. The compensation provided by a shunt active filter is determined by the reference current signal generated by the controller. However, when compared to conventional controllers, artificial intelligence [12]-based controllers have greater impacts. First, artificial neural networks (ANNs) are electronic models based on the neural structure of the brain. It is a network of artificial neurons that can learn from experience and make more accurate decisions. It can create complex nonlinear models with high speed and adaptability that can be trained at different frequencies [12]. Second, fuzzy logic is a technique that mimics human reasoning abilities, and it includes fuzzification, inference mechanisms, and defuzzification [13]. Khodayar et al. [14] proposed a fuzzy inference model based on deep learning that can extract useful patterns from input vectors to generate more accurate fuzzy rules. Finally, the adaptive neurofuzzy inference system (ANFIS) combines neural and fuzzy inference capabilities [15]. In this case, a neural network is used to automatically adjust membership functions and reduce the rate of errors in order to determine fuzzy logic rules. ANFIS [16] systems typically use a hybrid-learning algorithm to improve ability, accelerate convergence, and avoid trapping in local minima. As a result, the ANN employs an adaptive network with a back propagation algorithm. [17] evaluates a type-2 ANFIS that is more robust than traditional ANFIS due to the use of interval knowledge. In addition, Qureshi et al. [18] proposed a recurrent neuro-fuzzy controller for fuel cell systems that is more accurate than the traditional feedforward controller. The synchronous reference frame (SRF) theory and instantaneous reactive power (IRP) theory are used in this paper to generate reference voltage and reference current signals. For DC voltage regulation, the ANFIS controller with multi-layer feedforward neural network architecture is used.

II.CONFIGURATION OF THE PROPOSED SYSTEM

The proposed system is made up of an FCIUPQC and an ANFIS controller. Figure 1 depicts the proposed system's topology. It has two IGBTbased voltage source converters that are linked back to back via a common DC-link capacitor. The FC is connected to the UPQC via the DClink. The four-leg converter in the FCI-shunt UPQC's will inject both reactive and harmonic components of load current to make the source current sinusoidal and balanced. It also removes the neutral current via the fourth leg. Similarly, the FCI-UPQC series part has a three-leg VSC and will inject both fundamental and harmonic voltages. The series VSC is connected before the sensitive linear load to protect it from voltage distortion from the source side and to make the load voltage as high as sinusoidal. The performance of the proposed system is analysed in the three-phase four-wire system with three different loads: non-linear, unbalanced, sensitive. Three-phase uncontrolled rectifier with resistive and inductive loads on the DC side acts as a nonlinear load whereas three single-phase resistive and inductive loads with different rating act as an unbalanced load. Three-phase resistive and inductive loads are used as a sensitive linear load.

These three loads are applied to different feeders.

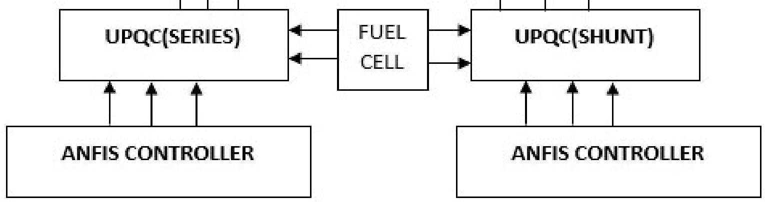


Fig: 1 Proposed System Configuration

III.CONTROL STRATEGY required to maintain the DC-link voltage. As a result, this power flow is added as a

Reference signals are generated by the DCreference for the current controller, which link. The controller is given the difference controls the inverter to provide the required between the actual and reference signals. The compensation current while maintaining the controller's output is used for pulse DC-link voltage of the shunt active filter. generation. The ANFIS controller is used to Similarly, the reference voltage signal is used extract reference signals in this paper. The in the series active filter. The proposed signal from this controller is extracted using system employs IRP theory in conjunction the IRP algorithm by a shunt active filter. The with a proportional-integral (PI) controller main lead in providing compensation is the for both shunt and series components. The reference current signal generated by ANFIS primary function of the series active filter is controller-based IRP theory. In distributed to compensate for voltage flaws by injecting systems, shunt active filters eliminate current harmonics, neutral current compensation, appropriate voltage. The voltage injected by the series active filter is connected in series load balancing, power factor correction, and with the sensitive load via an injection voltage regulation, while series active filters transformer and an LC filter, which are used protect load voltage from any short duration to prevent switching harmonics generated by voltage disturbances such as voltage sag, VSC [23]. The DC voltage is connected to the voltage swell, and so on from the supply side VSC's DC side via a capacitor containing fuel and aid in harmonic reduction.. The ANFIS cells. The data from the PI controller is used controller controls a small amount of active to train and test the ANFIS controller. This current by comparing the actual DC-link ANFIS controller compensates for voltage voltage of a shunt active filter with a sag, swell, harmonics, neutral current, source reference voltage, and the inverse of this current balance, and maintains the DC-link control corresponds to the power flow voltage.

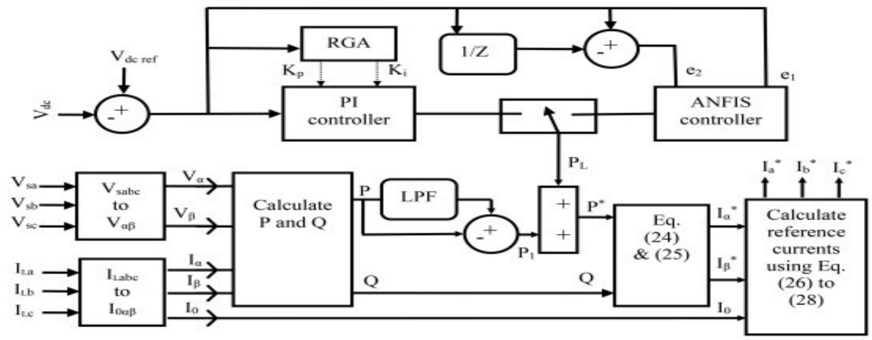
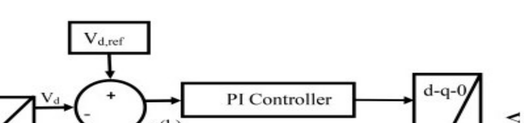


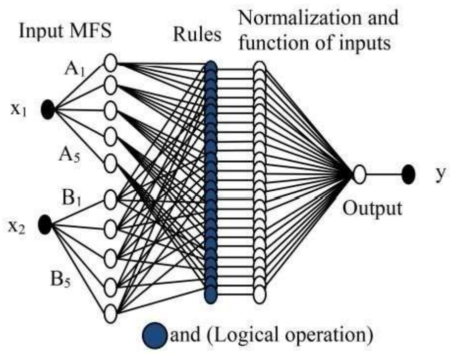
Fig. 2: Extraction of reference current using ANFIS controller based IRP theory

Fig. 3: Extraction of the voltage reference for the series active filter

IV.DC voltage regulation using ANFIS controller

The ANFIS controller receives the difference between the actual DC-link voltage and the reference voltage. The controller's output is used to generate pulses that control the converter's IGBTs. The PI controller parameters were successfully optimised using the real number genetic algorithm [24]. Load nonlinearity causes signal distortions, which are typically rectified by using traditional PI controllers, which can fail to provide high accuracy, fast reference signal processing. As a result, an ANFIS controller with a high dynamic response is used to keep the converter system stable over a wide operating range. The ANFIS controller combines neural network learning capabilities with fuzzy logic reasoning capabilities. The ANFIS controller makes use of the hybrid algorithm, a combination of the least-squares method and back propagation gradient descent method. The ANFIS is given two inputs, e1 and e2, where the error between actual and reference DC voltages is e1 and the change in error is e2. ANFIS architecture is composed of five layers. In Fig. 4, all of the square nodes are adaptive, meaning their parameters can be changed during training, whereas all of the circle nodes have fixed parameters. Layers 1 and 4 are adaptive nodes, while the remaining nodes are circle nodes. Layer-1 parameters are known as premise parameters, while layer-4 parameters are known as consequent parameters. In a forward pass, the leastsquares method is used by fixing the premise parameters and adjusting the result. The gradient descent method is used in a backward pass, in which error signals propagate backward by adjusting premise parameters and fixing the consequent parameters.





Layer 1: e1 is the input to node 1, Ai is the linguistic label linked with this node function and seve n triangular membership functions are used. The node equation is given below:

$$O_i^1 = \mu A_i(e_1), \quad \mu B_i(e_2)$$

$$\mu A_i(e_1), \quad \mu B_i(e_2) = \begin{cases} 0 & e_1 \le a_i \\ \dfrac{e_1 - a_i}{b_i - a_i} & a_i \le e_1 \le b_i \\ \dfrac{c_i - e_1}{c_i - b_i} & b_i \le e_1 \le c_i \\ 0 & c_i \le e_1 \end{cases}$$

where i = 1, 2, …, 7. Oi 1 is the output of the ith node in layer 1, ai , bi , ci are the parameters of the triangular membership functions. Layer 2: The node is labelled as ∏. The incoming signals from layer 1 are multiplied and sent to layer 3

$$\omega j = \mu A_i(e_1) \times \mu B_i(e_2)$$

where i = 1, 2 ,…,7 and j = 1, 2, 3 ,…, 49. The firing strength of a rule is represented by the nodal output.

Layer 3: It is labelled as n. The normalised firing strength of every rule is calculated using the output of this layer

$$\overline{\omega_j} \frac{\omega_j}{\sum_{k=1}^{49} \omega_k}$$

where j = 1, 2, …, 7. Layer 4: The parameters of this layer are called consequent parameters

$$O_j^4 = \overline{\omega}_j f_j = \overline{\omega}_j (r_j e_1 + s_j e_2 + t_j)$$

Rules

$$\text{If } e_1 = A_1 \text{ and } e_2 = B_1 \text{ then } f_1 = r_1 \cdot e_1 + s_1 \cdot e_2 + t_1$$
$$\text{If } e_1 = A_1 \text{ and } e_2 = B_2 \text{ then } f_2 = r_2 \cdot e_1 + s_2 \cdot e_2 + t_2$$
$$\vdots$$
$$\text{If } e_1 = A_7 \text{ and } e_2 = B_7 \text{ then } f_{49} = r_{49} \cdot e_1 + s_{49} \cdot e_2 + t_{49}$$

where Oj 4 is the output of the ith node in layer 4, ωj is the outpu t from layer 3, rj , sj , tj are the consequent parameters set which are determined during training, Ai , Bi are the fuzzy membership functions, i = 1, 2, …, 7 and j = 1, 2, 3, …, 49.

Layer 5: This layer is the summation of all the incoming signals and is given as

$$y = \sum_{j=1}^{49} \overline{\omega}_j f_j = \sum_{j=1}^{49} \left[(\overline{\omega}_j e_1) r_j + (\overline{\omega}_j e_2) s_j + (\overline{\omega}_j) t_j \right]$$

The results illustrate the evident impact of e1 on voltage regulation. The ANFIS in the proposal uses 49 rules with seven membership functions for each input variable. .The ANFIS used was trained with 60,001 data points, and the data was verified with 60,000 data points. The ANFIS controller controls the small amount of active current by comparing the actual DC-link voltage and the reference voltage. The power flow developed in response to the controller's output maintains the DC link. The power flow is used as a reference for the current controller, which controls the inverter to provide the necessary compensation current to keep the FCI-UPQC voltage stable.

IV.SIMULATION RESULTS:

The performance of the proposed FCI-UPQC is analysed with linear, nonlinear and unbalanced loads under various situations with ANFIS controller using MATLAB/SIMULINK. All the voltage measurements are expressed in per unit system and the current measurement in the actual value system. In the proposed work, the shunt converter of FCI-UPQC is switched on at 0.05 s to clearly represent the role of the shunt converter.

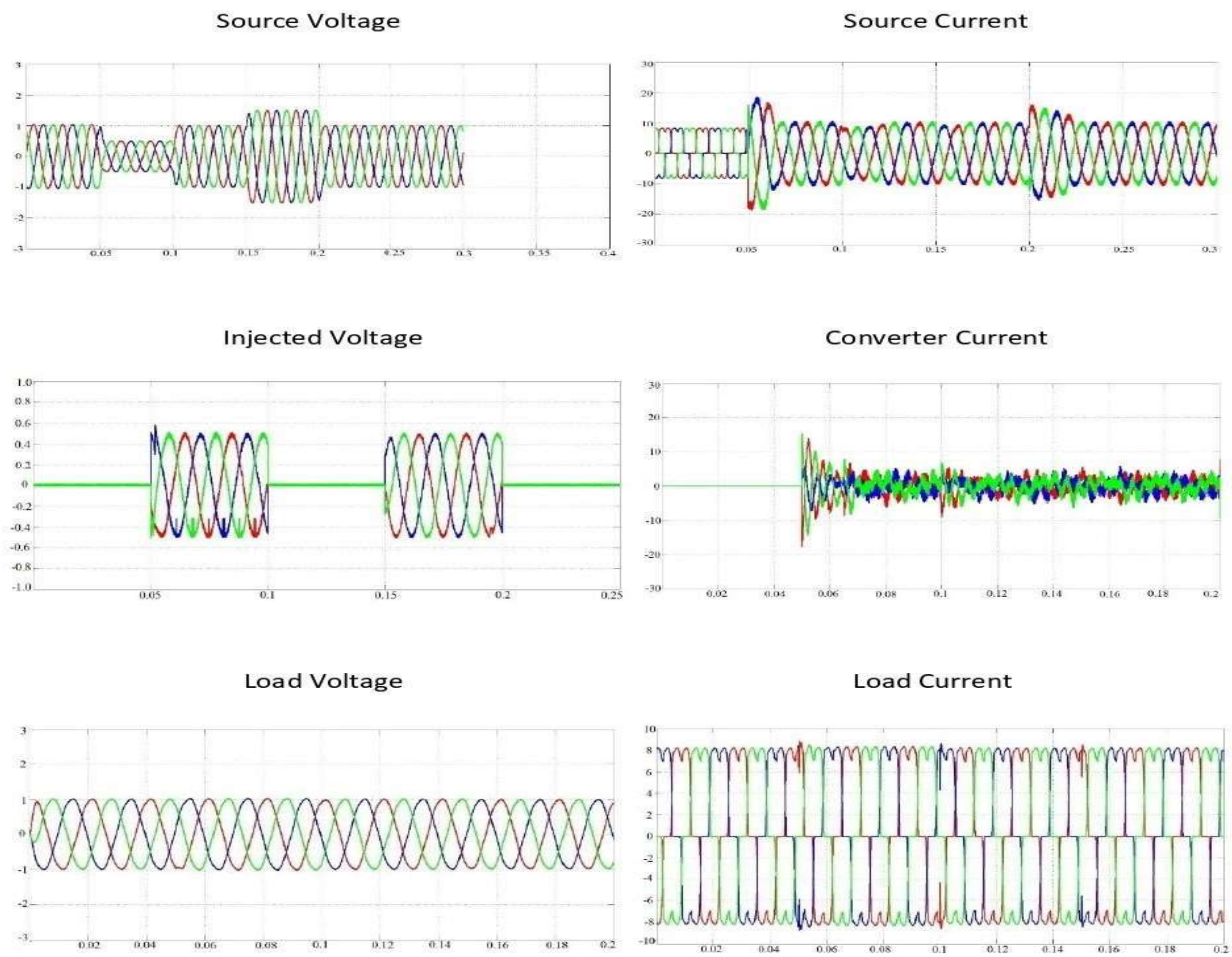
The sub-plots in Fig. 5 show the performance of the FCI-UPQC with ANFIS controller under voltage sag and swell conditions, with the source voltage sag occurring between 0.5 and 1 s and the voltage swell occurring between 0.15 and 0.2 s. The corresponding injected voltage will be in phase with the source voltage during sag conditions and 180° out of phase with the source voltage during voltage swell conditions. The load current is not sinusoidal because the load is nonlinear. As a result, the authors are employing FCI-UPQC to compensate for and maintain the quality of the source current waveform. During 0-0.05 s, the shunt converter is turned off, so the load current is the same as the source current with no compensation. In the sub-plots of Fig. 6, the harmonic disturbances are introduced in source side voltage and current from 0.1 to 0.2 s under non-linear load conditions and its corresponding response (load voltage and source current) was obtained. It is observed that from 0.1 to 0.2 the source current harmonics cannot be eliminated

Figure 7 shows that after compensation, the percentage THD in voltage is greatly reduced. The primary goal of converter current (IC) is to keep source current (IS) sinusoidal, balanced, and in phase with supply voltage (VS). As a result, whenever there is an unbalance, it provides the necessary compensation to load current (IL). The load current is not in phase with the source voltage because the load is

unbalanced. As a result, the authors use FCIUPQC to compensate and maintain IS. Figure 8 shows how the percentage total harmonic distortion (THD) in current is reduced primarily after compensation.

Table illustrates the voltage and current THD comparison between the proposed method and the literature results.

neutral current Icn is injected in opposite phase to maintain the source side neutral current almost near to zero. ANFIS controller offers better harmonic compensation in the



distribution grid.

Fig. 5 Performance of FCI-UPQC under voltage sag, swell and current harmonics disturbances

It is observed that the proposed method is more efficient than conventional methods.

Consider a situation described in Fig. 9 under unbalanced load condition, there will be a respective converter current addition to maintain the source current waveform quality. In addition, the load neutral current (In) produced during the unbalanced load need to be cancelled hence a converter

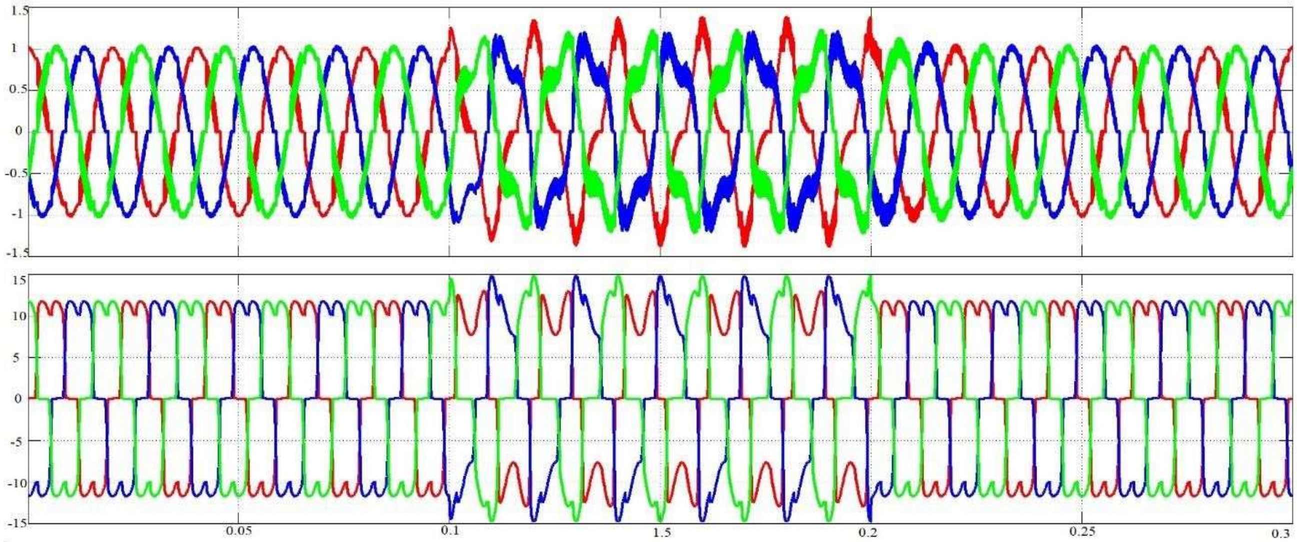


Fig.6 A Performance of circuit without any controller under load voltage and source current

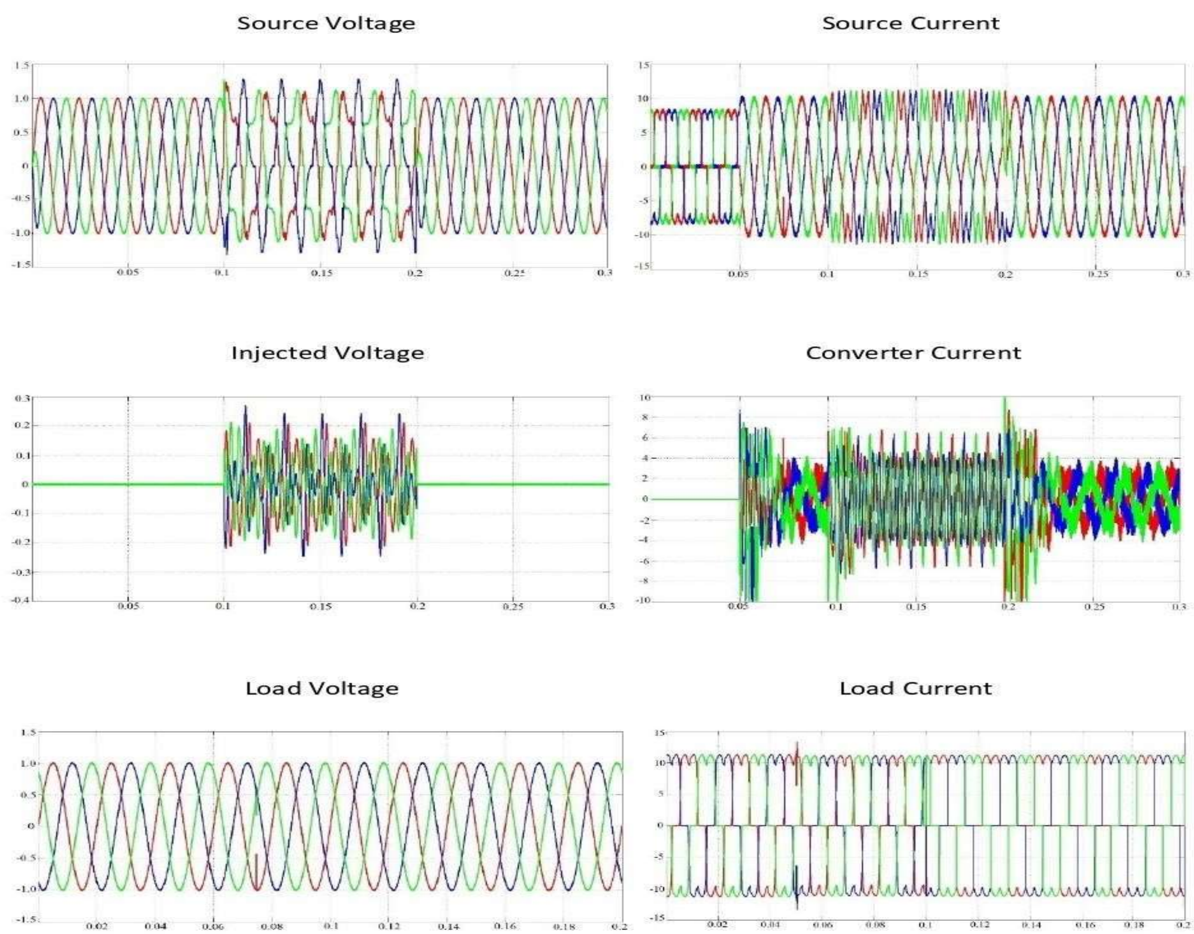
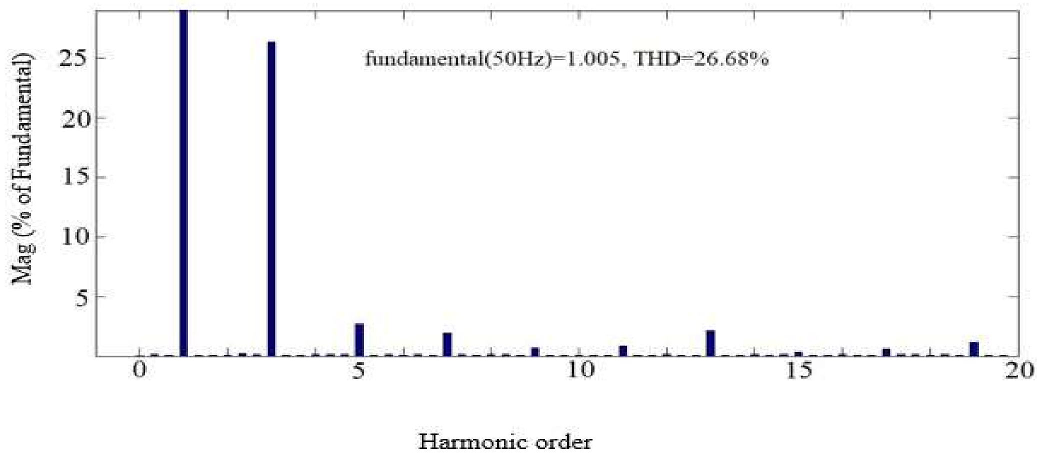
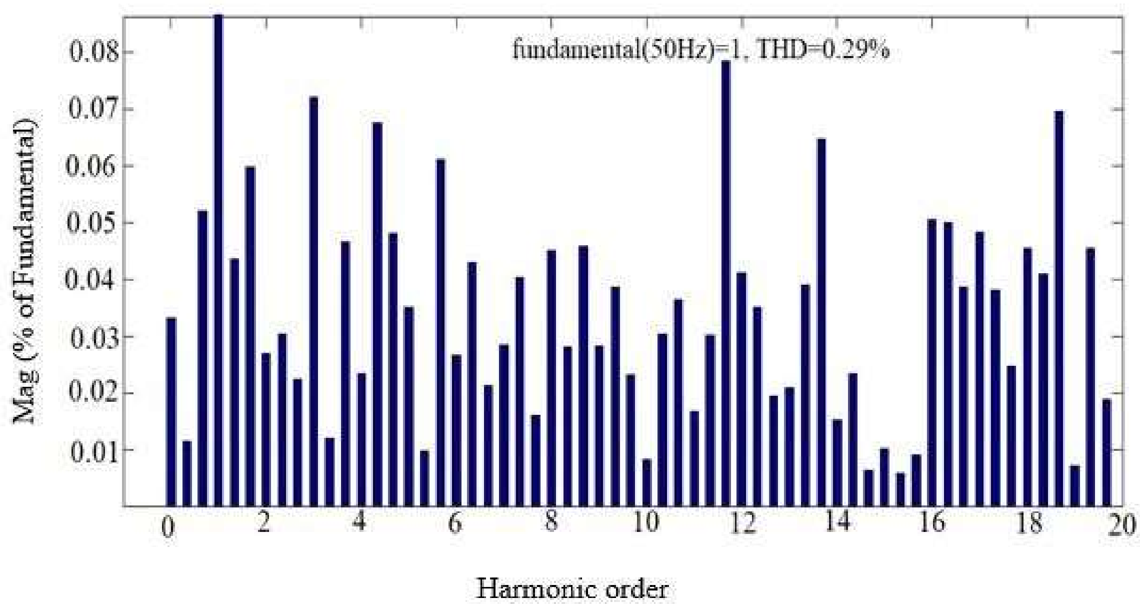


Fig. 6 B Performance of FCI-UPQC under source side voltage and current harmonics disturbances



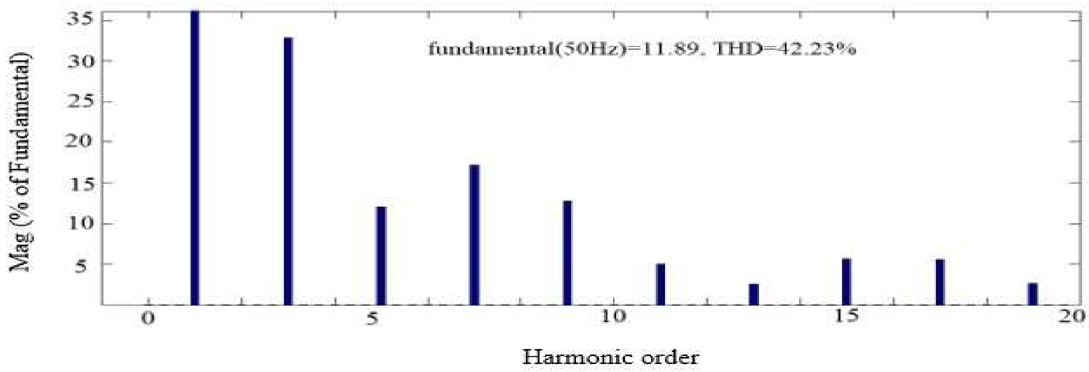
(A)



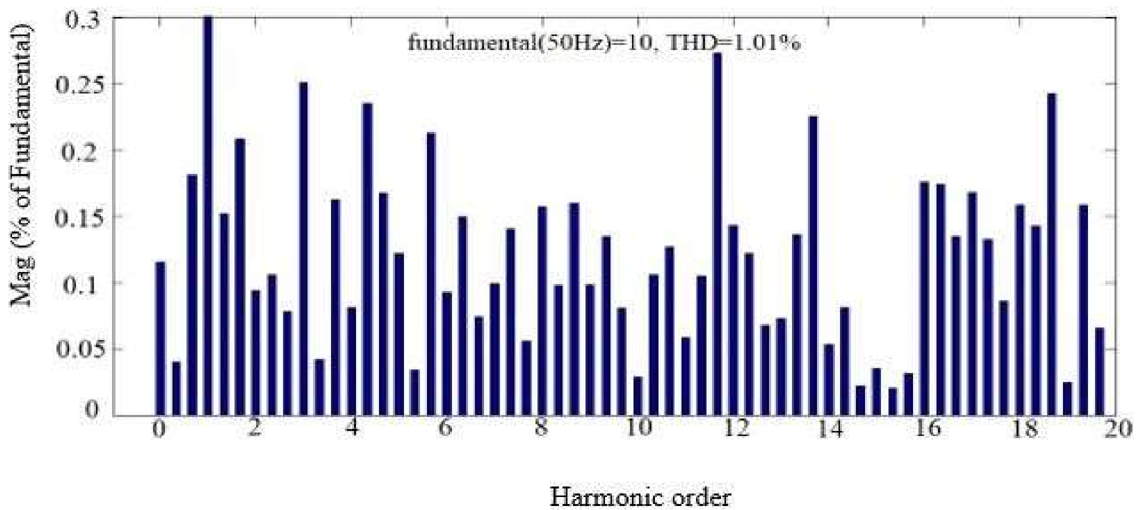
(B)

Fig. 7 Voltage THD compensation

(a) Before compensation, (b) After compensation



(A)



(B)

Fig. 8 Current THD compensation

(a) Before compensation, (b) After compensation

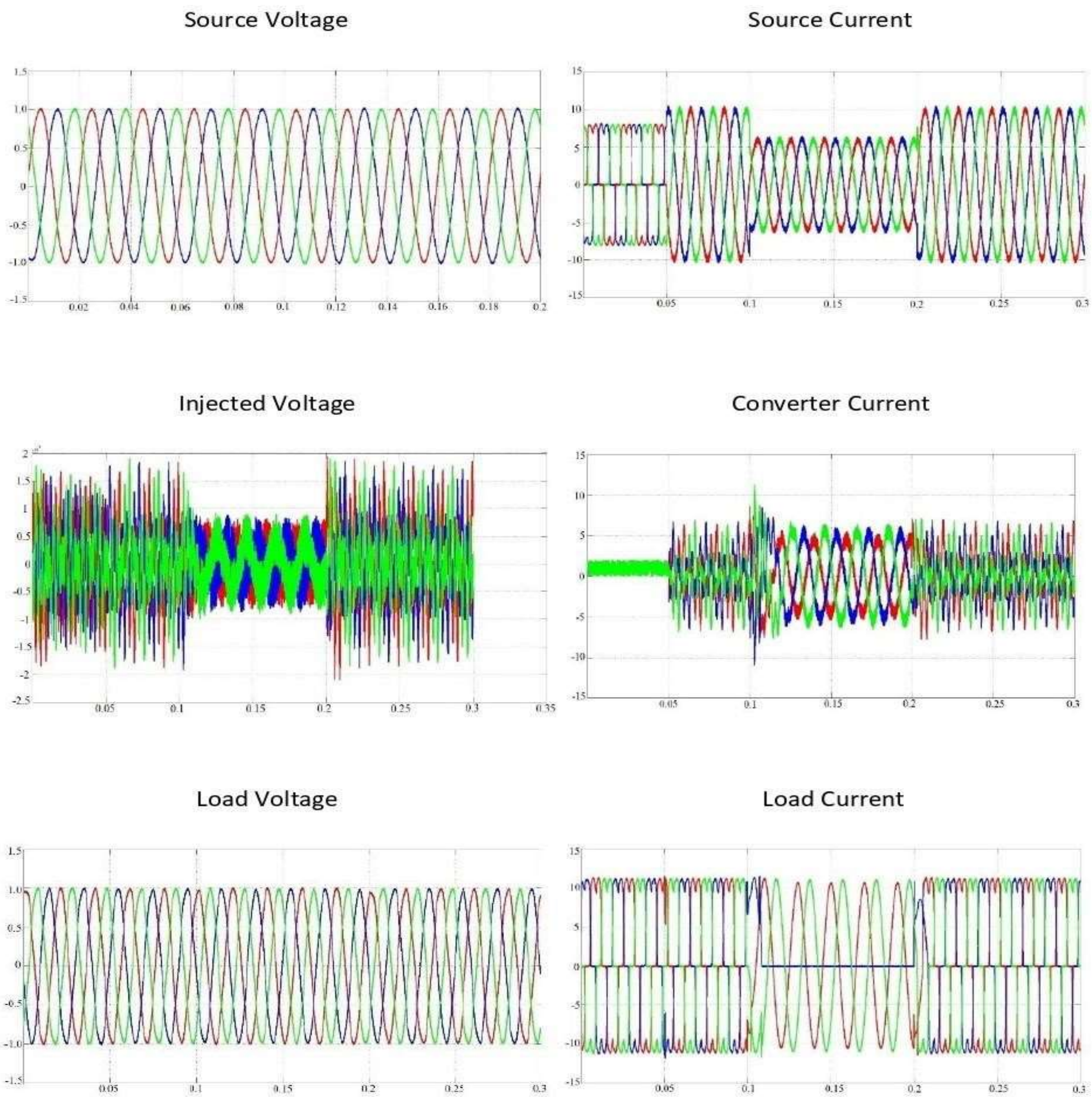


Fig. 9 Performance of FCI-UPQC under current harmonics with the unbalanced load conditions

Comparison of harmonic compensation with and without controller

Voltage/current	THD (%) in sensitive load voltage and source current	
	Without controller (%)	with controller(%)
Load Voltage	26.68	0.29
Source current	42.23	1.01

V.CONCLUSION

In this paper, a novel utility of FCIUPQC as a compensating and an interconnecting device for a three-phase four-wire distribution grid is extensively simulated in MATLAB/SIMULINK. It was observed that the proposed FCI-UPQC efficiently compensates the problem of load current and supply voltage imperfections with quick response and high reliability at the same time. The proposed system has an enhanced performance under unbalanced, non-linear and sensitive linear load conditions.

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