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Performance of unified power quality conditioner (UPQC) based on fuzzy controller for attenuating of voltage and current harmonics

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Abstract. Power quality-related issues such as current and voltage distortions can adversely affect home and industrial appliances. Although several conventional techniques such as the use of passive and active filters have been developed to increase power quality standards, these methods have challenges and are inadequate due to the increasing number of applications. The Unified Power Quality Conditioner (UPQC) is a modern strategy towards correcting the imperfections of voltage and load current supply. A UPQC is a combination of both series and shunt active power filters in a back-to-back manner with a common DC link capacitor. The control of the voltage of the DC link capacitor is important in achieving a desired UPQC performance. In this paper, the UPQC with a Fuzzy logic controller (FLC) was used to precisely eliminate the imperfections of voltage and current harmonics. The results of the simulation studies using MATLAB/Simulink and Simpower system programming for R-L load associated through an uncontrolled bridge rectifier was used to assess the execution process. The UPQC with FLC was simulated for a system with distorted load current and a system with distorted source voltage and load current. The outcome of the comparison of %THD in the load current and source voltage before and after using UPQC for the two cases was presented.

1. Introduction

One of the issues that is increasingly bordering electricity consumers is power quality. This is due to the sensitivity of the equipment and the non-linear nature of loads in both domestic environments and the power sectors. Power quality is generating more concerns among electricity users. Electricity supplies that were once acceptable to the users are now considered as problematic [1,2] and the solution to issues of power quality is within the reach of the users and the distribution operators. The active power filters are connected in shunt, series and vice versa to compensate for the distortions in

current and voltage and to provide quality solutions. The UPQC has been proposed as a powerful compensating device for simultaneously dealing with the issues of current and voltage qualities [3-5]. The UPQC which is made up of shunt and series active filters can compensate for distorted voltage at the source side and current at the load side to ensure the load voltage and supply currents are sinusoidal. Although the effectiveness of UPQC in the improvement of power quality, its application is still limited. The passive component of the proposed system was designed to achieve a good performance [6-9]. The UPQC was used in this study as a universal active power conditioning device for the mitigation of both current and voltage harmonics at a power distribution network.
The UPQC performance rely mainly on a quick and accurate compensation of the derived signals. The UPQC is designed based on FLC strategy to actively and reactively compensate for power. The FLC is used to overcome the nonlinear problems efficiently. The schematic representation of the UPQC is presented in Figure 1.

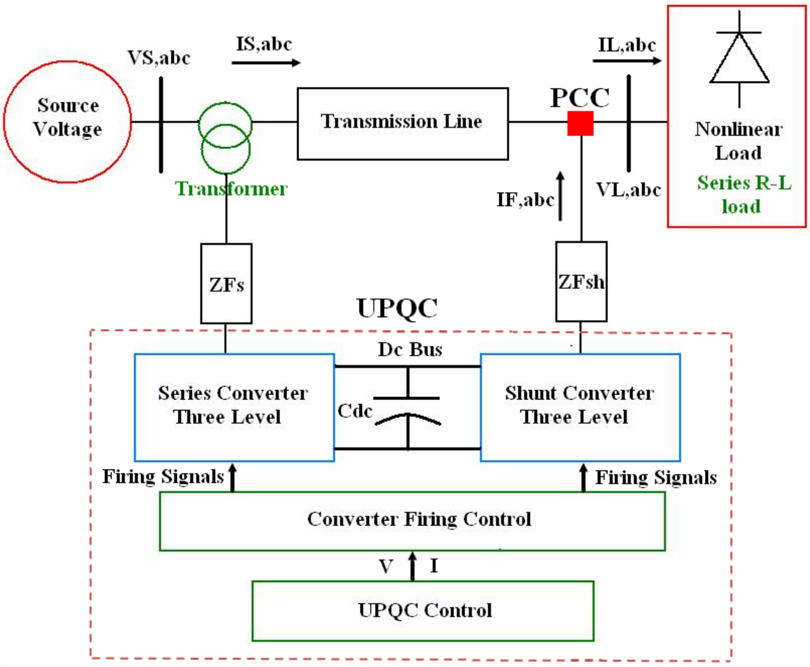

Figure 1. A representation of a UPQC.

Series filters are active filters or series converter which are serially connected through an injection transformer and acts as a controlled voltage generator. Series filters can compensate for voltage imbalance, harmonics and voltage regulation at the point of common coupling (PCC). Additionally, it can provide the harmonic isolation between a distribution system and a sub-transmission system. The shunt active filter is the second unit which is parallel connected with the load and it also generates controlled current. The current harmonics are absorbed by the shunt active filter, which similarly compensates for the current harmonics introduced by the load. Additionally, it maintains the DC current to a desired value. Another element in the power line conditioner is a DC link inductor which stores energy. The active power filter requires a minute amount of power to compensate for harmonics. The DC inductor serves as a source of DC power and therefore, does not require external power source. Meanwhile, the maintenance of a steady DC in the energy storage component requires drawing a small fundamental current to compensate for the active filter losses [10-12].

2. Control algorithm

FLC is a systematic approach for the control of non-linear-based procedures which depends on human knowledge and experience. A fuzzy controller can utilize multiple inputs and output variables. Inverter convert either DC voltage or AC currents into AC current or voltage. Hysteresis voltage and current control is used to generate to make a switching signal for operating the inverter. RL Load is connected. The overall function of UPQC mainly depends on the series and shunt active power filter controller.

2.1. Series converter control

In the voltage-source-inverter-based UPQC, hysteresis voltage control (HVC) is used for the control of the series converter (series filter). Series active filters provide a high impedance to current harmonics and obstructs their load to source streaming and source to load headings, and in like manner, presents as a regulated voltage supply. The elimination of the harmonic components in voltage supply is the major objective of series compensators; the voltage from the series filter is given by Equation 1 [13], where Figure 2 showed the series converter in terms of a control block diagram.

$$V_{ah} = V_{1na} + V_{1pa} + \sum_{k=2}^{\infty} V_{kn} \sin(k\omega t + \theta_{kn}) \quad (1)$$

Where: V_{ah} is the voltage which created by series filter, V_{1na} is the negative sequence components, and V_{1pa} is the positive sequence components.

To ensure the load voltage is sinusoidal, the phase-locked loop (PLL) based unit vector template (UVT) is multiplied with a constant of equal strength to the peak amplitude of the fundamental input voltage so that the voltage of the reference loads is obtained. The UVTs with the respective phase delays for individual phases are achieved and are stated below:

$$U_a = \sin(\omega t) \quad (2)$$

$$U_b = \sin(\omega t + 120) \quad (3)$$

$$U_c = \sin(\omega t - 120) \quad (4)$$

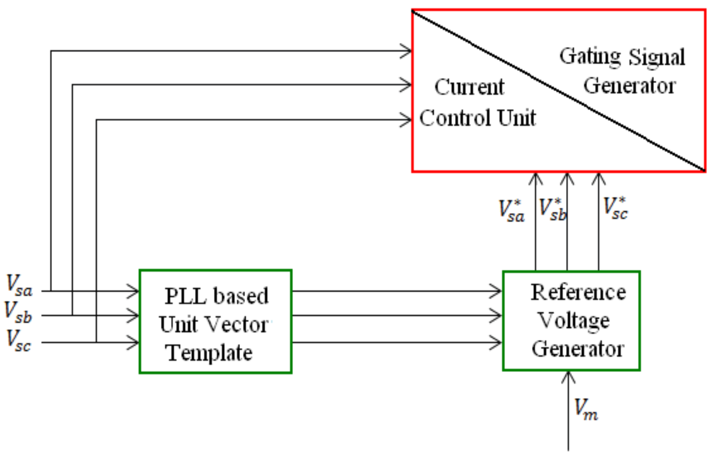

Figure 2. Block diagram of series converter controller.

The generation of the compensation signals is as follows:

$$V_{fa} = V_{sa} - V_m . U_a \quad (5)$$

$$V_{fb} = V_{sb} - V_m . U_b \quad (6)$$

$$V_{fc} = V_{sc} - V_m . U_c \quad (7)$$

Where: (U_a, U_b, $U_{c,}$) and (V_{sa}, V_{sb}, V_{sc}) represent 3-phase unit current vectors multiplication and the 3-phase supply voltage respectively, and V_m is the supplied voltage amplitude.
The gating signal needed for the series converter is obtained by comparing the actual and compensation signals at the terminals of the series converter. The generated error is passed to the hysteresis controller.

2.2. Shunt converter control
The increasing nonlinearity of loads and power in electronic equipment is causing harmonics in the distribution systems. These harmonics can be compensated by a shunt converter (shunt filter) where the DC voltage is detected and benchmarked to a reference voltage and the signal error processed and seen as a magnitude of the reference 3-phased supply current. The phase unit vector is used to calculate the reference current. The 3-ph shunt current for harmonics compensation is presented in equation 8 [14].

$$I_{sha} = \frac{V_{ia}}{Z_{sh}};\ I_{shb} = \frac{V_{ib}}{Z_{sh}}; I_{shc} = \frac{V_{ic}}{Z_{sh}} \quad (8)$$

Where: I_{sha}, I_{shb} and I_{shc} are the shunt currents of phase a, b and c , V_{ia}, V_{ib}, V_{ic} are the injected voltage in phase a, b and c, and Z_{sh} is the shunt impedance. A block diagram of the shunt converter is shown in Figure 3.

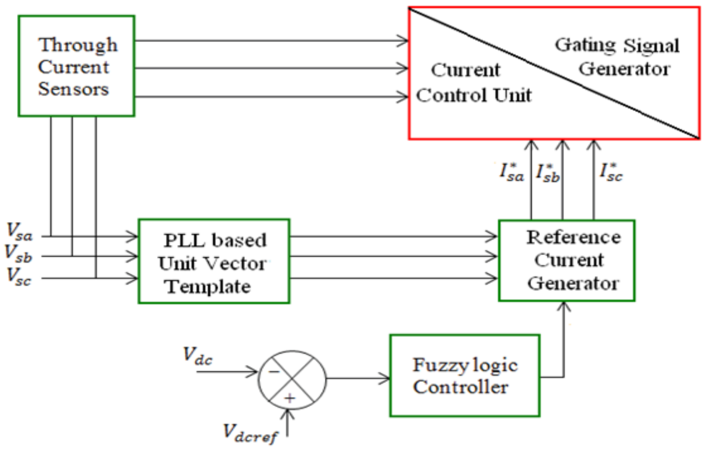

Figure 3. A shunt converter controller.

3. Fuzzy logic control
The FLC is based on the fuzzy set theory in which there is an inevitable transition between membership and non-membership function, which results in fuzzy set ambiguity. When there are lengthy mathematical calculations, the best approach is to deploy the FLC. The fuzzy logic theory can be regarded as a qualitatively-defined mathematical multi-valued logic that involves artificial intelligence and probability theory to proffer solution to problems since it mimics the human brain and uses approximate reasoning when relating different data sets and making decisions. Figure 4 show the three basic components (fuzzification, decision making and de-fuzzification) of fuzzy logic-based control schemes.

The FLC input is the sensed DC link voltage value. The voltage value is through fuzzification to a fuzzy value. The input values (in the fuzzification method) are converted to linguistic values such as positive-small (PS), positive-medium (PM) positive-big (PB) and negative-big (NB), negative-medium (NM), negative-small (NS), very-small (VS). These values are characterized by memberships.

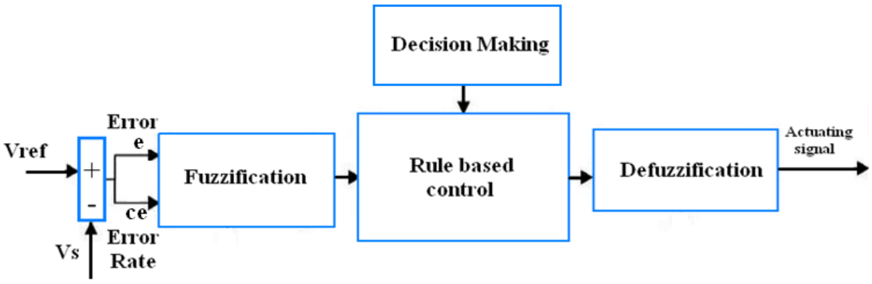

Figure 4. Fuzzy logic control scheme.

The input signal measurement in a fuzzy control system is interpreted as a fuzzy singleton using the Mamdani-type-inference system in which the linguistic variables (input and output) assume are presented as fuzzy variables. Figure 5(a) and (b) show the input variable of fuzzification while Figure 5(c) show the output variable of de-fuzzification. The fuzzy set membership function is an assembly of the indicator functions in classical sets. The fuzzy variables are determined by membership functions and typified by position, width, shape or whole overlap. In the controller, the triangular membership form is used.

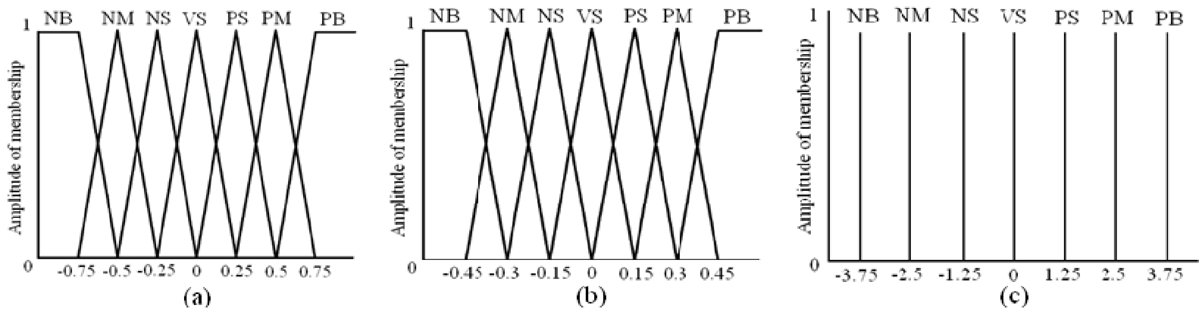

Figure 5. Variable of fuzzy logic (a) Input variable of fuzzification (error), (b) Input variable of fuzzification (error rate), (c) Output of defuzzification (Actuating signal) .

The fuzzy rule base gathers the information of a given problem and employ human control. The fuzzy rule base is developed using 7 x 7 matrix, where the central area of the method is for the de-fuzzification method of getting the crisp function from the fuzzy set.

4. Results and discussion

A three-phase UPQC with fuzzy logic controller is connected to supply voltage 400V, 50Hz and with a nonlinear load comprised of 3-phase bridge rectifier feeding an RL load. This configuration is modeled in MATLAB/Simulink and the performance of this UPQC is estimated in terms of mitigation of current and voltage harmonics, where the simulation circuit is shown in Figure 6 and the parameters circuit states as following:

Grid line voltage is 400V (peak), grid resistance is 0.001 Ω, grid impedance is 10 mH, grid frequency is 50 HZ, load inductance is 0.05 H, load resistance is 100 Ω, filter resistance is 10 mΩ, filter inductance is 3.6 mH, DC link voltage is 680 V and DC link capacitor is 750 µF.

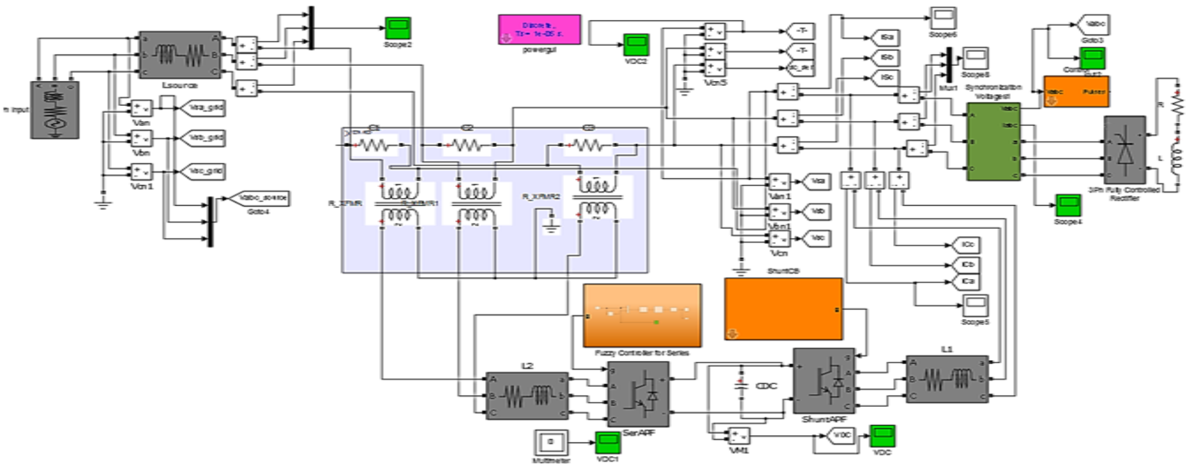

Figure 6. Matlab simulation circuit.

4.1. Case study one :System with distorted load current

A nonlinear load is a diode bridge rectifier connected to the series RL load to create the harmonics inside the system. UPQC is connected to operate for compensate the load current. FLC is employed to regulate the DC link voltage. UPQC steady state performance is examined and the simulation results are shown in the Figure 7.

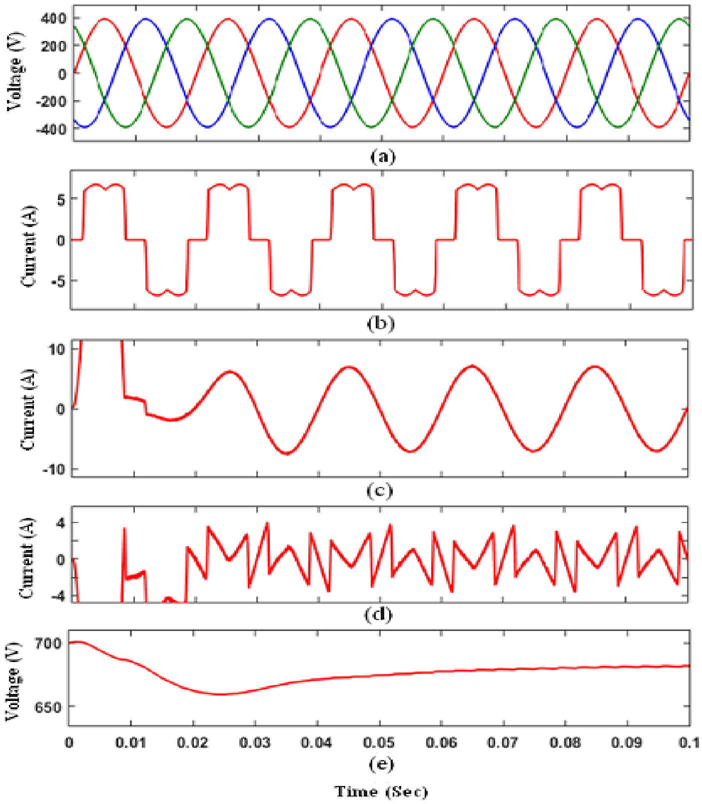

Figure 7. Simulation circuit (a) Source voltage without UPQC, (b) Load current without UPQC, (c) Load current with UPQC, (d) Filter current, and (e) DC link voltage.

It can be clearly seen that the source voltage waveform is pure sinusoidal and the load current waveform has some harmonic components as shown in figure 7(a) and 7(b) respectively. Figure 7(c) and (d) illustrate the operation UPQC has cancelled the effect of distorted load current by injecting the current is equal to harmonic current magnitude. The THD of load current is reduced from 36.37% to 2.10% as in Figure 8. Also UPQC is able to regulate the DC link voltage to its reference value (680v) as shown in Figure 7(e).

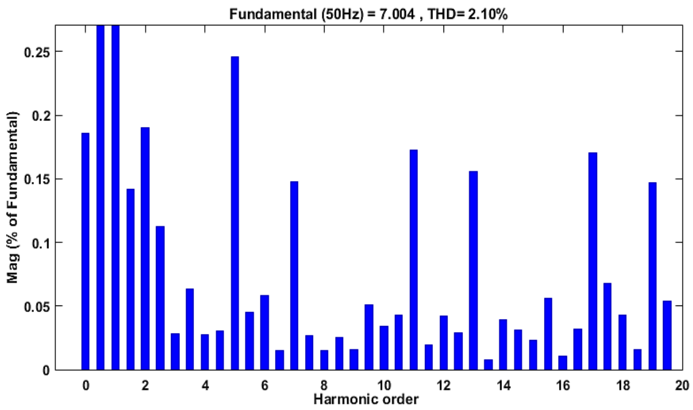

Figure 8. THD of load current after connecting UPQC filter.

4.2. Case study two: System with distorted source voltage and load current

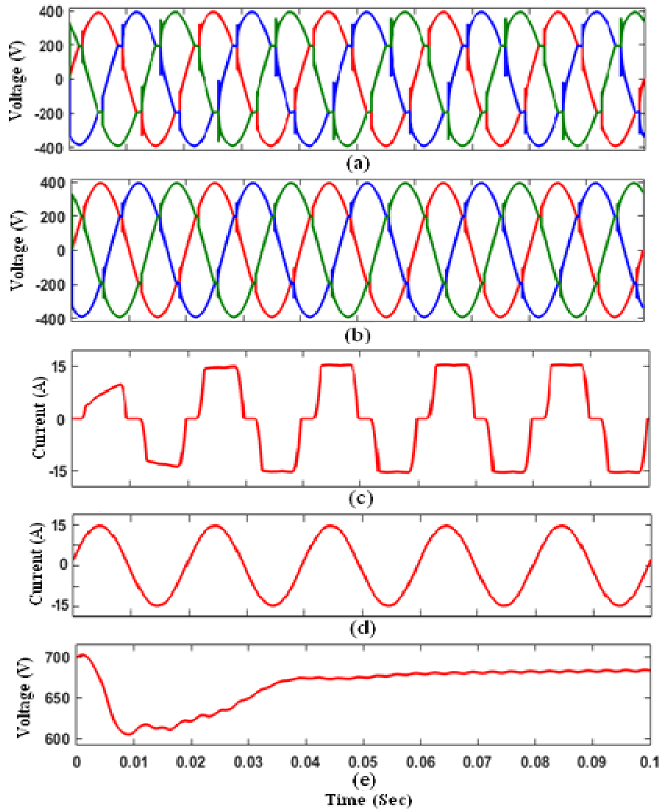

Figure 9. Simulation circuit (a) Source voltage without UPQC, (b) Source voltage without UPQC, (c) Load current without UPQC, (d) Load current with UPQC, and (e) DC link voltage.

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Source voltages with 5th, 7th and 11th harmonics order are shown in Figure 9(a), as well the current waveform as displayed in Figure 9(c) which has high harmonics components. The compensated supply voltage and current waveform are depicted in Figure 9(b) and (d) when the UPQC becomes active. Also FLC has been maintained the DC link voltage to its reference value (680v) as in Figure 9(e).

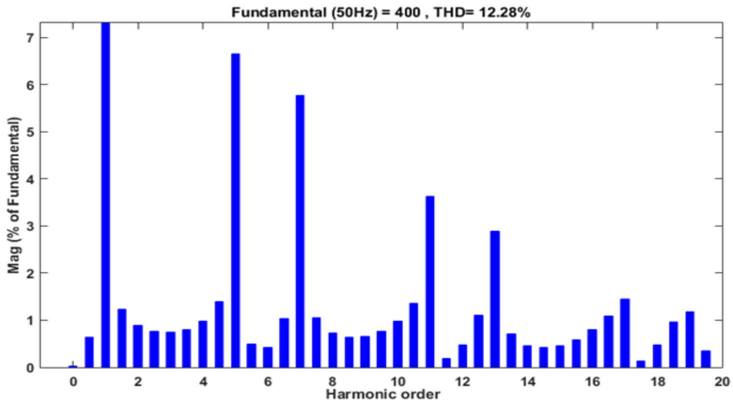

Figure 10.THD of source voltage without UPQC filter.

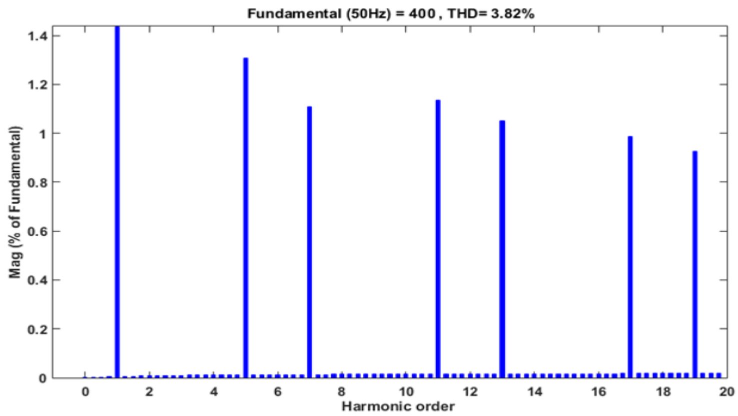

Figure 11 . THD of source voltage with UPQC filter.

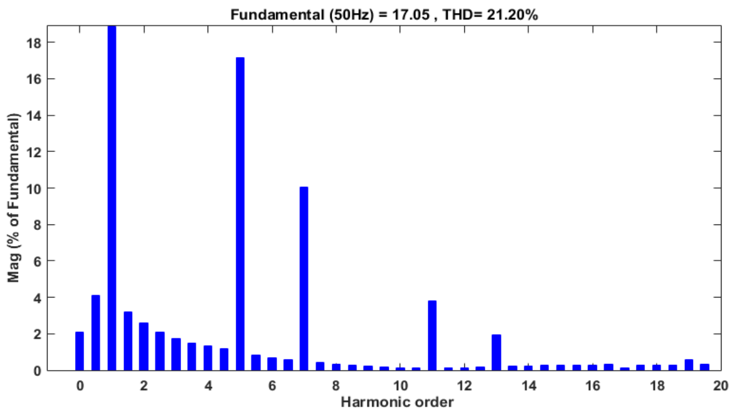

Figure 12 . THD of load current without UPQC filter.

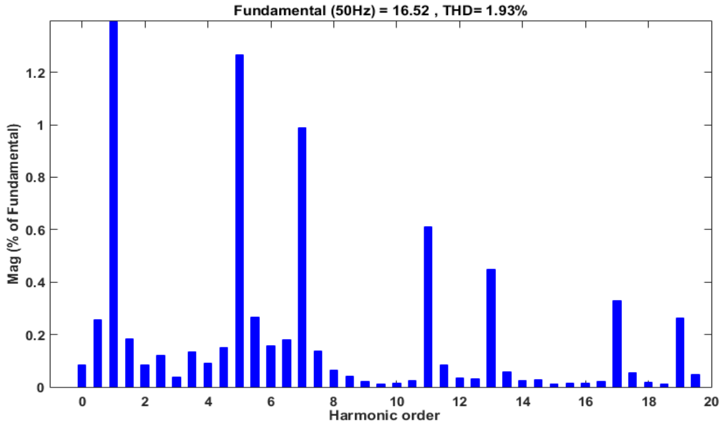

Figure 13 . THD of load current with UPQC filter.

The harmonics in the model system is analyzed in the source voltage and load current, where THD of the voltage before being connected to the UPQC was 12.28% as in Figure 10 and 3.82% after being connected to the UPQC with FLC, as shown in Figure 11.The THD of the load current before applying the UPQC was 21.20% as shown in Figure 12 and 1.93% after connection to the UPQC with FLC, as shown in Figure 13.

Table 1. THD values of load current and source voltage (with and without UPQC filter).

Harmonic order	Performance system					
	Case one		Case Two			
	THD of load current before filter	THD of load current with filter	THD of voltage source before filter	THD of voltage source with filter	THD of load current before filter	THD of load current with filter
3th	2.52	0.12	0.74	0.01	1.76	0.04
5th	11.07	2.02	6.64	1.31	17.18	1.27
7th	4.03	0.9	5.77	1.11	10.4	0.99
9th	1.20	0.01	0.66	0.01	0.21	0.02
11th	4.67	1.33	3.63	1.13	3.78	0.61
13th	2.58	1.12	2.88	1.05	1.95	0.45
15th	1.32	0.01	0.46	0.02	0.26	0.01
17th	3.55	1.11	1.64	0.99	0.11	0.33
19th	1.54	0.95	1.17	0.39	0.56	0.26
THD %	36.37	2.10	12.28	3.82	21.20	1.93

Table 1 depicts the harmonics values for each harmonic order before and after using UPQC with FLC for voltage and current waveforms. Based on the Table 3, the high harmonics value were the 5th and 7th for voltage, which were 6.64% and 5.77% respectively, while the values were 17.18% and 10.04% for current respectively. However, the 5th and 7th harmonics value have been reduced by UPQC to 1.31% and 1.11% in voltage waveform and to 1.27% and 0.99% in current waveform.

5. Conclusions

This paper presents the proposed scheme of UPQC for harmonics compensation of load current and source voltage in distribution systems using FLC which regulates the DC voltage. The performance of proposed UPQC for power quality improvement was extensively investigated under two simulation case studies and from the studies, it was noted that the proposed scheme adequately compensated the load current and source voltage harmonics to meet the regulations of IEEE Standard 519.

Acknowledgments

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