Improvement of Power Quality Using a Hybrid Interline UPQC

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Abstract— This paper proposed the reduced rating star connected transformer based interline unified power quality conditioner. This work comprises of unified power quality conditioner connected between the two feeders, star connected transformer and LC filter. This hybrid approach significantly improves the performance of UPQC under unbalance source voltage condition. The UPQC adopted to compensate current and voltage-quality problems of sensitive loads and suppressing the load current harmonics under distorted supply conditions. The series converter control strategy is based on the fuzzy-logic controller. The extensive simulation results have carried out in MATLAB/Simulink environment power system blockset toolboxes. From the results it has shown that hybrid interline UPQC achieves superior capability of mitigating the effects of voltage sag/swell and suppressing the load current harmonics, phase current harmonics and neutral current under distorted supply conditions. To validate the results produced by the proposed method, it is compared with the conventional UPQC method and better results obtained from the hybrid approach.

Keyword- Power quality, Interline unified power quality conditioner, Fuzzy logic controller, Neutral current

I. INTRODUCTION

The increase in commercial and industrial loads has results in severe power quality problem in the distribution side. The consumption of electricity is increased randomly due to increases in consumers. Due to switching operation and nonlinear load the major disturbance is occurred in the distribution side. The major disturbances in the distribution side causes losses, mis-operation of customer equipment, damage electrical equipments. This major disturbance in the distribution side is minimized by the proposed method to a great extent. The use of non-linear loads for distribution systems has a major issue for a long time for both power provider and consumers [1]. In past Power problems are solved with the help of LC passive filters. However, this kind of converter cannot solve certain variations in the load current waveform [2]. They also can produce series and parallel resonance with source impedance. To solve these problems, several solutions have been developed and Unified Power Quality Conditioner (UPQC)) is the one of the most popular solution used nowadays. The UPQC can perform the functions of both DSTATCOM and DVR [3]. The UPQC consists of shunt and series converter having a common DC link. The series converter is connected in series with a distribution feeder 1, while the shunt converter is connected in shunt with the feeder 2. The DC links of converter are connected through a common DC capacitor.

The UPQC is connected between the two different feeder from the different substation is said to be Interline Unified Power Quality Conditioner (IUPQC) [4], [5]. The IUPQC mitigates the voltage sags/swell in the feeder 1 for sensitive loads and compensate the harmonics in feeder 2 for non linear loads. The shunt converter is connected to the reduced rating star connected transformer. The reduced rating transformer is minimum volt ampere transformer for compensating the source current harmonics and neutral current. The reduced rating star connected transformer based IUPQC has proposed in this paper. The star connected transformer neutral point is connected through the LC filter [6]. The LC filter suppresses the excessive neutral current flow in the distribution system. The reduced star connected transformer based IUPQC is said to be Hybrid IUPQC [7], [8]. The LC filter suppresses the excessive neutral current flow in the distribution system. The result obtained from the HIUPQC approach clearly shown that power quality of the distribution system is increased from that of the conventional method [9], [10]. The simulation of the proposed method has been carried out by MATLAB software. The results are compared with source side and load side it shown that new scheme has compensates the disturbances on both side with superior capability.

II. CONFIGURATION 0F HYBRID IUPQC

The proposed methodology comprises of the reduced rating star connected transformer based IUPQC. The two sources are taken from the different substation. The series converter is connected in feeder 1 through the series reactor from the line similarly through the shunt reactor connected in feeder 2 is shunt converter. The series and shunt converter is linked with common DC link and capacitor. The proposed UPQC model is shown in Fig. 1.

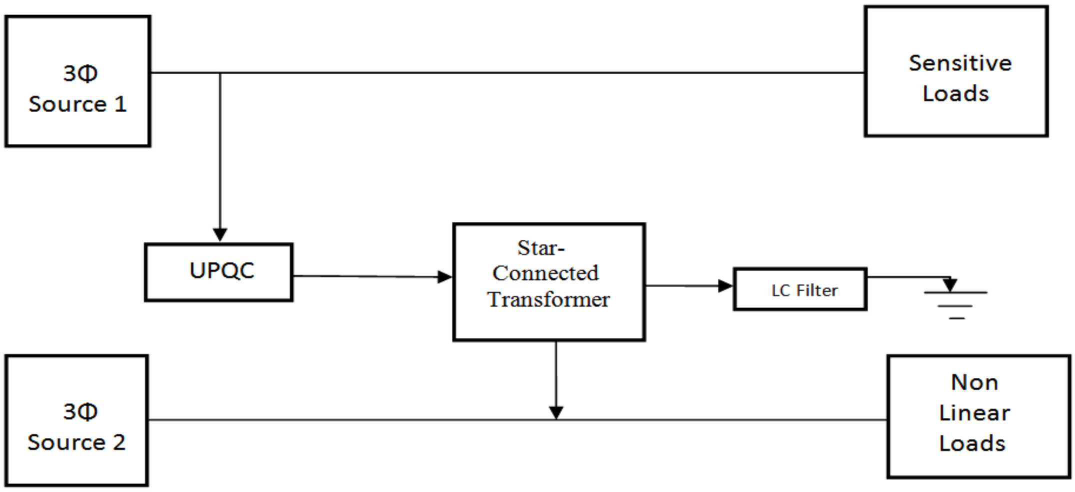

Fig. 1. Proposed HIUPQC model

The IUPQC is connected with reduced rating star connected transformer. The neutral of the star connected transformer is connected with LC filter and its remains to earth. This hybrid approach reduces the phase current harmonics and compensates the neutral current. The disturbance is made by the programmable voltage source then the result obtained with and without IUPQC is analyzed in source side as well as the load side. To obtain sinusoidal load voltage with fixed amplitude V, the output of series converter is expressed as in (1)

$$v_{sr} \ = \ (v - v_{1p}) \sin\left(\omega\, t + \Theta_{1p}\right) - v_{Ln}\,(\mathrm{t}) - \sum_{k}^{t} = 2v_{K}\,(\mathrm{t}) \tag{1}$$

Where v_{sr} is the series converter voltage compensation, v_{1p} is the Positive sequence voltage amplitude fundamental frequency, Θ_{1p} is the initial phase of voltage for positive sequence, v_{Ln} is the Negative sequence component, ωt and v_K (t) is the constant.

The shunt converter acts as a controlled current source and its output components should include harmonics and negative-sequence components in order to compensate these quantities in the load current, when the output current of shunt converter Ish is kept to be equal to the component of the load as given in the following equation (2)

$$I_L \ = I_{1p} \cos(\,\omega t + \ \Theta_{1p}) \sin\left(\,\Theta_{1p}\right) + I_{Ln} \ + \sum_{k}^{\infty} = 2I_{L\,K} \tag{2}$$

Where I_L is the shunt converter current, I_{1p} is the Positive sequence voltage amplitude fundamental frequency, Θ_{1p} is the initial phase of voltage for positive sequence, I_{Ln} is the Negative sequence component ωt and $I_{L\,K}$ is the constant.

The control of dc-link voltage plays an important role in achieving the desired UPQC performance. During the system vary conditions, such as sudden load change, voltage sag/swell, the dc-link should respond as fast as possible to restore the dc-link voltage at set reference value. The DC link control strategy is based on Fuzzy Logic Controller (FLC). It is the control strategy which decides the behavior and desired operation of a particular system. The UPQC system depends upon its different control algorithm. The UPQC control strategy calculates the reference signals (current and voltage) and decides the switching operation of inverter switches, such that the desired performance of the system can be achieved.

III. SERIES CONVERTER CONTROL

The various disturbances like switching operation and other faults occur in the distribution system causes voltage sags and swell. It affects the consumer equipment severely. The series converter compensates the voltage sag and swells in the distribution network. The fuzzy logic controller based series converter controller is shown in Fig. 2.

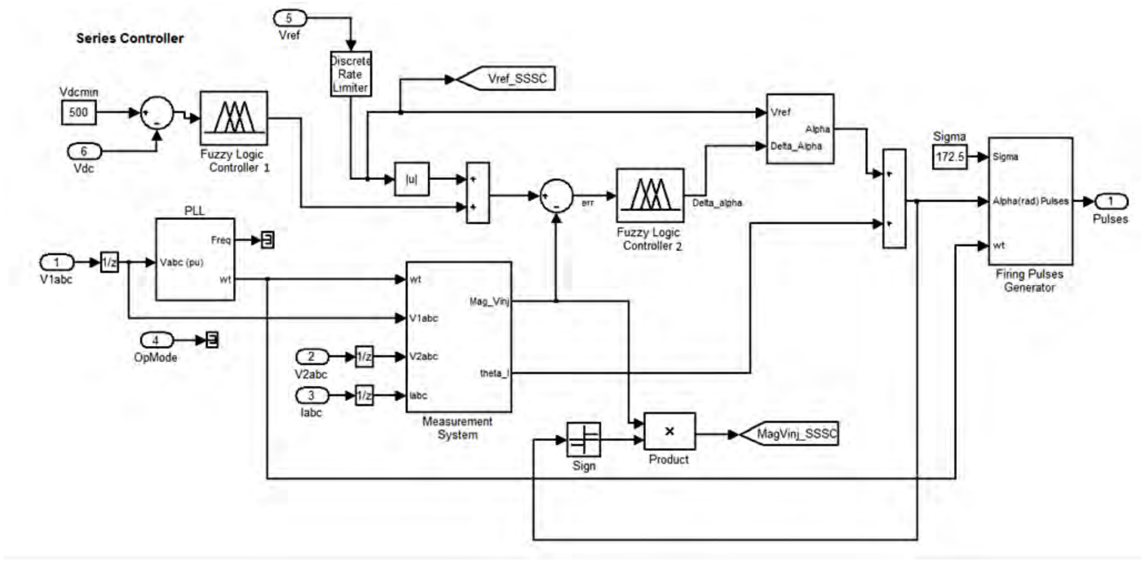

Fig. 2. FLC based series converter controller

The DC link measured voltage is compared with the reference voltage by comparator. The error signal obtained from the comparator is processed with FLC 1.The actual value of voltage in phase a, b, c is processed with the magnitude of the injected voltage in series converters. This output value is compared with output of FLC 1 by comparator. The amplitude of voltage is used for reference current calculation. The amplitude of the voltage computed from the three phase sensed value voltage as expressed as in (3).

$$v_{sm} = \left[\tfrac{2}{3} \left(v_{sa}^{2} + v_{sb}^{2} + v_{sc}^{2} \right) \right]^{\frac{1}{2}} \quad (3)$$

Where v_{sm} is the amplitude of supply voltage., v_{sa}, v_{sb}, v_{sc}, are the three phase supply voltage.

The error signal from that comparator is again processed in the FLC 2. The output of FLC 2 is given to PWM. Depending on the firing signals from PWM the series converters compensate the voltage sags and swell. The compensation of voltage sag/swell is based on reference value of injected voltage. The reference value of the injected voltage is depends on the specification of the system. The reference values of injected voltage are expressed as in (4), (5), (6).

$$v_{ia} = \sqrt{2}\; v_{inj} \sin\left(\omega t + \delta_{inj}\right) \quad (4)$$

$$v_{ib} = \sqrt{2}\; v_{inj} \sin\left(\omega t + 2\frac{\pi}{3} + \delta_{inj}\right) \quad (5)$$

$$v_{ic} = \sqrt{2}\; v_{inj} \sin\left(\omega t - 2\frac{\pi}{3} + \delta_{inj}\right) \quad (6)$$

$$v_{inj} = v_s - v_l \quad (7)$$

Where v_s – supply voltage, v_l – load voltage., v_{ia},v_{ib}, and v_{ic} are three phase reference voltage, δ_{inj} is the phase of the injected voltage and the ωt is constant.

IV. Shunt Converter Control

Due to increasing in nonlinear load and power electronic equipment in distribution systems causes harmonics. This harmonics and is compensate by the shunt converter. The dc link voltage is sensed and compared with reference voltage. The error signal is processed and it considered as the magnitude of the three phase supply current references. The reference current is calculated by using the unit vector in phase, with the actual supply voltage the three phase unit vector in phase is derived as in (8).

$$u_{sa} = \frac{v_{sa}}{v_{sm}},\; u_{sb} = \frac{v_{sb}}{v_{sm}},\; u_{sc} = \frac{v_{sc}}{v_{sm}} \quad (8)$$

Where $v_{sm}$is the amplitude of supply voltage., v_{sa}, v_{sb}, v_{sc}, are the three phase supply voltage and u_{sa}, u_{sb}, u_{sc} are the multiplication of three phase unit current vectors.

The three phase shunt current for compensation of harmonics as expressed as in (9)

$$I_{sha} = \frac{v_{ia}}{z_{sh}}, \quad I_{shb} = \frac{v_{ib}}{z_{sh}}, \quad I_{shc} = \frac{v_{ic}}{z_{sh}}$$

(9)

Where I_{sha}, I_{shb}, I_{shc}, is the shunt current in phase a, b and c., v_{ia}, v_{ib}, v_{ic}, is injected voltage in phase a, b and c., z_{sh} is impedance of the transformer.

The multiplication of magnitude with unit current vectors obtained from three phase reference supply current. This reference current is compared with actual supply current, and then the error value is obtained. The error signal obtained is converted in to PWM signals. Depending on the PWM signal obtained the shunt converter compensates the harmonic and reactive power in the distribution system.

V. FUZZY LOGIC CONTROLLER

The sensed DC link voltage value is input of the FLC. The voltage value is converted in to fuzzy value by fuzzification method. In this fuzzification method the input values is converted in to linguistic value, which may be viewed as labels of fuzzy sets. In fuzzy control system, the measurement of the input signal is interpreted as a fuzzy singleton.

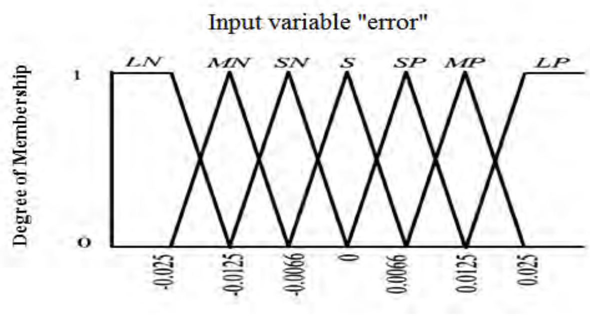

Fig. 3. Fuzzification input voltage variable 1

Here mamdani type fuzzification is used. In mamdani type fuzzy inference system, both the input and output linguistic variables will take fuzzy variables as values. The input variable of fuzzification is shown in Fig. 3, Fig. 4 and output variable of defuzzification is shown in Fig. 5. The membership function of a fuzzy set is a generalization of the indicator function in classical sets. Fuzzy variables are defined by membership function and characterized by shapes, position and width or whole overlap. The triangular membership is used in the controller.

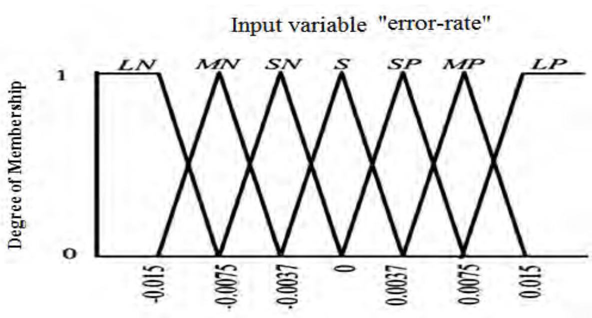

Fig. 4. Fuzzification input voltage variable 2

The fuzzy rule base assemblies plant information and apply the human control expertise to the given problem. The Rule base was formed using a 7*7 matrix. Centroid of area method is used for defuzzification method to obtain the crisp value from the fuzzy value.

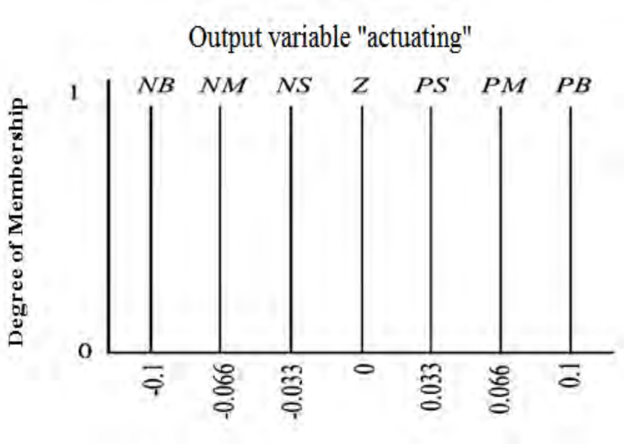

Fig. 5. Defuzzification output voltage variable

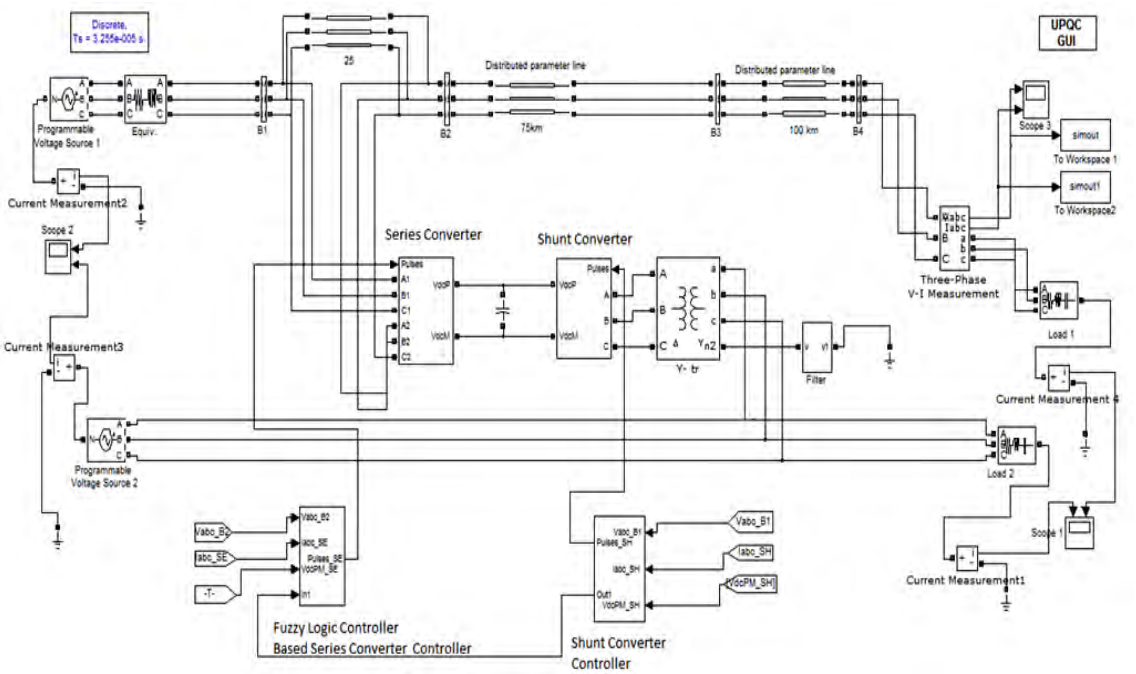

Fig. 6. Simulation diagram

The simulation diagram is shown in Fig. 6. The design of IUPQC is based on the parameter specification of the distribution system. The two feeders are considered in the system. The 5^{th}, 7^{th} and 11^{th} order harmonics are created in this scheme. The reduced rating star connected transformer is connected with the UPQC. In this scheme the sensitive load is connected in near to the series converter side, where as the industrial and domestics loads are connected in near to the shunt converter side. The system parameter from the above table as consists of three phase source with line impedance are based on the distance of distributed parameter line are taken. The DC link capacitor is based on the voltage circulation in the DC link. The minimum volt-ampere star connected transformer is connected on the load side. The system parameters are shown in Table I.

TABLE I
System Parameters

System Input Quantity	3ϕ supply voltage frequency line impedance	415V (Ph-Ph) 50 Hz 0.004Ω + j0.016Ω
LC Filter	filter inductance (L_f) filter capacitor (C_f)	8mH 36 μF
DC Link	capacitor	1100 μF
Non Linear Load	load impedance	40Ω+j10Ω
Reduced Rating Transformer	star connected transformer	20kVA

VI. RESULTS AND DISCUSSION

The UPQC has simulated using the proposed hybrid UPQC with DG. The source voltage waveform before and after connecting the UPQC are analyzed. It noticed that the source voltage is distorted before connecting the UPQC and it becomes sinusoidal after connecting the UPQC. The voltage waveform on source side without UPQC is shown in Fig. 7 and with UPQC is shown in Fig. 8. It has clearly shown that the voltage sag and swell present in the waveform is compensated after connecting the UPQC. The voltage sags and swell present in the load side are also reduced, due to source side compensation.

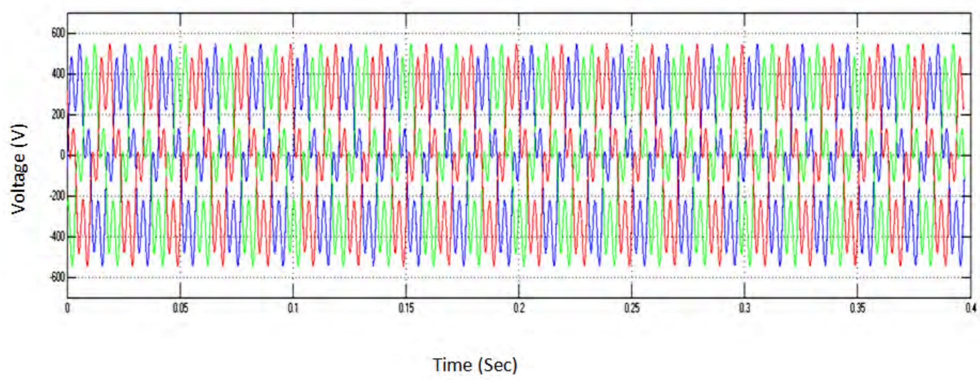

Fig. 7. Voltage waveform without UPQC

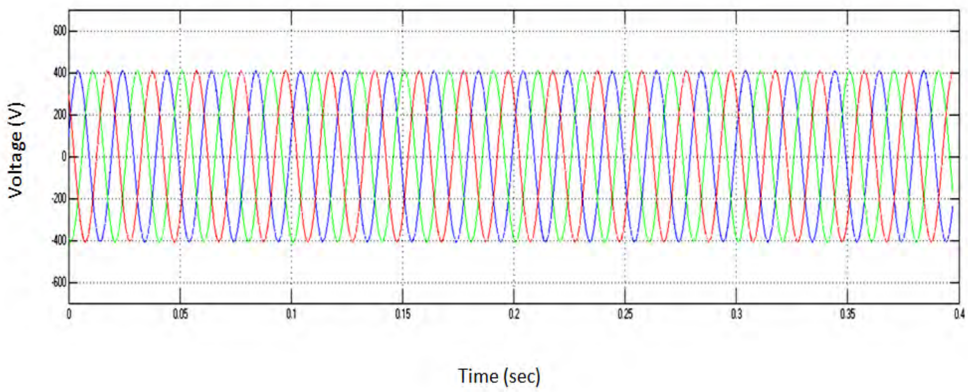

Fig. 8. Voltage waveform with UPQC

The current waveform obtain from the load side contains harmonics on before connecting the UPQC as in Fig. 9 and after connecting the UPQC as in Fig. 10. It shown that high order harmonics present in waveform is reduced after connecting the UPQC.

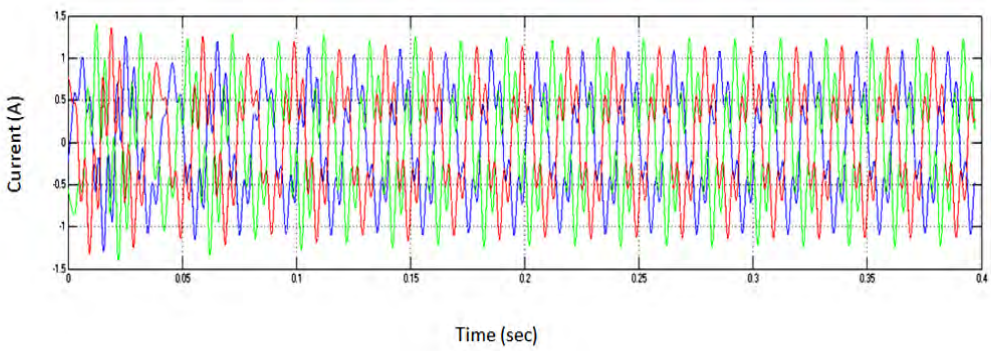

Fig. 9. Current waveform without UPQC

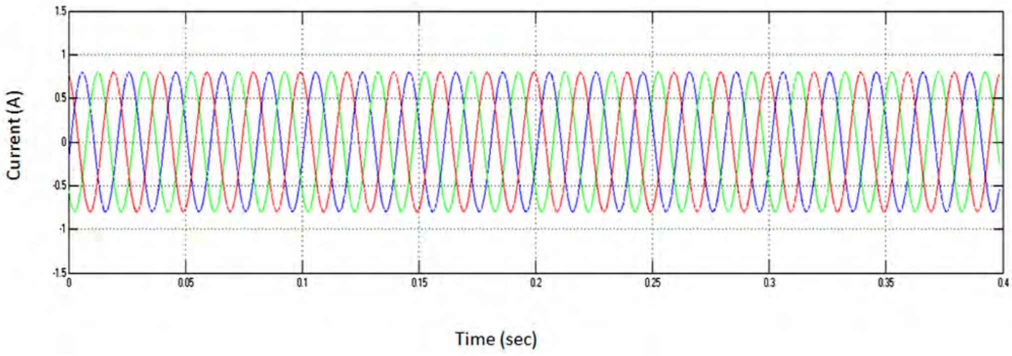

Fig. 10. Current waveform with UPQC

The harmonic distortion in the system is analysed in source side as well as the load side. When compared to load side the source side harmonics is low. The THD in the source side before connecting the IUPQC is 12.86% as in Fig. 11 and with IUPQC is 2.27% as in Fig. 12. However the THD in the load side before connecting the IUPQC is 20.29% as in Fig. 13 and after connecting the IUPQC is 3.04% as in Fig. 14. The THD in conventional IUPQC method on load side is 4.64% as shown in Fig. 15.

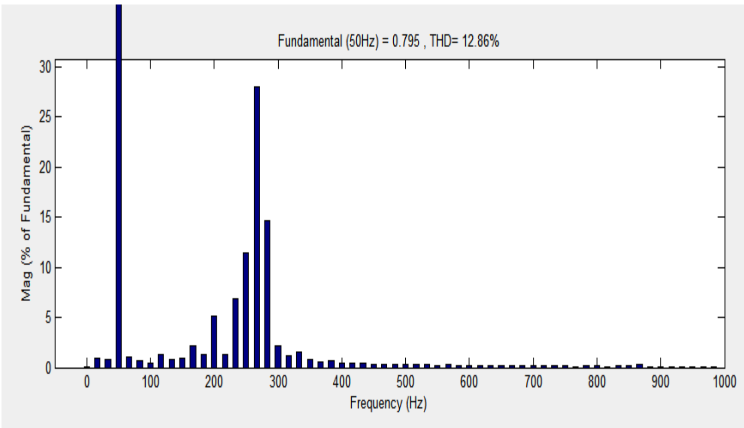

Fig. 11. THD without IUPQC in source side

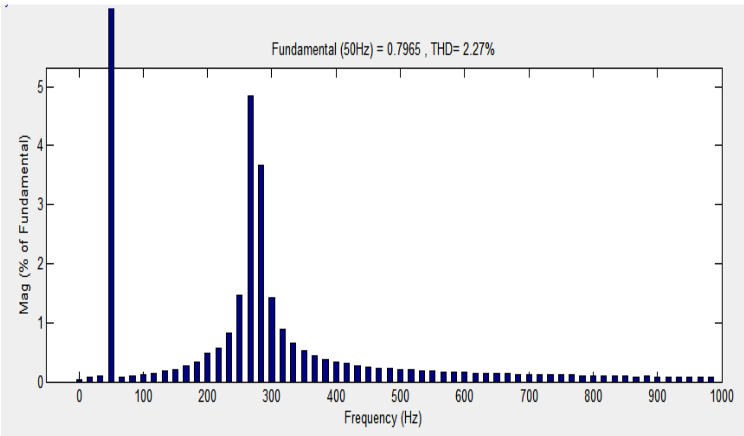

Fig. 12. THD with IUPQC in Source side

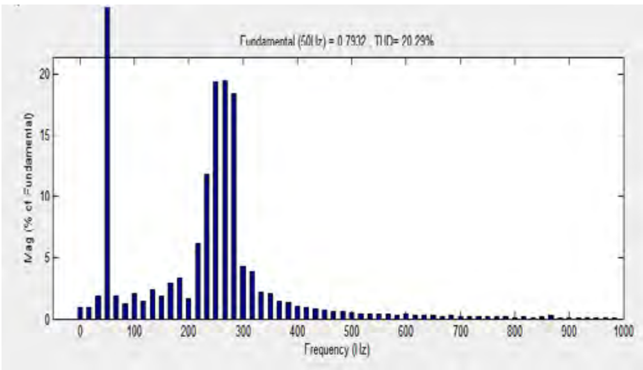

Fig. 13. THD without IUPQC in load side

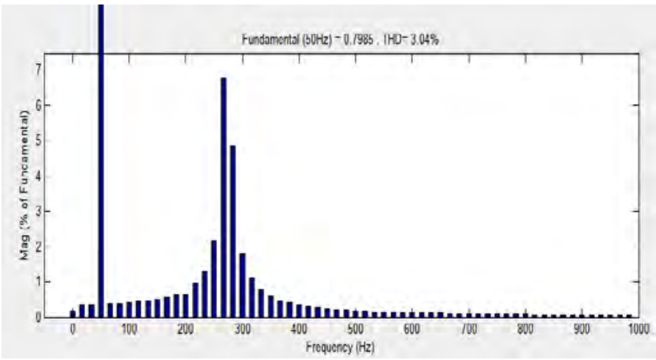

Fig. 14. THD with IUPQC in load side

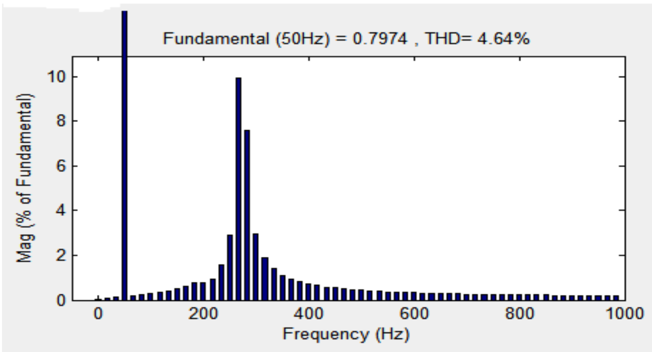

Fig. 15. THD with conventional IUPQC in load side

VII. Conclusion

This paper presents a reduced rating star connected hybrid IUPQC in distribution systems for simultaneous compensation of load current harmonics, voltage sag/swell and source neutral current. The star connected transformer has an advantage of using minimum volt-ampere rating and consequently, the cores are economical to build and occupy low space. The performance of proposed IUPQC has been investigated through extensive simulation studies. From these studies it is observed that the proposed scheme completely compensated the source current harmonics, load current harmonics, voltage sag/swell and neutral current.

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