A New Control Strategy with Fuzzy Logic Technique in Distribution System for Power Quality Issues

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Abstract- A new control structure for two feeders, three phase four wire distribution systems (3P4W) operating with multi-converter unified power quality conditioner (MC-UPQC) is proposed in this paper. The modified synchronous reference frame theory (MSRF) is mainly used in the new controller design. The proposed system is designed and applied for two feeders of 3P4W with UPQC. This system associated with three voltage source converter which is connected commonly to two feeder distribution systems. Under linear and nonlinear load conditions, the proposed control scheme is simulated with 3P4W and it is efficiently compensate the voltage sag and reduce the total harmonics distortion. The fast dynamics response of dc link capacitor is achieved with the help of FLC controller (Fuzzy logic controller). The neutral current flowing in series transformers of the two feeders is zero with the implementation of proposed system.

Keywords—Power Quality, MSRF, MC-UPQC, VSC, FLC.

1. Introduction

In relatively power electronics devices are connected to the power distribution system, in increasing the reliability and the quality of power supplied to the consumers. The family of Custom Power Devices (CPD) are DSTATCOM, DVR and UPQC. CPD can provide an integrated solution for the problems faced by the utilities and power distributors. This leads to the performance functions of load compensations and voltage control at the same time. Due to the development in recent years so many PQ problems are discussed with the help of power electronics converters.

The three phase four wire (3P4W) distribution system utilizing UPQC to balance the unbalanced load currents, neutral current compensation using PI control technique is reported in [1]. When the system is effecting unbalance of power quality issues, in order to overcome to design of UPQC with new control technique for the improvement of power quality using FLC alone, along with PI controller and its comparison is reported in [2]. When the system is connected to 3P4W, the improvement of power quality issues like a voltage, current unbalance, distortions, reactive power demanded by the load using UPQC is reported in [5] -[10].

The proposed MC-UPQC system is consisting of 3 VSC's associated to system for instantaneous mitigation of voltage and current imperfection [11] - [14]. The 3P4W DS of single feeder line it can be provided the neutral conductor along with the three power lines from the generation station [8] - [10] to improve the unbalanced voltage and current by using PI controller. A new control strategy of 3P4W UPQC for power quality improvement is reported in [15] - [18].

The different controller schemes discussed in the above literature are used to compensate the power quality problems. Even though they are many control techniques are available to control the one feeder, to compensation of voltage/current unbalance neither less these reported controller not compensated load and shunt neutral currents. In feeder one the voltage and current total harmonics distortion is very high. The transformer neutral current have some distortions which means it is not equal to zero during all operating conditions were not discussed and the dynamic response of the dc link capacitor voltage is very slow based on PI control technique [1]. To achieve this, 4 leg VSC in shunt VSC part is used in proposed system to compensate the neutral current. This paper proposes, the MSRF theory based controller for two feeder 3P4W system fed UPQC. In this system, series transformer's neutral wire is connected to load as a fourth wire of 3P4W systems. Different types of faults will also be considered for the analysis. The system consists of 2 series converters and one shunt back to back converter with common DC-link capacitor in order to maintain the voltage [24]. This new control scheme has been modelled with FLC for above mentioned power quality problems of two feeder 3P4W for fast dynamic response of dc link capacitor voltage.

This paper is carried out with the analysis of power quality issues in 3P3W and 3P4W system in section1, the chapter 2 discuss the Proposed System Description, chapter 3 discuss the control strategy for the MC-UPQC, chapter 4 discuss the Fuzzy logic controller discussion, chapter 5 discuss the simulation results and discussion and finally conclude the paper.

2. Proposed System Description

The MC-UPQC is allied to the distribution side to make the system without any distortions. This system is connected with two feeders along with linear/non-linear load. The single line diagram of MC-UPQC for the proposed control scheme of two feeder 3P4W systems is shown in Fig. 1.

The schematic of the proposed two feeder 3P4W distribution system is connected to MC-UPQC as shown in Fig. 2.

The schematic circuit consists of two series converter having three-legged Voltage Source Converter (VSC), one shunt converter with four-legged VSC. The two feeders are connected the two different substations that are supplying the linear/non-linear loads. While considering to controlling the voltage sources in which three linear transformers connected in series along with two series inverter.

If any neutral current is found to be present it flow through the fourth wire of the system. The four-leg Voltage Source Inverter (VSI) based shunt active filter topology [3],[4],[10] is used to compensate the harmonics in source currents and other current related issues. This result in the current at transformer neutral point will be zero. The proposed scheme can also be used to compensate the power quality problems related to different types of faults that occurs in the two feeders.

In feeder one, the source side voltages, load voltage, injected and DC link voltage is denoted by V_{s1}, V_{l1}, $V_{inj\text{-}se1}$ and V_{dc} are respectively. The current on the source side, load side, shunt current, neutral current on load side, shunt neutral current and transformer neutral currents are represented by I_{s1}, I_{l1}, I_{sh1}, I_{ln}, $I_{sh\text{-}n}$ and $I_{sr\text{-}n}$ respectively. Similarly in feeder two, the source voltage, injected voltage, load voltage, source current, load current and transformer neutral current are represented by V_{s2}, V_{inj2}, V_{l2}, I_{s2}, I_{l2} and $I_{sr\text{-}n2}$ respectively.

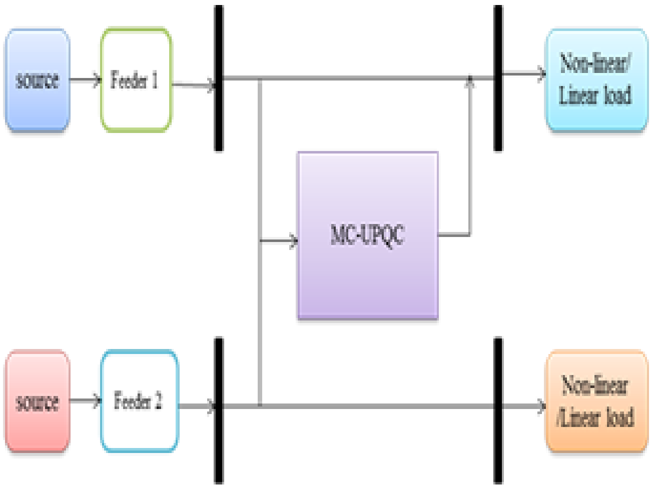


Fig.1. Single line diagram of MC-UPQC

When the system is affected with non-linear load such as power electronics devices the voltage variation, current variation and harmonics are present in distribution system. In order to eliminate the power quality issues and also for fast dynamic response of the system a suitable controller is used and it is discussed in next chapter.

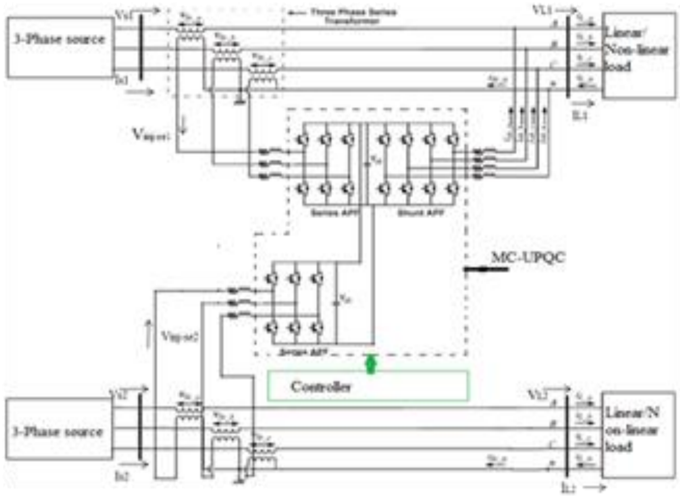


Fig.2. The schematic of the proposed two feeder 3P4W distribution system is connected to MC-UPQC

3. Control Strategy for the MC-UPQC

The shunt and series APF of the MC-UPQC is designed with proposed controller. The function of series APF is to eliminate harmonics and for compensating reactive power, supply voltage in both feeders. Whereas the shunt APF functions to eliminate the supply current harmonics, distortions and also to compensate unbalance, negative sequence current, reactive power, neutral current, thereby maintaining the transformer neutral current as zero during entire operating conditions.

3.1. The Control Strategy for the Series APF's

When the supply voltage is distorted from its original value in feeder one, the PLL is used to accomplish synchronization to bring back to its original supply voltage. The control algorithm for series APF's of two feeders is shown in Fig. 3.

The instantaneous p – q theory is expanded from the concept of single phase p-q theory [5], [6], [10], [19] and the corresponding voltage equations are mentioned below in eq. (1), (2) & (3). The voltages found at the point of common coupling were added to the eq. (1), (2) & (3) and it is given to the relay. The relay output after getting compared with the reference voltages are given to convert block to generate a gate signal for the series inverter. According to the expanded theory, the phase angle of each phase voltage and currents it can be extracted as a three independent 2-ϕ system is charitable by Π/2 lead or lag, this can be applied for three phase balanced system as well as an unbalanced system also. The proposed series APF block diagram as shown in Fig. 3 (a).

$$V_a = V_m \sin(wt) \tag{1}$$

$$V_b = V_m \sin(wt-120^o) \tag{2}$$

$$V_c = V_m \sin(wt+120^o) \tag{3}$$

The series controller connected in feeder two is used to mitigate voltage sag and reduce the THD. The control algorithm for the series VSC block diagram is shown in Fig. 3(b).

The Modified Synchronous reference frame (MSRF) theory is used for the series VSC is designed with improved PWM generator in the proposed scheme. The series VSC is based on the unit vector template by expanding from the concept of MSRF theory. According to this theory, this can also be applicable for both three phase balanced and unbalanced system. The three phase load voltages are transformed into load synchronous reference voltages using eq. (4).

$$\begin{bmatrix} v_{l-d} \\ v_{l-q} \\ v_{l-0} \end{bmatrix} = \begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} \begin{bmatrix} v_{l-a} \\ v_{l-b} \\ v_{l-c} \end{bmatrix} \tag{4}$$

Where,

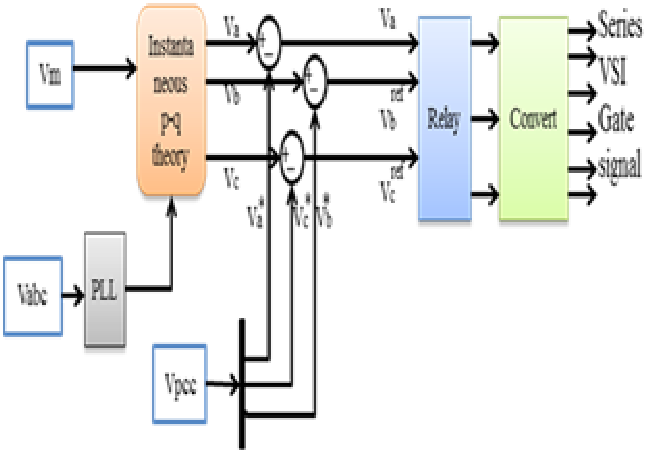
$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin wt & \sin\left(wt - \frac{2\pi}{3}\right) & \sin\left(wt + \frac{2\pi}{3}\right) \\ \cos wt & \cos\left(wt - \frac{2\pi}{3}\right) & \cos\left(wt + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{5}$$

The expected load Synchronous reference dq0 voltages are subtracted with the $V_{l\text{-}dq0}$ in eq. (6) obtained from eq. (4). Again the compensation reference feeder dq0 voltages are transformed back to the synchronous reference feeder voltages using eq. (7).

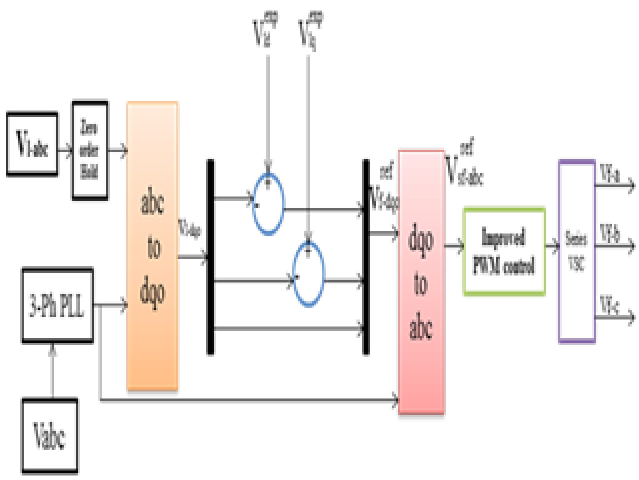
$$\begin{bmatrix} v_{f-d}^{ref} \\ v_{f-q}^{ref} \\ v_{f-0}^{ref} \end{bmatrix} = \begin{bmatrix} v_{l-d} \\ v_{l-q} \\ v_{l-0} \end{bmatrix} - \begin{bmatrix} v_{l-d}^{exp} \\ v_{l-q}^{exp} \\ v_{l-0}^{exp} \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} v_{sf-a}^{ref} \\ v_{sf-b}^{ref} \\ v_{sf-c}^{ref} \end{bmatrix} = \begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix}^{-1} \begin{bmatrix} v_{f-d}^{ref} \\ v_{f-q}^{ref} \\ v_{f-0}^{ref} \end{bmatrix} \tag{7}$$

The compensated synchronous reference abc voltages were forwarded to improve the operation of PWM generator. The output of the PWM generator is directly given to control part of series VSC as shown in Fig. 3 (b). However, even the source voltage is distorting the series control objective have to be maintained. Due to the series transformer across the injected voltage which cancel out the harmonics present in the supply and load voltage with the help of ripple filter, thereby making them free-from distortion.



(a)



(b)

Fig.3. Control algorithm for series APF for (a) feeder one (b) feeder two

3.2. The Control Scheme of the Shunt APF's

It consists of the generation of three phase reference supply currents; due to the non-linear load on the 3P4W system connected to the source side by which currents are unbalanced. The proposed control system is compensating these unbalanced source currents on the source side by expanding the concept of modified p-q theory [1]. The control algorithms for the shunt APF block diagram are shown in Fig. 4.

On load side the three phase load currents are different due to fundamental load active and reactive power. To overcome this unequal load power demand from the source side, the fundamental three phase active powers can be perfectly balanced; by the following method the unequal load power should be correctly redistributed between source, MC-UPQC and load such that the three phase load from the source would be linear and equal loads.

In order to overcome from this error between desired capacitor voltage and measured values, at FLC is installed. The three phase load instantaneous p-q theory voltage and current can be added to get the active power estimation. The 3-φ source currents were compared to the reference currents through which generates the appropriate shunt gate signals to be given for shunt VSI.

$$P_{labc} = V_{labc\alpha\text{-}\beta} + I_{labc\alpha\text{-}\beta} \tag{8}$$

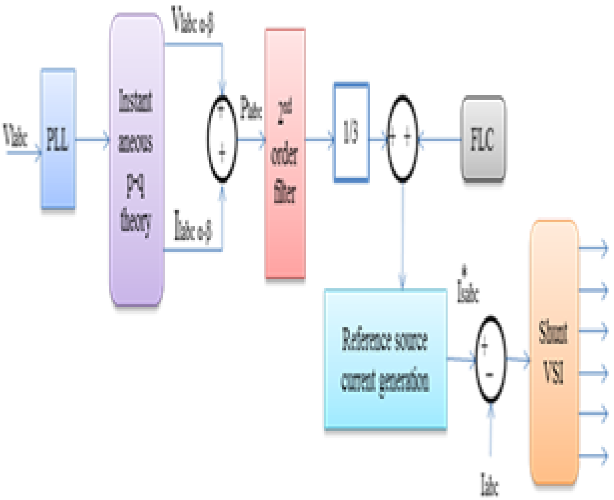


Fig.4. Control algorithms for the shunt APF block diagram.

4. Fuzzy Logic Controller

The system dc link voltage response is very slow due to PI controller. In order to achieve fast dynamic response of dc link voltage, the FLC has been proposed in shunt controller part of the system. Because, the PI controller based scheme has produces a very slow dynamic response for the same system. Fuzzy memberships that are designed based on the eq. (9).

$B^{(p)}$ = *IF* R_1 *is* S_1 *AND* R_2 *is* S_2 ....R_n *is* S_n *THEN S is* $C^{(p)}$ (9)

Where,

R_1, R_2.........R_n is the input variables vector
S is the output or control variable
n is the no. of fuzzy variables (N=5)
F_1, F_2.......F_n is the fuzzy sets
P =1, 2, 3....N
N is the number of rules (N=5).

To design an FLC, the error dc capacitor voltage (V_{dc}) and change in reference dc capacitor voltage error (ΔV_{dc}) are considered.

$$v_{e\,fuzzy} = v_{dc} - v_{dc}^{ref} \tag{10}$$

The proposed construction of a FLC as given in Fig. 5. Actual crisp input values and its approximates are nearly closer to respective universes of its course. If the fuzzified inputs are designated by singleton fuzzy sets [20]-[23]. The Fuzzy control rules are designed for a fuzzy set of the control input in each combination of fuzzy sets for V_{dc} and ΔV_{dc}. The per phase fundamental active power estimation is added with eq. (10) and it is forwarded to reference source current generation. The p-q theory based currents are given to relay which is sensed to control the signals of shunt VSC circuit as shown in Fig. 5.

In this paper, instead of using conventional (PI) controller mentioned in references a FLC is being used for its transient

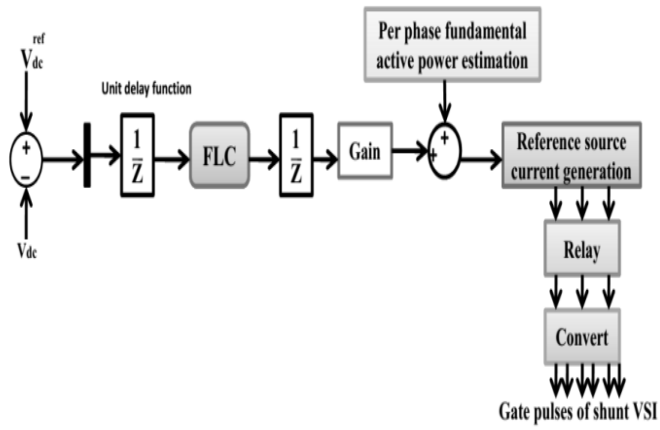


Fig.5. Proposed structure with FLC.

response to make MC-UPQC very fast in reducing the total harmonic distortions on source and load side voltages as well as currents on both the feeders. Here five labels of fuzzy subsets; negative large (NL), negative medium (NM), zero (ZR), positive medium (PM), positive large (PL). The control rule base table 1. In which the row and column represents the error and its changes respectively.

Table 1. Rule Based For Voltage Control

ΔV_{dc} → / V_{dc} ↓		INPUT 2				
		NL	NM	ZR	PM	PL
INPUT 1	NL	NL	NL	NM	NM	ZR
	NM	NL	NM	NM	ZR	PM
	ZR	NM	NM	ZR	PM	PM
	PM	NM	ZR	PM	PM	PL
	PL	ZR	PM	PM	PL	PL

5. Simulation Results and Discussion

In order to justify the strategies of new control scheme discussed above, a MATLAB based simulation designed as the system described in Fig. 2, and then the results are compared with a conventional system. In conventional method, the author considered only one feeder and use p-q theory based PI controller. The transformer neutral current magnitude is not reached to zero [1]. In this paper, two feeders are considered for all the analysis. The proposed new control scheme gives the better simulation results in all aspects than the conventional system.

The three phase rectifier load is on at t = 0.1sec, fundamental frequency 60 Hz to realize voltage harmonics in source voltage. With the help of new control scheme mentioned in the MC-UPQC connected between two feeder systems is used to realize in terms of voltage/current balancing, harmonic mitigation, source voltage/current compensation, power factor correction for both linear and nonlinear loads as well as maintaining the transformer neutral current as zero during all operating conditions.

5.1. Performance Analysis of MC-UPQC Connected to Feeder One

The compensated source, load and injected currents are shown in Fig. 6. The THD seems to be reduced for compensated source current from 2.31% to 2.28%, whereas the shunt neutral current from 90.94% to 90.90% and load current from 12.15% to 12.12% respectively. Due to unbalanced load condition the load neutral current (25A) that may follow towards the transformer neutral point. The load, injected shunt neutral current, dc-link capacitor voltage, transformer neutral current and harmonic spectra are shown in Fig. 8 (a)-(e) respectively. In this wave form we can see that transformer neutral current is without any distortions, with reduced THD from 0.24% to 0.21% and the dc-link capacitor voltage is maintained constant without any distortions. The Simulation results of compensated source currents, load currents and injected currents is shown in Fig.7

At time t=0.2 sec, series APF is turned on and the voltage profile are shown in Fig. 8. The THD value has reduced for source voltage from 27.08% to 27.05%, load voltage from 1.51% to 1.48% and injected voltage from 154.56% to 154.47%.

5.2. Performance Analysis of MC-UPQC Connected to Feeder Two

The performance of MC-UPQC under new control scheme connected to feeder 2 is done to improve the source voltage and load current. MSRF based control techniques incorporated in this new control scheme. The simulation results are shown in Fig. 9-10. Series APF is turned on at t = 0.25 sec, and it gets starts compensating for the source voltages harmonics immediately by injecting out the phase harmonic voltages thus by making the source and load voltage free from distortions. The source voltage, source current, injected voltage and load voltage simulations are shown in Fig. 9.

In feeder 1, it is observed that source voltages are having distortions from 0.1 to 0.2 sec along with injected voltage also. The source voltage in feeder 1 is distorted with THD value of 27.08%, to compensate this distorted voltage in feeder 1 it is extended to feeder 2 with a new control scheme incorporated in the MC-UPQC using MSRF based FLC which results in reduced THD value of 0.19%. The feeder 2 load current and transformer load neutral simulations, harmonic spectra are shown in Fig. 10.

The comparison between conventional and new control scheme with reduced THD values are mentioned in table 2. From the results it is observed that the proposed new control scheme gives better results even under the system is subjected to different types of faults like Line-Ground, Line-Line, Line-Line-Ground, Line-Line-Line and without faults. The system with and without controller, the load neutral and shunt neutral having 25A is verified. Not only these currents were compensated but also load neutral current flowing in the fourth wire of transformer neutral point is also maintained zero during all the operating conditions.

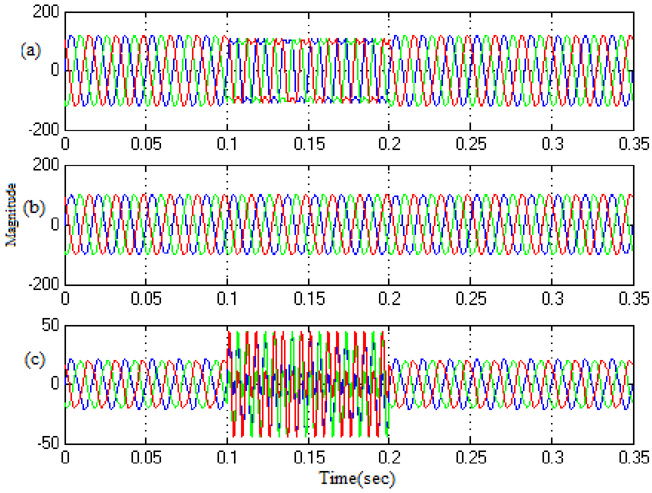


Fig.6. Simulation results of (a) source, (b) load and (c) injected voltage in feeder 1

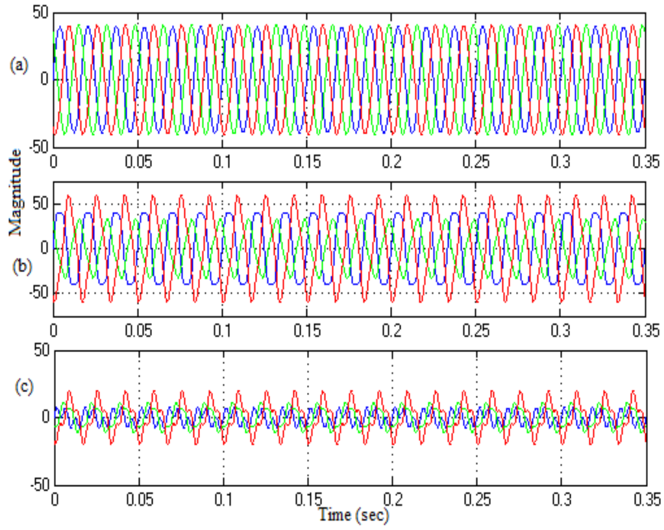


Fig.7. Simulation results of (a) compensated source currents (b) load currents and (c) injected currents

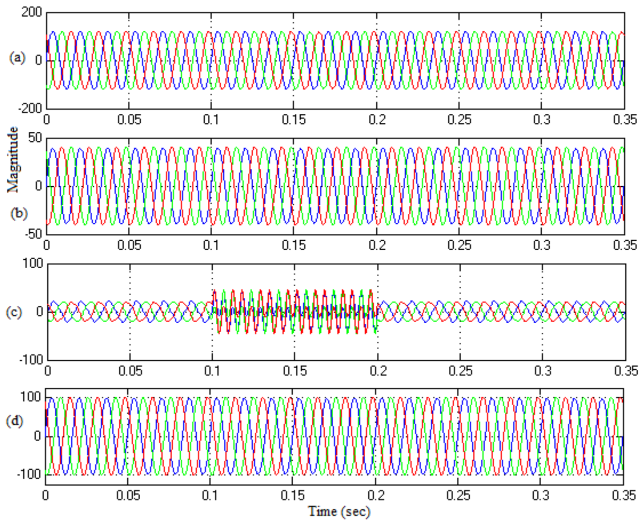


Fig.9. Results of Feeder 2 (a) source voltages, (b) source current, (c) injected voltage and (d) load Voltage

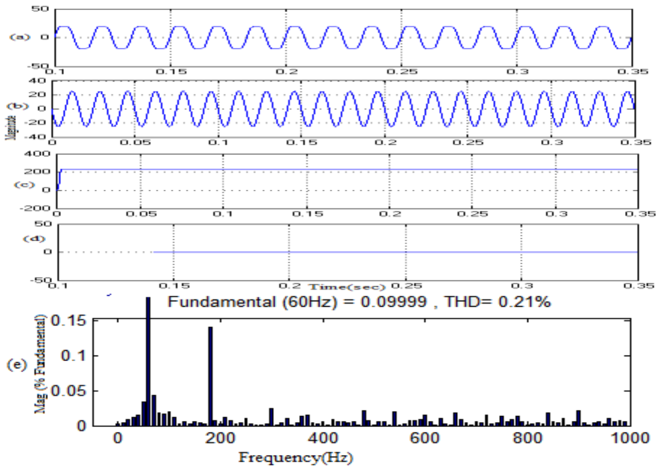


Fig.8. Simulation results of (a) load neutral current (b) injected shunt neutral current (c) dc-link capacitor voltage (d) transformer neutral current and (e) THD of transformer neutral current

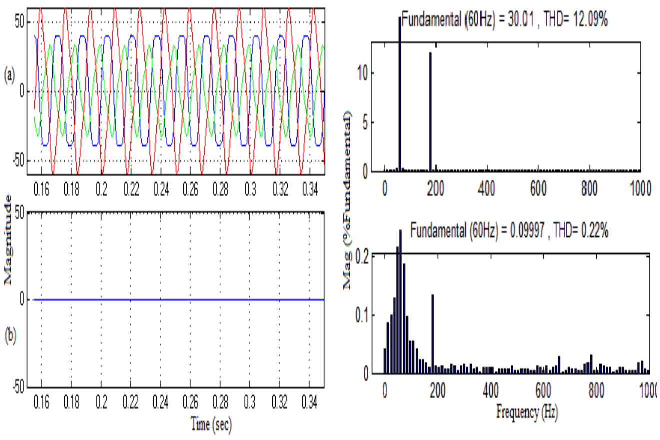


Fig.10. Simulation results and THD Value of (a) feeder 2 load current, (b) transformer load neutral current

Table 2. % THD values comparison between existing system and novel control strategy.

Voltage/ Current	Existing System[1]	Novel Control Strategy
Feeder 1	**Considered**	**Considered**
Source Voltage	27.08	**27.05**
Load Voltage	1.51	**1.48**
Injected Voltage	154.56	**154.47**
Source Current	2.31	**2.28**
Load Current	12.15	**12.12**
Shunt Current	90.94	**90.90**
Neutral Current	0.24	**0.21**
Feeder 2	Not Considered	**Considered**
Source Voltage	Not Considered	**0.19**
Load Voltage	Not Considered	1.48
Injected Voltage	Not Considered	154.47
Source Current	Not Considered	2.28
Load Current	Not Considered	**12.09**
Neutral Current	Not Considered	0.21

6. Conclusion

The proposed control structure for two feeders 3P4W operating with MC-UPQC effectively simulated and the results are verified. The proposed control scheme is simulated with 3P4W under various operating conditions and compared with conventional controller. This scheme is efficiently compensate the voltage sag, swell, reduce the total harmonics distortion and also effectively improved the dynamic response of dc link voltage. The MSRF theory has been used in four leg shunt VSC part of the proposed control scheme and it is help to reduce the transformer neutral current to zero. The effect of series converter is to eliminate the distortions on the supply side voltages due to unbalanced load conditions; the effect of shunt converter is not only to compensate the neutral current it also to make the current balanced on the source side, when they act individually.

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