

Power Quality Mitigation Using Multi Converter Unified Power Quality Conditioner For the Application of Multi Feeder Systems

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Abstract : The new unified power-quality conditioning system (MC-UPQC), capable of simultaneous compensation of voltage and current in multifeeder/multibus systems. In this configuration, one shunt voltage-source converter (shunt VSC) and two or more series voltage-source converter (series VSCs) exist. This system can be applied to adjacent feeders to compensate the supply-voltage and load current imperfections on the main feeder and full compensation of supply voltage imperfections on the other feeder. The converters are connected back to back on the dc side and share a common dc-link capacitor which is proposed in this configuration. Hence, power can be transferred from one feeder to adjacent feeders for the compensation of sag/swell and interruptions. The present work study the compensation principle and different control strategies are used here based on PI Controller of the MC-UPQC in detail. The results are obtained in MATLAB/SIMULINK on a two-bus/two-feeder system show the efficiency of the proposed configuration.

Keywords : Power Quality (PQ), Unified Power Quality Conditioner (UPQC), Voltage Source Converter (VSC).

1. INTRODUCTION

The Power Quality (PQ) problems such as voltage harmonics, voltage flickers and imbalance in distribution systems are caused due to the rapid increase of nonlinear loads has become the serious concern. In addition, lightning strikes on transmission lines the switching of capacitor banks and various network faults will also cause PQ problems such as, voltage sag/swell, transients and interruptions in transmission lines [1]. On the other hand, an increase of sensitive loads involving digital electronics and complex process controllers requires a pure sinusoidal supply voltage for proper load operation. It is necessary to meet the PQ standard limits which include some sort of compensation. The rapid switching of electronic devices creates additional problem, this makes voltages and currents at the point of common coupling (PCC) highly distorted. [2] For various distribution voltage levels irrespective of voltage fluctuations, blocking of voltage and current unbalance from passing upwards from various distribution levels, maintaining near unity power factor power drawn from the supply, reduction of voltage harmonics and current harmonics in the system and suppression of unnecessary supply neutral current The power semiconductor devices, in general known as active power filters (APF's), are the equipment used to prevent the power quality issues due to their dynamic and adjustable solutions in recent days [3]. For the suppression of negative load influence a shunt active power filter is used on the supply network, but if there is a supply voltage imperfection, a series active power filter is required to provide full compensation.

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The Custom Power Devices [4] and Flexible AC Transmission Systems (FACTS) devices like Distributed Static Compensator (DSTATCOM) is a static compensator that is used for the correction of line currents, regulate system voltage and reduce voltage harmonics, Dynamic Voltage Restorer (DVR) mitigates voltage sags by injecting a compensating voltage into the power system in synchronous real time. The DVR is a high-speed switching power electronic converter that consists of an energy storage system that feeds three independent single-phase pulse width modulated (PWM) inverters and Unified Power Quality Conditioner (UPQC) [5] etc., deals with the issues related to power quality using same control strategies and concepts. In recent years, solutions based on flexible ac transmission systems (FACTS) have appeared. In distribution systems the application of FACTS concepts has resulted in a new generation of compensating devices A UPQC is the extension of UPFC [6] concept at the distribution level is the best solution to make the overall power distribution system more healthy. It is a versatile device consists of combined series and shunt converters for simultaneous compensation of voltage and current imperfections in a supply feeder [7]. Recently more researches are going on reduction of sags and swells by using UPQC. The swells are not as common as sags, but the effects of a swell can be very effective than the voltage reduction. The common cause of voltage sag and swell is sudden change of line current flowing through the impedance of the source. The main objective is to maintain the load bus voltage to be sinusoidal and the major concern is the active power and reactive power during the fault conditions.

This proposed topology enables UPQC to have a compact dc-link voltage without compromising its compensation capability. Active power filters (APF) have been proposed an efficient tool for power quality improvement. Active power filters can be categorized as shunt and series based on their system configuration. The voltage based distortions are generally taken care by the series APF, while shunt APF mitigates current based distortions. Recently more researches are going on reduction of sags and swells by using UPQC. The voltage swells are not as common as sags, but the effect of a swell can be very effective than the voltage reduction. The sudden change of line current flowing through the impedance of the source is the common cause of voltage sag and swell. The main objective is to maintain the load bus voltage to be sinusoidal and the major concern is to maintain the active power and reactive power during the fault conditions. UPQC is commonly connected with back to back to voltage source converters through a DC link capacitor.

The new configuration of UPQC is known as the Multi Converter Unified Power-Quality Conditioner (MC-UPQC) is presented in this paper. This system is extended by adding a series-VSC in an adjacent feeder. The proposed topology is capable of compensating the voltage and current imperfections in both feeders by sharing power compensation between two adjacent feeders which are not connected. The system is also capable of compensating interruptions without the need of a battery storage system and consequently without storage capacity limitations.

2. PROPOSED SYSTEM

MC-UPQC STRUCTURE

The internal structure of MC-UPQC is shown in Fig. 1 consists of three Voltage Source Converters (VSC1, VSC2, and VSC3) which are connected back to back through a common dc-link. In this configuration, VSC1 is connected in series with BUS1 and VSC2 is connected in shunt with load L1 at the Feeder1 end. VSC3 is connected in series with BUS2 at the end of Feeder2. In Fig. 1 as shown all the converters are supplied from a common dc-link capacitor and connected to the distribution system through a transformer. Secondary (distribution) sides of the series-connected transformers are directly connected in series with BUS1 and BUS2, and the secondary (distribution) side of the shunt-connected transformer is connected in parallel with load L1. Each of the voltage source converters (VSC) cause to happen by a three-phase converter with a commutation reactor (L_f) and high-pass output filter (R_f, C_f). In order to prevent the flow of switching harmonics into the power supply, the high pass output filter (R_f, C_f) and commutation reactor (L_f) are connected.

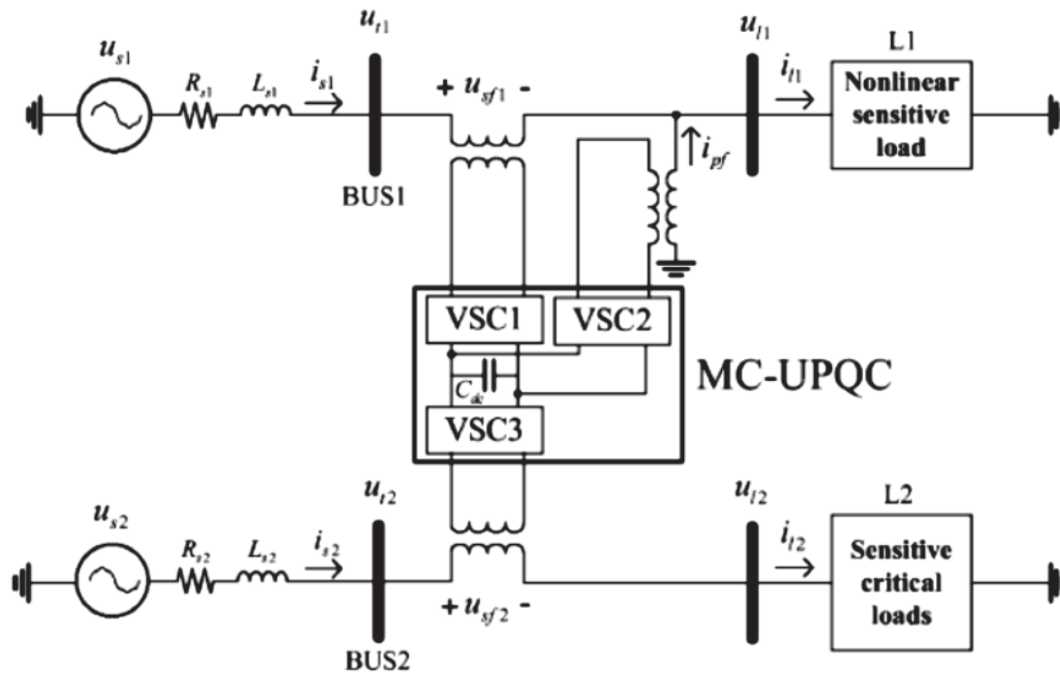


Fig. 1. Schematic Diagram of MC-UPQC used in a distribution system.

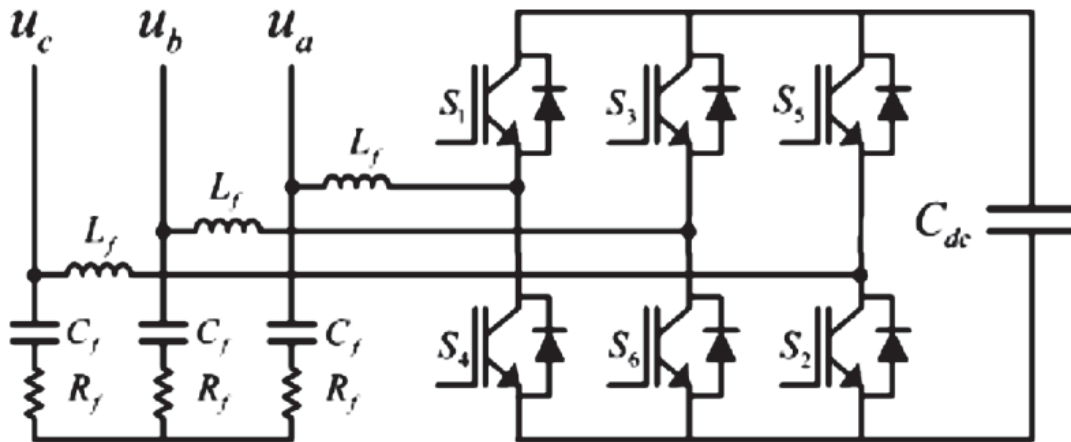


Fig. 2. Equivalent Circuit of VSC.

3. CONTROL STRATEGY

MC-UPQC consists of shunt and series voltage source converter (VSC) which are controlled independently as shown in Fig. 2 are chosen to be hysteresis current control and sinusoidal pulse-width modulation (SPWM) voltage control algorithm which is based on d-q method [4]. These two parts have different functions as follows:

Shunt –VSC is used to :

1. Compensate the reactive power of the load.
2. Compensate the load current harmonics.
3. Regulate the voltage of common dc-link capacitor.

A. Control of Shunt VSC

The control block diagram for the shunt VSC is shown in Fig.3. The measured load current is transformed into the synchronous reference frame by using dq0 reference frames the sine and cosine functions are sent from PLL (Phase Locked Loop) in accordance with (1)

$$i_{l,dq0} = \mathbf{T}_{abc}^{dq0} i_{l-abc} \quad (1)$$

Where the transformation matrix is,

$$\mathbf{T}_{abc}^{dq0} = \begin{bmatrix} \cos(\omega t) & \cos(\omega t - 120^\circ) & \cos(\omega t + 120^\circ) \\ -\sin(\omega t) & -\sin(\omega t - 120^\circ) & -\sin(\omega t - 120^\circ) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

The fundamental positive sequence components are transformed into dc quantities by this transform in d and q axes, which can be extracted by low-pass filter (LPF) easily. All harmonic components are transformed into ac quantities with a fundamental frequency shift.

$$i_{l,d} = \bar{i}_{l,d} + \tilde{i}_{l,d} \quad (2)$$

$$i_{l,q} = \bar{i}_{l,q} + \tilde{i}_{l,q} \quad (3)$$

Where, i_{ld}, i_{lq} are d - q components of load current, $\bar{i}_{ld}, \bar{i}_{lq}$ are dc - components, $\tilde{i}_{ld}, \tilde{i}_{lq}$ are ac –components of i_{ld}, i_{lq} .

If i_{pf} is the shunt VSC current and i_s feeder current and knowing $i_s = i_l - i_{pf}$, then d - q components of the shunt VSC reference current is defined as follows:

$$i_{pf-d}^{ref} = \tilde{i}_{l,d} \quad (4)$$

$$i_{pf-q}^{ref} = i_{l,q} \quad (5)$$

Accordingly, the d - q components of the feeder current are

$$i_{s,d} = \bar{i}_{l,d} \quad (6)$$

$$i_{s,q} = 0 \quad (7)$$

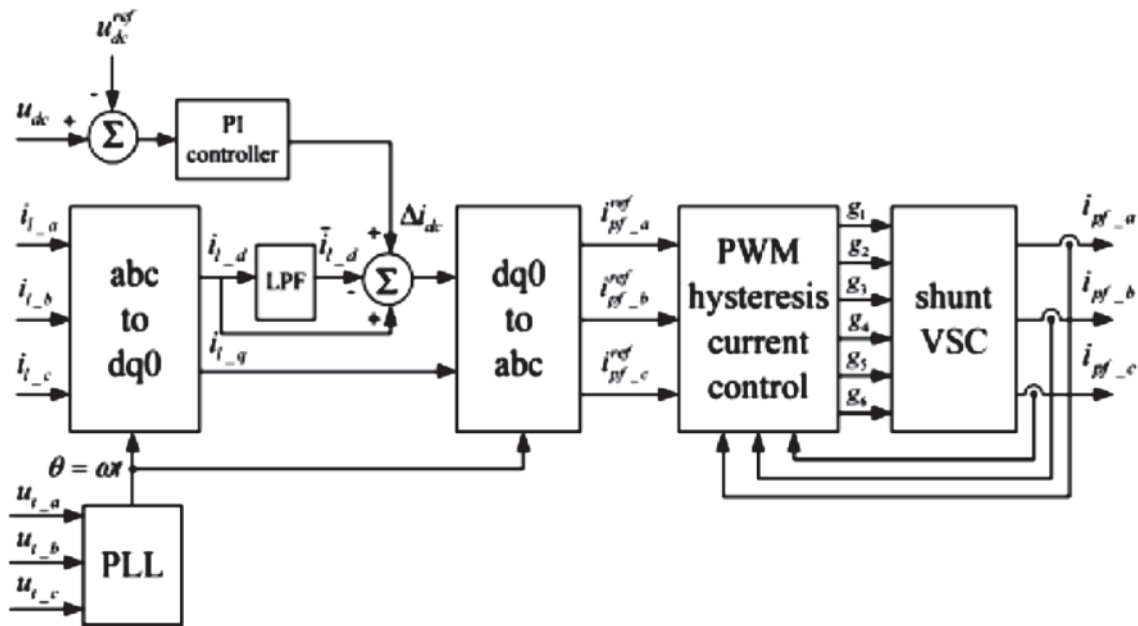


Fig. 3. Control block diagram of shunt VSC.

This means there are no reactive components and harmonics in the feeder current. The switching losses affect the dc-link capacitor voltage to decrease. Other disturbances, such as the sudden variation of load and unbalances can also have an effect on the dc link. A proportional–integral (PI) controller is

used to regulate the dc-link capacitor voltage, as shown in Fig. 5. The input of the PI controller is the error between the reference value (u_{dc}^{ref}) and its actual capacitor voltage (u_{dc}). The output (*i.e.*, Δi_{dc}) of the PI controller is added to the component of the shunt-VSC reference current component in d-axis to form a new reference current which is as follows

$$\begin{cases} i_{pf-d}^{ref} = \bar{i}_{id} + \Delta i_{dc} \\ i_{pf-q}^{ref} = i_{iq} \end{cases} \quad (8)$$

The reference current in (8) is then transformed back into the abc reference frame as shown in Fig. 3. By using PWM hysteresis current control, the output-compensating currents in each phase are obtained.

Series –VSC is used to :

1. Compensate voltage sags and swells.
2. Reduce voltage harmonics and compensate voltage harmonics.
3. Eliminate the system interruptions.

Control of series VSC

The series VSC eliminates the system side voltages which may contain negative-sequence as well as harmonic components. The control of series VSC is shown in Fig 4.

The system voltages are transformed into synchronous dq0 reference frames.

$$u_{t,dq0} = T_{abc}^{dq0} u_{t,abc} = u_{t1p} + u_{t1n} + u_{t10} + u_t$$

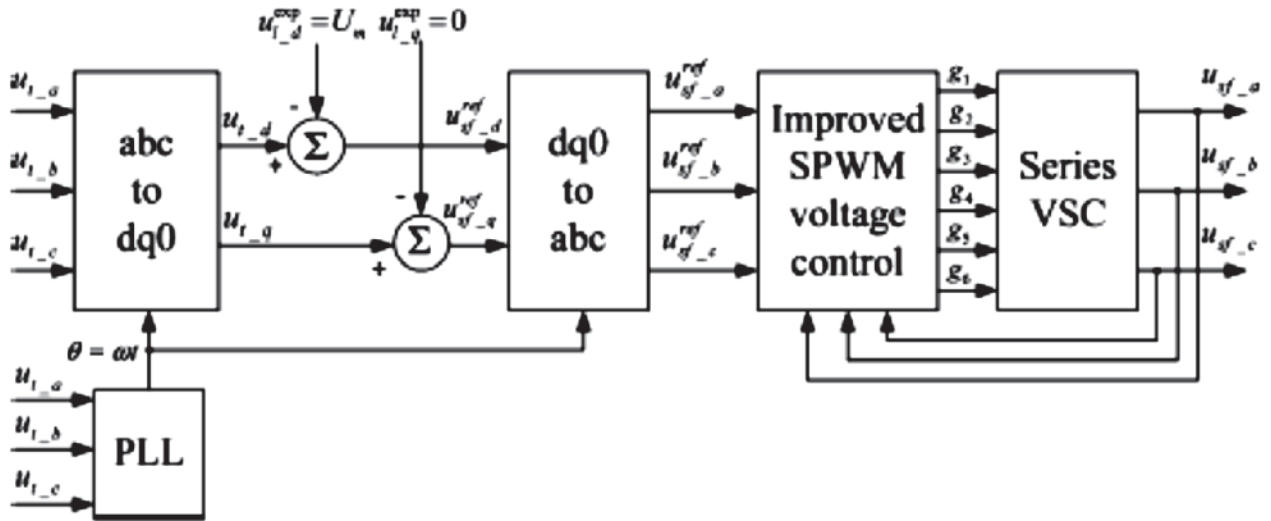


Fig. 4. Control block diagram of series VSC.

Where

$$\begin{aligned} u_{t1p} &= [u_{t1p-d} \quad u_{t1p-q} \quad 0]^T \\ u_{t1n} &= [u_{t1nd} \quad u_{t1q} \quad 0]^T \\ u_{t10} &= [0 \quad 0 \quad u_{00}]^T \\ u_{t1} &= [u_{t1-d} \quad u_{t1q} \quad u_{t1-0}]^T \end{aligned} \quad (9)$$

u_{t1p} , u_{t1n} , are u , the harmonic components and frequency positive, negative, zero-sequence components respectively, τ is the harmonic component of bus voltage.

According to control objectives of the MC-UPQC, it should be kept sinusoid for the load bus voltage with constant amplitude even if the voltage on system side is disturbed. Hence the estimated load bus voltage in d-q-o reference frame has only one value.

$$u_{l_dq0}^{exp} = T_{abc}^{dq0} u_{l_abc}^{exp} \quad (10)$$

Where

$$u_l^{exp} = \begin{cases} Um\cos\omega t \\ Um\cos(\omega t - 120) \\ Um\cos(\omega t + 120) \end{cases}$$

The compensating voltage in the dq0 reference frame is

$$u_{sf_dq0}^{ref} = u_{t_dq0} - u_{l_}^{exp}$$

This means $u_{t_p_d}$ in (9) should be maintained at (U_m) whereas all other unwanted components must be eliminated. By using an improved SPWM voltage control technique (sine PWM control with minor loop feedback) [8], the compensating reference voltage in (5) is then transformed back into the abc reference frame the output compensation voltage of the series VSC can be obtained.

4. SIMULATION RESULTS

In order to verify the effectiveness of control algorithm discussed utility network with realistic parameters and moderately complex load situation, a MATLAB/SIMULINK based digital simulation is carried out. The performance of MC-UPQC under such environment with different conditions such as current harmonics, voltage harmonics, voltage sags and voltage swell compensation are tested. The performance of the proposed MC-UPQC is presented as shown. In Fig 1 the power system consists of two three-phase, three-wire 380(v) (rms, L-L), 50Hz utilities.

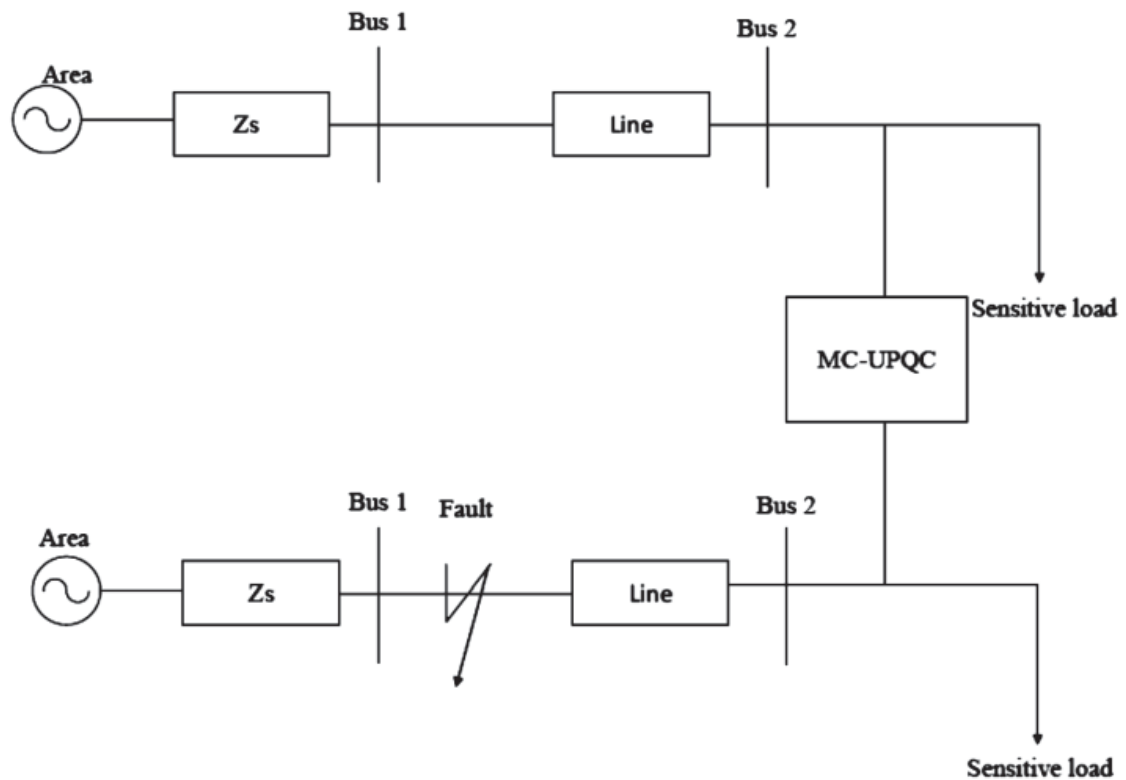


Fig. 5. Single-line diagram of mc-upqc.

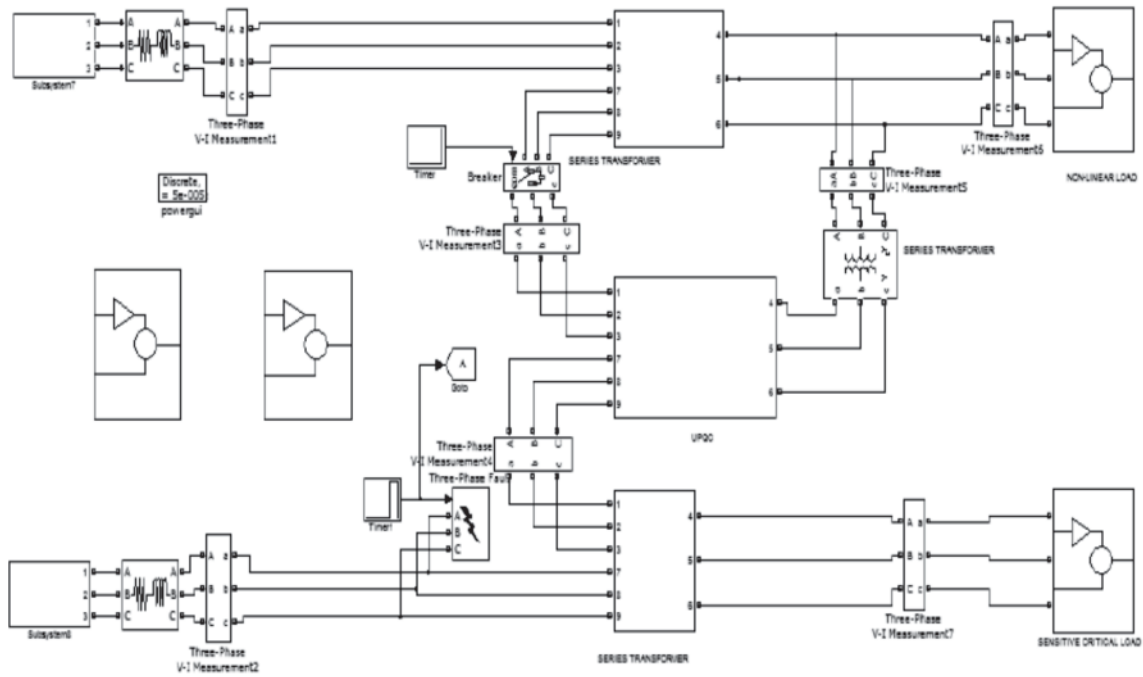


Fig. 6. Simulation model of mc-upqc.

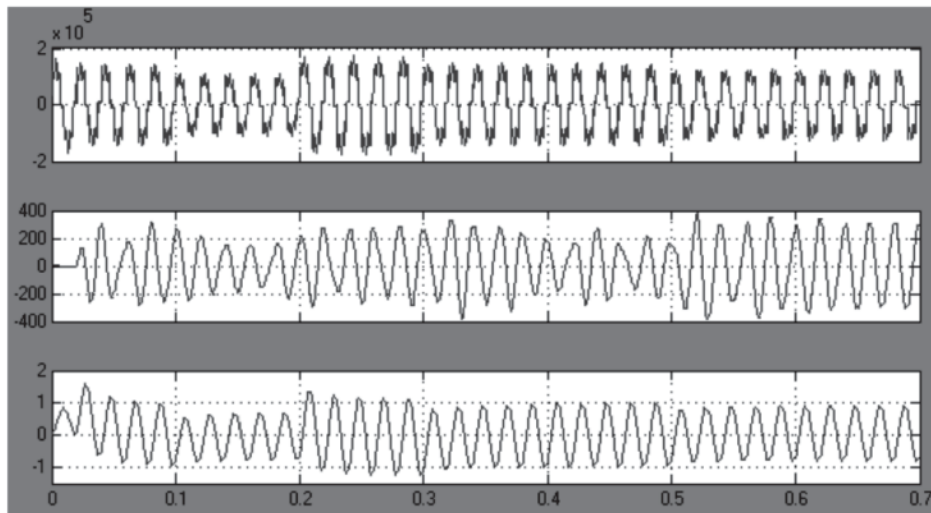
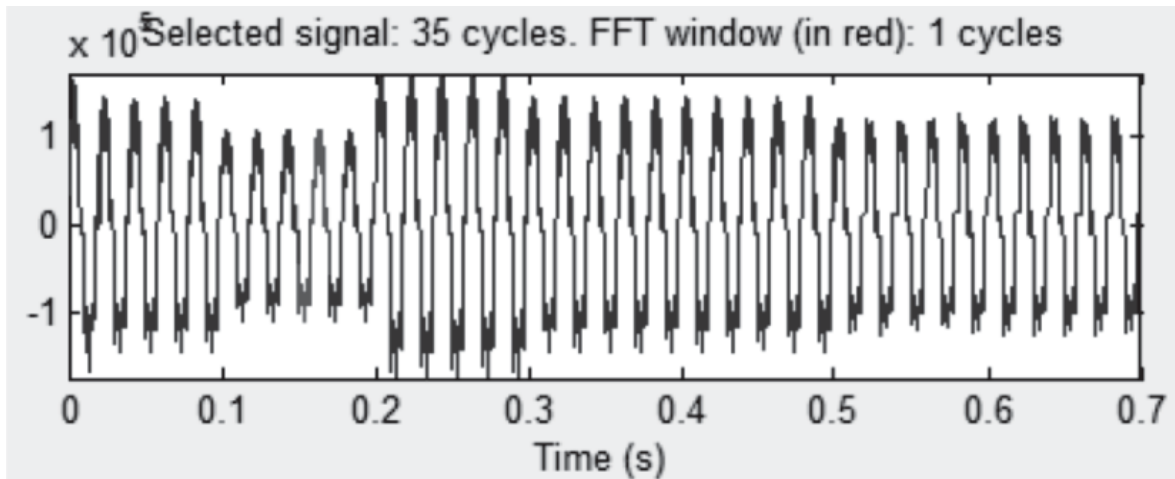
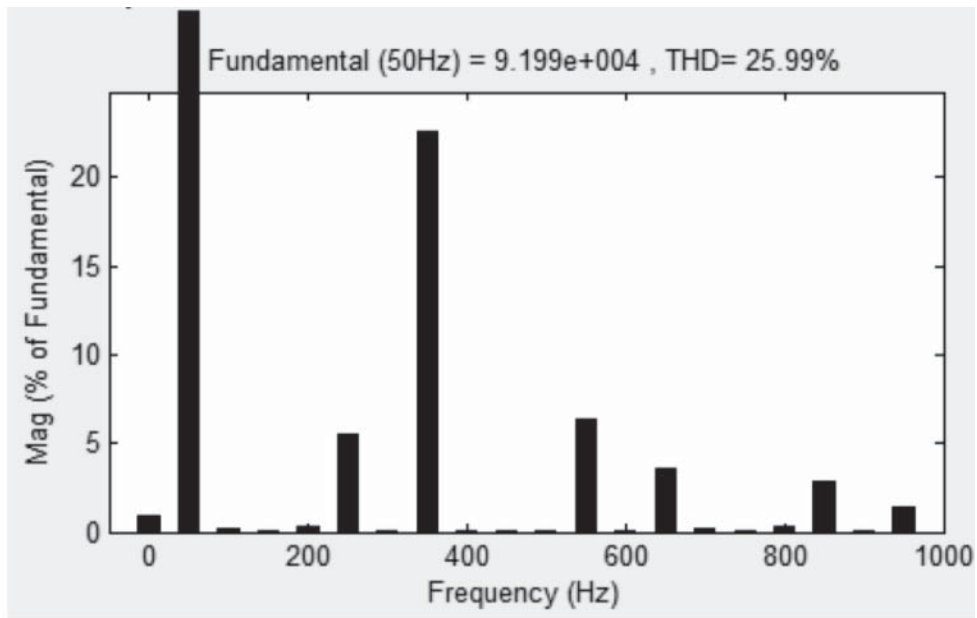
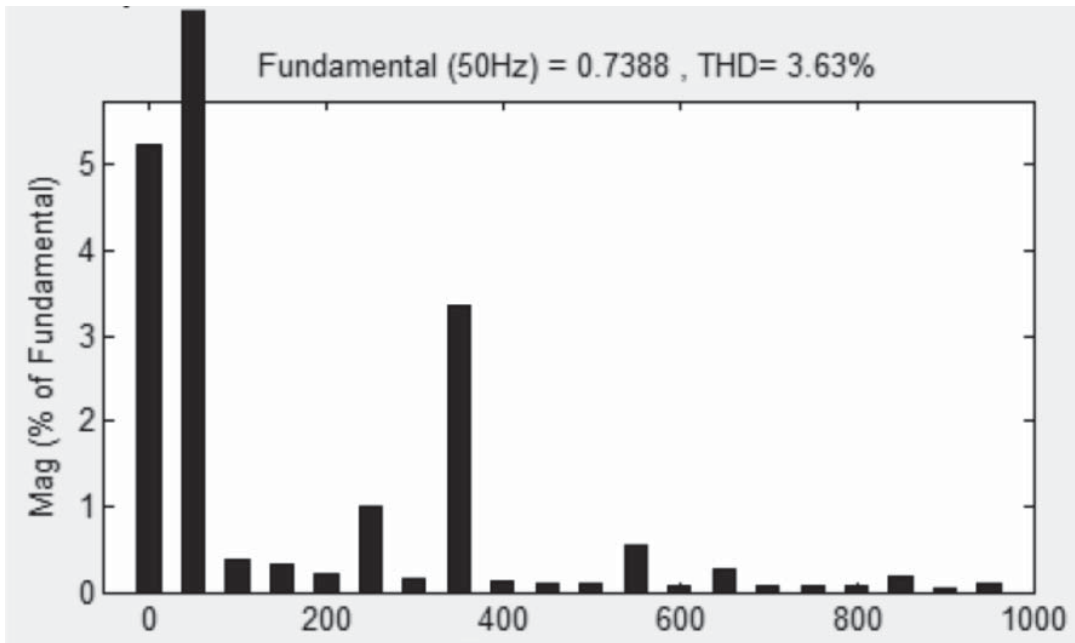
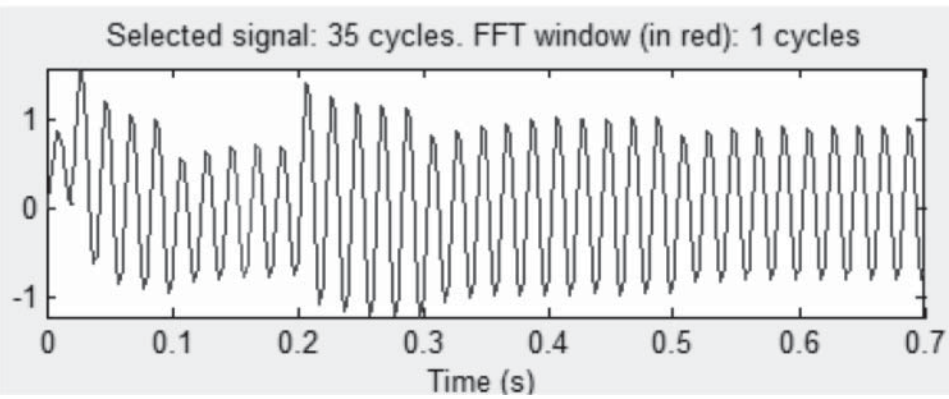


Fig. 7. Feeder 1 BUS 1 voltage, series compensating voltage, and load voltage.





FFT of BUS1 Voltage in Feeder1



FFT Analysis of Load BUS1 Voltage in Feeder 1, the THD has been reduced from 25.99% to 3.63%.

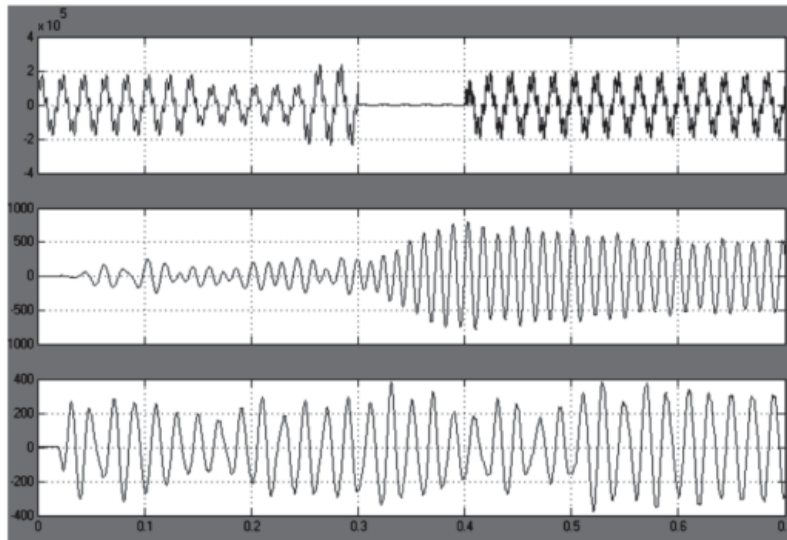
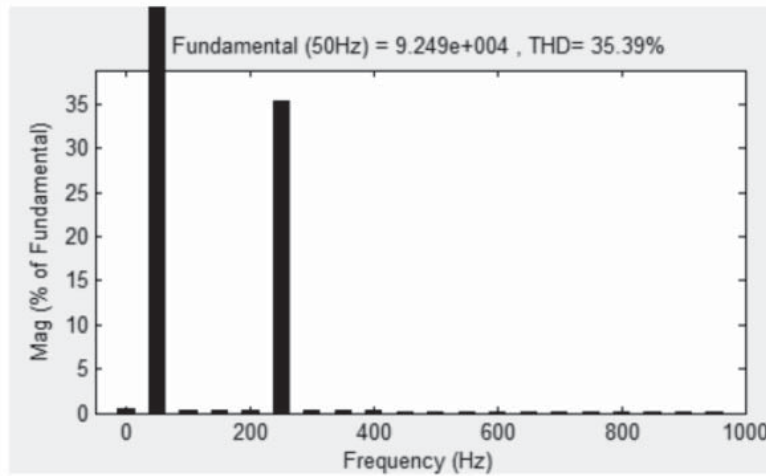
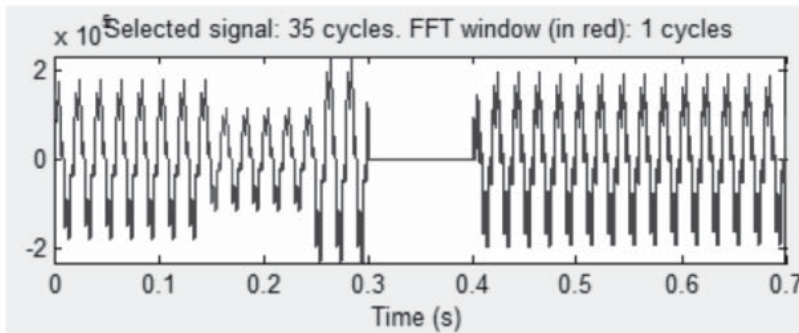
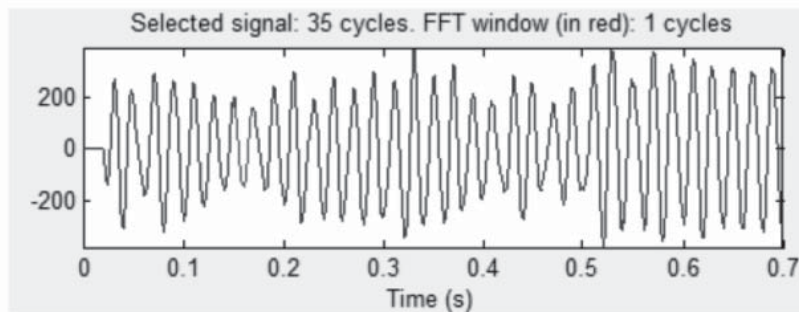
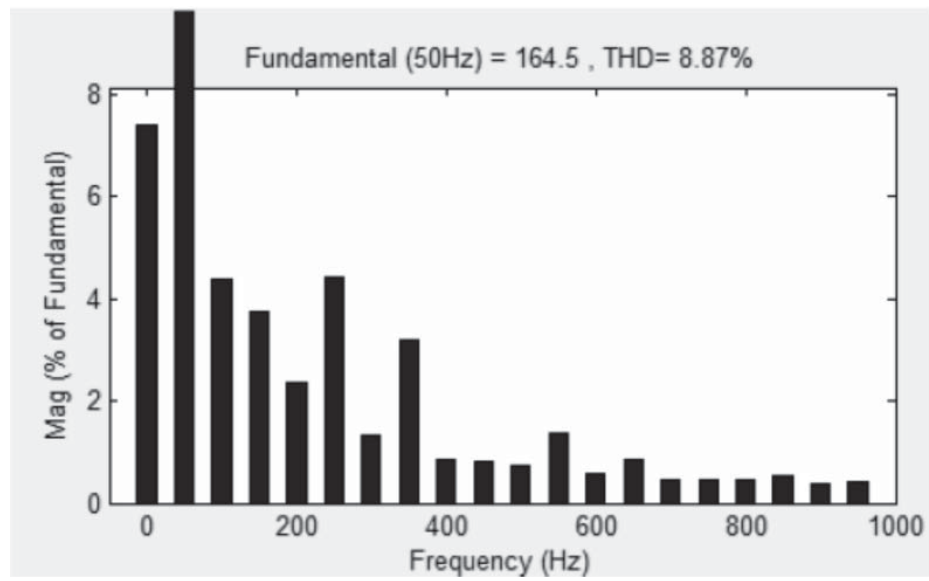


Fig. 8. Feeder 2 BUS 2 voltage, series compensating voltage, and load voltage.



FFT of BUS2 Voltage in Feeder2





FFT Analysis of Load BUS1 Voltage in Feeder 1 the THD has been reduced from 35.39% to 8.87%.

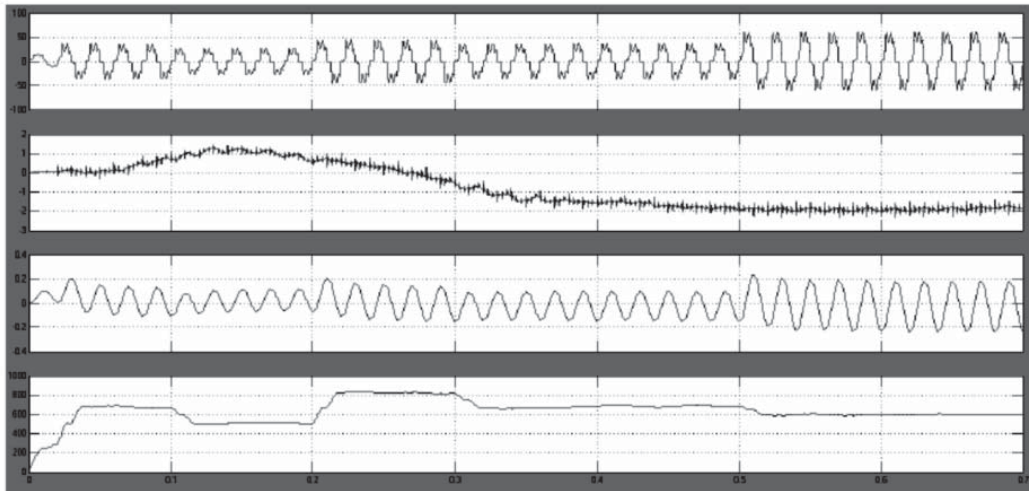


Fig. 9. Non-linear load current, shunt compensating current, Feeder1 current, and capacitor voltage.

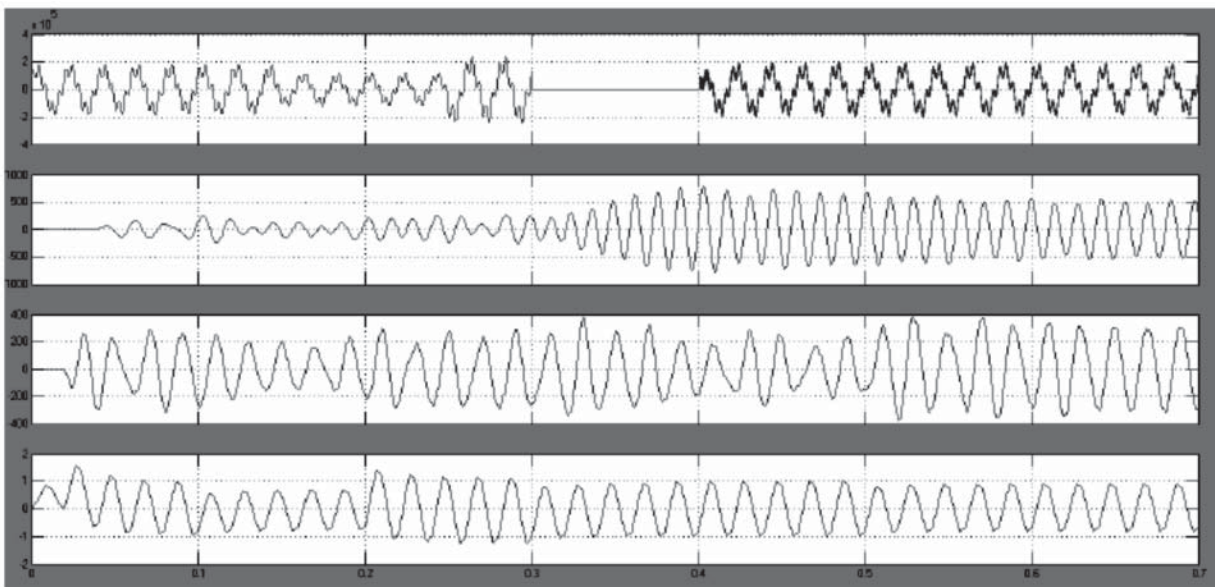


Fig. 10. Simulation results for an upstream on Feeder 2:BUS2 voltage, compensating voltage and load L1 and L2 voltages.

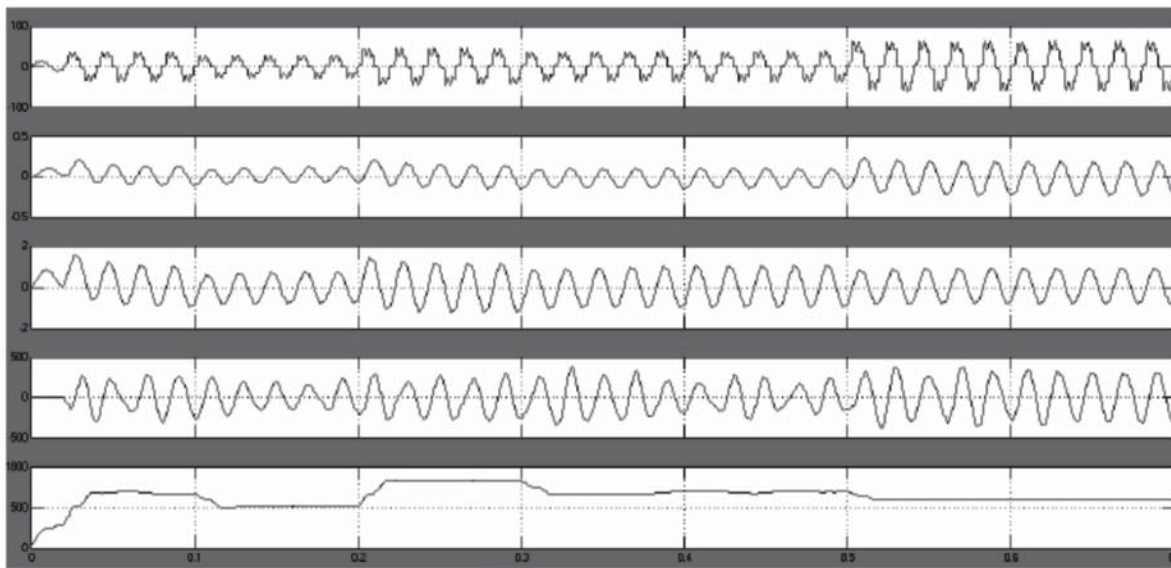


Fig. 11. Simulation results for load change: nonlinear load current, Feeder1 current, load L1 and L2 voltages, and dc-link capacitor voltage.

5. CONCLUSION

In this paper, a new unified power-quality conditioning system (called MC-UPQC) capable of compensation for voltage and current in adjacent feeder is modeled using MATLAB/SIMULINK and results are shown. Compared to a conventional UPQC, the MC-UPQC is capable of fully protecting critical & sensitive loads against distortions, sag/swell, and interruption in two-feeder system. From these Results we can say that the MC-UPQC system is also capable of compensating for interruptions without the need of a battery storage system.

This MC-UPQC system can be extended to three or more feeders by adding a series VSC in an adjacent feeder. The dynamic response of the MC-UPQC system can also be improved by using Fuzzy Logic controller.

6. REFERENCES

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