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A NOVEL MULTI LEVEL CONVERTER UNIFIED POWER-QUALITY (MC-UPQC) CONDITIONING SYSTEM ON LINE LOADING, LOSSES, AND VOLTAGE STABILITY OF RADIAL DISTRIBUTION SYSTEMS

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KEYWORDS:

ABSTRACT
This paper presents a new unified power-quality conditioning system (MC-UPQC), capable of simultaneous compensation for voltage and current in multi-bus/multi-feeder systems. In this configuration, one shunt voltage-source converter (shunt VSC) and two or more series VSCs exist. The system can be applied to adjacent feeders to compensate for supply-voltage and load current imperfections on the main feeder and full compensation of supply voltage imperfections on the other feeders. In the proposed configuration, all converters are connected back to back on the dc side and share a common dc-link capacitor. Therefore, power can be transferred from one feeder to adjacent feeders to compensate for sag/swell and interruption. The proposed topology can be used for simultaneous compensation of voltage and current imperfections in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected. The system is also capable of compensating for interruptions without the need for a battery storage system and consequently without storage capacity limitations. The performance of the MC-UPQC as well as the adopted control algorithm is illustrated by simulation. The simulation results show that a significant amount of power-loss reduction, under voltage mitigation, and the enhancement of voltage stability margin can be obtained with an appropriate placement of the MC-UPQC in a distribution network. The performance comparison of the MC-UPQC with one previously reported design approach shows that it is more efficient in under voltage mitigation.

INTRODUCTION
With increasing applications of nonlinear and electronically switched devices in distribution systems and industries, power-quality (PQ) problems, such as harmonics, flicker, and imbalance have become serious concerns. In addition, lightning strikes on transmission lines, switching of capacitor banks, and various network faults can also cause PQ problems, such as transients, voltage sag/swell, and interruption. 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.

Recently, multi converter FACTS devices, such as an interline power-flow controller (IPFC) and the generalized unified power-flow controller (GUPFC) are introduced. The aim of these devices is to control the power flow of multi lines or a sub network rather than control the power flow of a single line by, for instance, a UPFC. When the power flows of two lines starting in one substation need to be controlled, an interline power flow controller (IPFC) can be used. An IPFC consists of two series VSCs whose dc capacitors are coupled. This allows active power to circulate between the VSCs. With this configuration, two lines can be controlled simultaneously to optimize the network utilization. The GUPFC combines three or more shunt and series converters. It extends the concept of voltage and power-flow control beyond what is achievable with the known two-converter UPFC. The simplest GUPFC consists of three converters—one connected in shunt and the other two in series with two transmission lines in a substation. The basic GUPFC can control total five power system quantities, such as a bus voltage and independent active and reactive power flows of two lines. The concept of GUPFC can be extended for more lines if necessary. The device may be installed in some central substations to manage power flows of multi lines or a group of lines and provide voltage support as well. By using GUPFC devices, the transfer capability of transmission lines can be increased significantly.

PROPOSED MC-UPQC SYSTEM
The single-line diagram of a distribution system with an MC-UPQC is shown in Fig. 1 As shown in this figure; two feeders connected to two different substations supply the loads L1 and L2. The MC-UPQC is connected to two buses BUS1 and BUS2 with voltages of u_{t1} and u_{t2}, respectively. The shunt part of the MC-UPQC is also

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connected to load L1 with a current of i_{l1}. Supply voltages are denoted by u_{s1} and u_{s2} while load voltages are denoted by u_{l1} and u_{l2}. Finally, feeder currents are denoted by i_{s1} and i_{s2} and load currents are i_{l1} and i_{l2}.

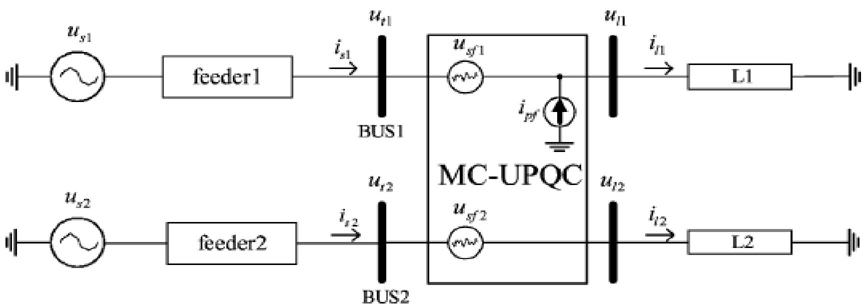

Fig. 1 Single-line diagram of a distribution system with an MC-UPQC

The internal structure of the MC-UPQC is shown in Fig. 5.2. It consists of three VSCs (VSC1, VSC2, and VSC3) which are connected back to back through a common dc-link capacitor. In the proposed configuration, VSC1 is connected in series with BUS1 and VSC2 is connected in parallel with load L1 at the end of Feeder1. VSC3 is connected in series with BUS2 at the Feeder2 end.

As shown in Fig. 2, all converters are supplied from a common dc-link capacitor and connected to the distribution system through 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.

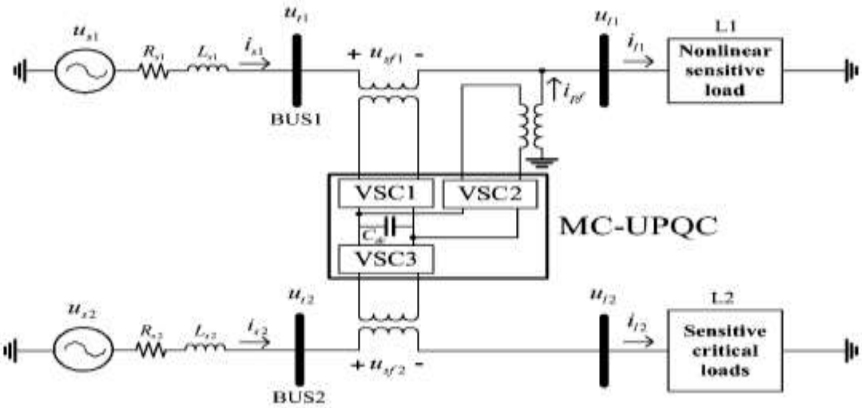

Fig. 2 Typical MC-UPQC used in a distribution system

The aims of the MC-UPQC shown in Fig. 2 are:

1) To regulate the load voltage (u_{l1}) against sag/swell and disturbances in the system to protect the nonlinear/sensitive load L1;
2) To regulate the load voltage (u_{l2}) against sag/swell, interruption and disturbances in the system to protect the sensitive/critical load L2;
3) To compensate for the reactive and harmonic components of nonlinear load current (i_{l1})

In order to achieve these goals, series VSCs (i.e., VSC1 and VSC3) operate as voltage controllers while the shunt VSC (i.e., VSC2) operates as a current controller.

CONTROL STRATEGY USED IN MC-UPQC

As shown in Fig. 2, the MC-UPQC consists of two series VSCs and one shunt VSC which are controlled independently. The switching control strategy for series VSCs and the shunt VSC are selected to be sinusoidal pulse width-modulation (SPWM) voltage control and hysteresis current control, respectively.

Functions of the shunt-VSC are:

1) To compensate for the reactive component of the load L1 current.

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2) To compensate for the harmonic components of the load current.
3) To regulate the voltage of the common dc-link capacitor.

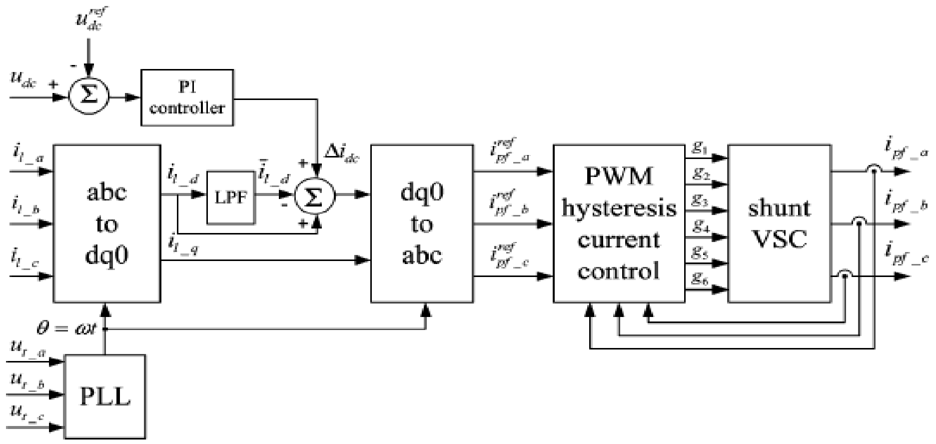

Fig. 3 Control block diagram of the shunt VSC

Functions of the series VSCs in each feeder are:
1) To mitigate voltage sag and swell;
2) To compensate for voltage distortion, such as harmonics;
3) To compensate for interruption (in Feeder2 only).

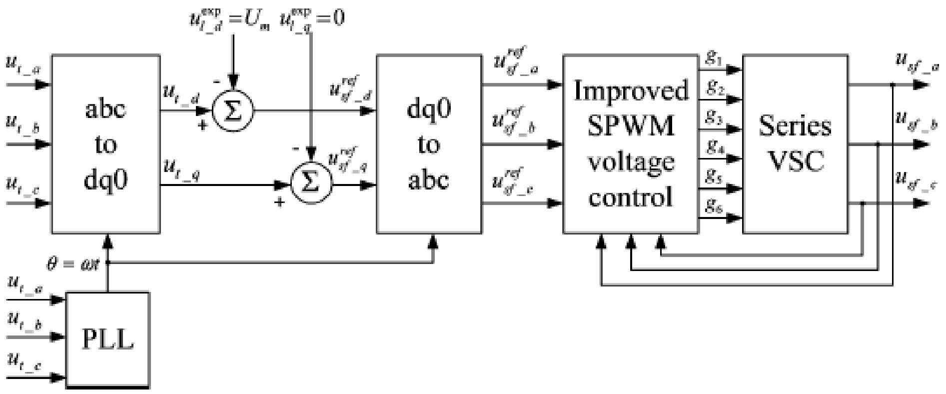

Fig. 4 Control block diagram of series VSC

MATLAB / SIMULINK RESULTS

The MATLAB/SIMULINK block diagram of a multi-converter unified power quality conditioner (MC-UPQC) shown in Fig. 5.

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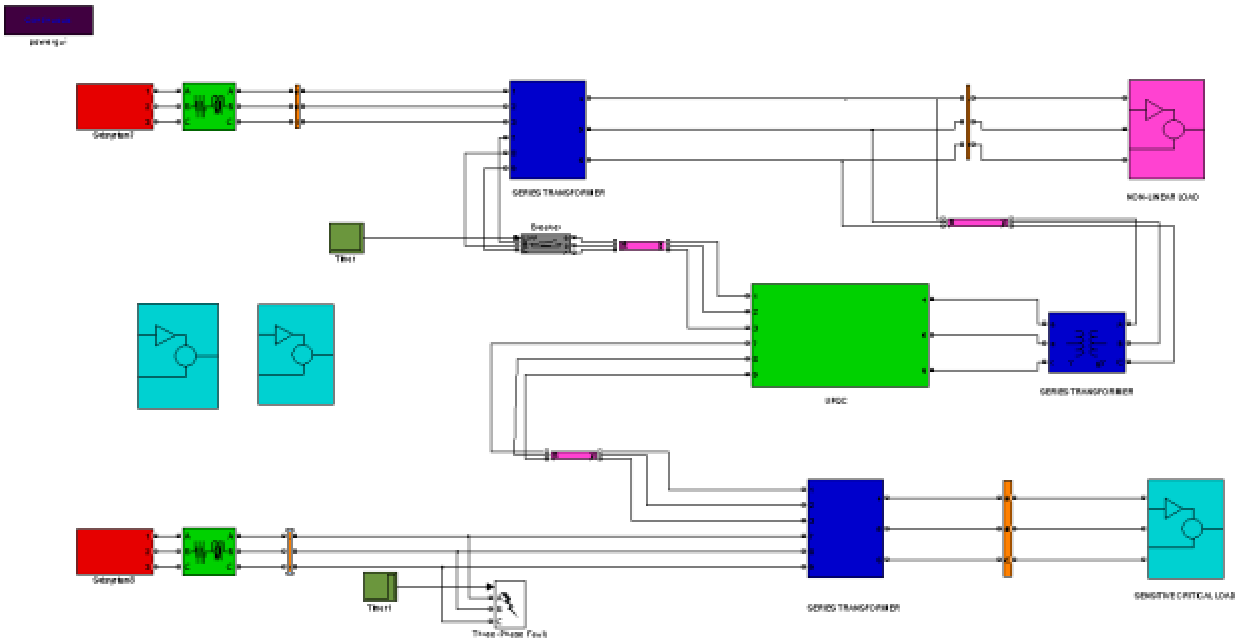

Fig. 5 MATLAB/SIMULINK block diagram of MC-UPQC

In order to verify the effectiveness of control algorithm in the previous chapters 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.

Let us consider that the power system in consists of two three-phase three-wire 380V (r.m.s, L-L), 50-Hz utilities. The BUS1 voltage (u_{t1}) contains the seventh-order harmonic with a value of 22%, and the BUS2 voltage (u_{t2}) contains the fifth-order harmonic with a value of 35%.

The MC-UPQC is switched on at t = 0.02 s. The BUS1 voltage, the corresponding compensation voltage injected by VSC1 and finally load L1 voltage are shown in Fig. 6. In all figures, only the phase *a* waveform is shown for simplicity.

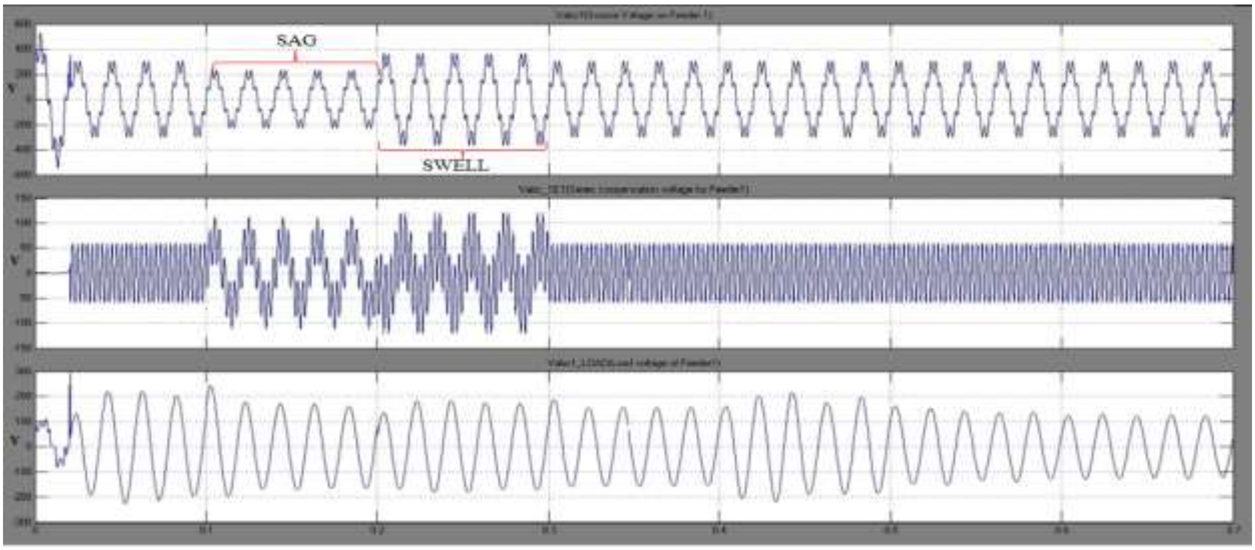

Fig. 6 Bus1 voltage, series compensating voltage and load voltage in Feeder 1

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Similarly, the BUS2 voltage, the corresponding compensation voltage injected by VSC3, and finally, the load L2 voltage are shown in Fig. 6. As shown in these figures, distorted voltages of BUS1 and BUS2 are satisfactorily compensated for across the loads L1 and L2 with very good dynamic response.

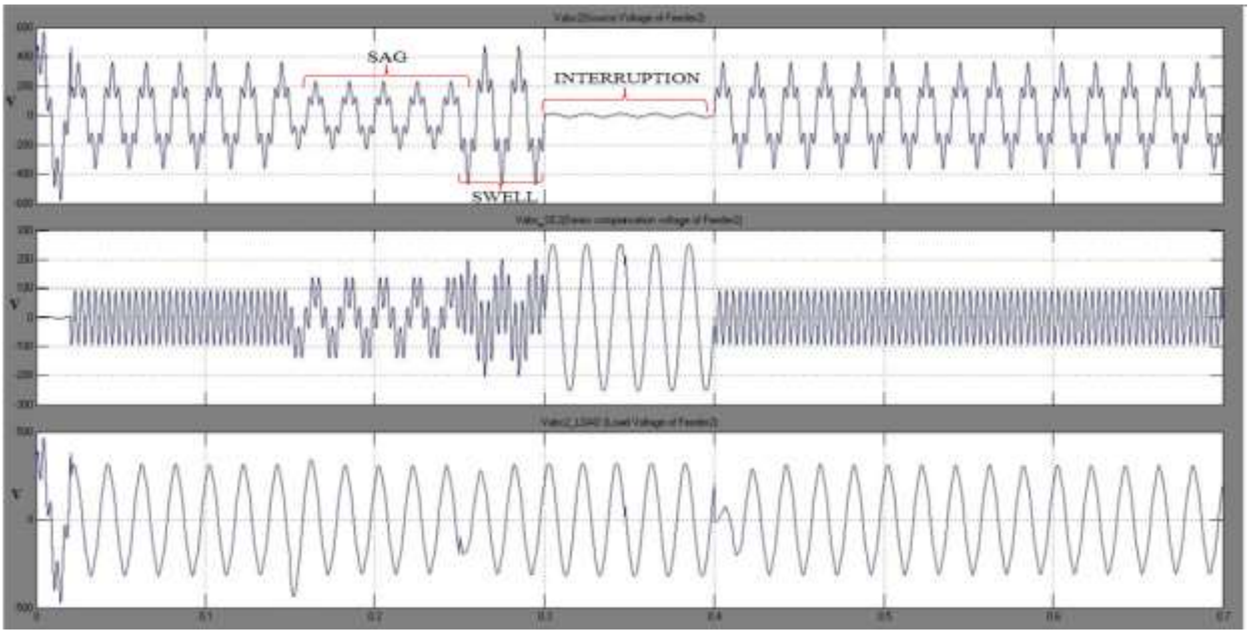

Fig. 7 BUS2 voltage, series compensating voltage, and load voltage in Feeder2

The nonlinear load current, its corresponding compensation current injected by VSC2, compensated Feeder1 current, and, finally, the dc-link capacitor voltage are shown in Fig. 8. The distorted nonlinear load current is compensated very well, and the total harmonic distortion (THD) of the feeder current is reduced from 27.5% to less than 5%. Also, the dc voltage regulation loop has functioned properly under all the disturbances, such as sag/swell in both feeders.

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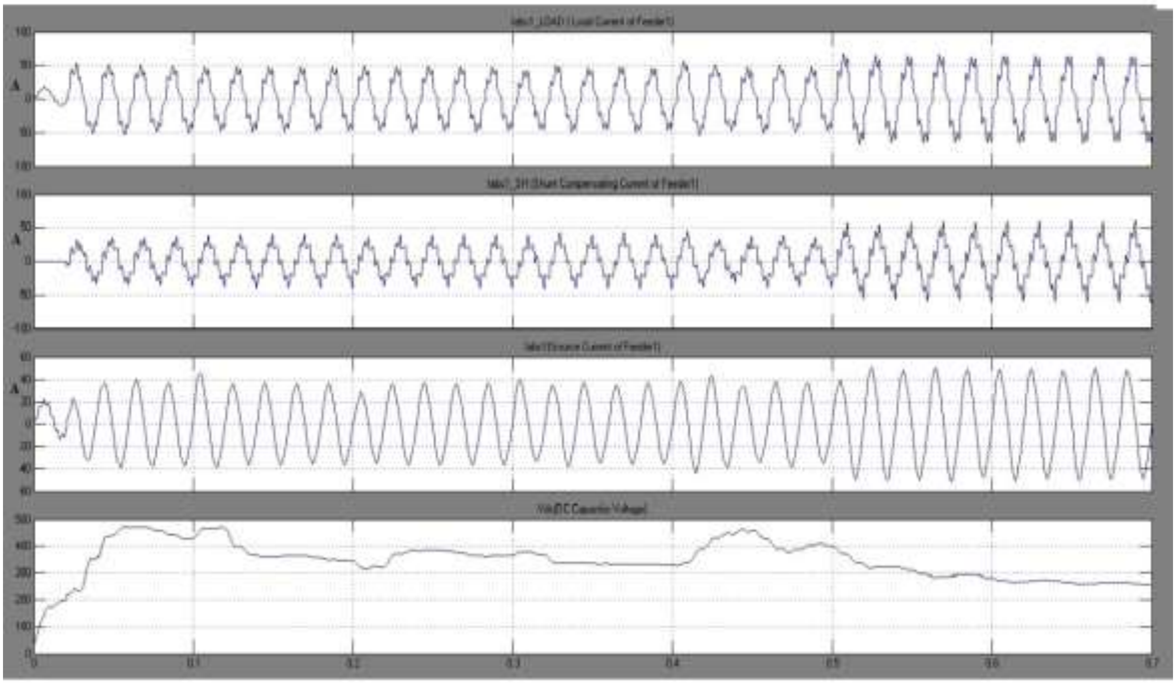

Fig. 8 Nonlinear load current, compensating voltage, and load voltage in Feeder2

One of the many solutions is the use of a combined system of shunt and Series converter like multi converter unified power quality conditioner (MC-UPQC) compensate the supply voltage and the load current or to mitigate any type of voltage and current fluctuations sag, swell and power factor correction in a power distribution network. The control strategies used here are based on PI controller of the MC-UPQC in detail.

CONCLUSION

In this paper, a new configuration for simultaneous compensation of voltage and current in adjacent feeders has been proposed. The new configuration is named multi-converter unified power-quality conditioner (MC-UPQC). The performance of the MC-UPQC is evaluated under various disturbance conditions and it is shown that the proposed MC-UPQC offers the following advantages: 1) power transfer between two adjacent feeders for sag/swell and interruption compensation; 2) compensation for interruptions without the need for a battery storage system and, consequently, without storage capacity limitation; 3) sharing power compensation capabilities between two adjacent feeders which are not connected

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