Multi converter Unified Power-Quality Conditioning for multi feeder System

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Abstract—This paper presents a new unified power-quality conditioning system (MC-UPQC), capable of simultaneous compensation for voltage and current in multibus/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 performance of the MC-UPQC as well as the adopted control algorithm is illustrated by simulation. The results obtained in PSCAD/EMTDC on a two-bus/two-feeder system show the effectiveness of the proposed configuration.

Index Terms—Power quality (PQ), PSCAD/EMTDC, unified power-quality conditioner (UPQC), voltage-source converter (VSC).

1. 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 In order to meet PQ standard limits, it may be necessary to include some sort of compensation. Modern solutions can be found in the form of active rectification or active filtering [2]. A shunt active power filter is suitable for the suppression of negative load influence on the supply network, but if there are supply voltage imperfections, a series active power filter may be needed to provide full compensation [3]. In recent years, solutions based on flexible ac transmission systems (FACTS) have appeared. The application of FACTS concepts in distribution systems has resulted in a new generation of compensating devices. A unified power-quality conditioner (UPQC) [4] is the extension of the unified power-flow controller (UPFC) [5] concept at the distribution level. It consists of combined series and shunt converters for simultaneous compensation of voltage and current imperfections in a supply feeder [6]-[8].Recently, multi converter FACTS devices, such as an interline power-flow controller (IPFC) [9] and the generalized unified power-flow controller (GUPFC) [10] 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 trans- mission 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 sup-port as well. By using GUPFC devices, the transfer capability of transmission lines can be increased significantly. Furthermore, by using the multiline-management capability of the GUPFC, active power flow on lines cannot only be increased, but also be decreased with respect to operating and market transaction requirements. In general, the GUPFC can be used to increase the transfer capability and relieve congestions in a flexible way. This concept can be extended to design multi converter configurations for PQ improvement in adjacent feeders. For ex-ample, the inter line unified power-quality conditioner (IUPQC), which is the extension of the IPFC concept at the distribution level, has been proposed in [11]. The IUPQC consists of one series and one shunt converter. It is connected between two feeders to regulate the bus voltage of one of the feeders, while regulating the voltage across a sensitive load in the other feeder. In this configuration, the voltage regulation in one of the feeders is per-formed by the shunt-VSC. However, since the source impedance is very low, a high amount of current would be needed to boost the bus voltage in case of a voltage sag/swell which is not feasible. It also has low dynamic performance because the dc-link capacitor voltage is not regulated.

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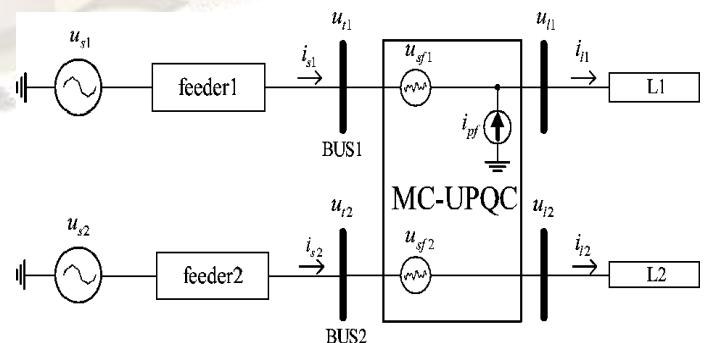**Vol. 2, Issue 1,Jan- Feb 2012, pp.212-221**

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

In this paper, a new configuration of a UPQC called the multi converter unified power-quality conditioner (MC-UPQC) is presented. The system is extended by adding a series-VSC in an adjacent feeder. 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.

II. PROPOSED MC-UPQC SYSTEM

A. Circuit Configuration

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 and   , respectively. The shunt part of the MC-UPQC is also connected to load L1 with a i_{l1} .current of . Supply voltages are denoted by u_{s1} and u_{s2} while load voltages are and Finally, feeder currents are denoted by and i_{s1} and i_{s2} load currents are an i_{l1} and i_{l2}.

Bus voltages and   are distorted and may be subjected to sag/swell. The load L1 is a nonlinear/sensitive load which needs a pure sinusoidal voltage for proper operation while its current is non sinusoidal and contains harmonics. The load L2 is a sensitive/critical load which needs a purely sinusoidal voltage and must be fully protected against distortion, sag/swell, and interruption. These types of loads primarily include production industries and critical service providers, such as medical centers, airports, or broadcasting centers where voltage interruption can result in severe economical losses or human damages.

B. MC-UPQC Structure

The internal structure of the MC-UPQC is shown in Fig. 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. Each of the three VSCs in Fig. 2 is realized by a three-phase converter with a commutation reactor and high-pass output filter as shown in Fig. 3. The commutation reactor an dhigh-
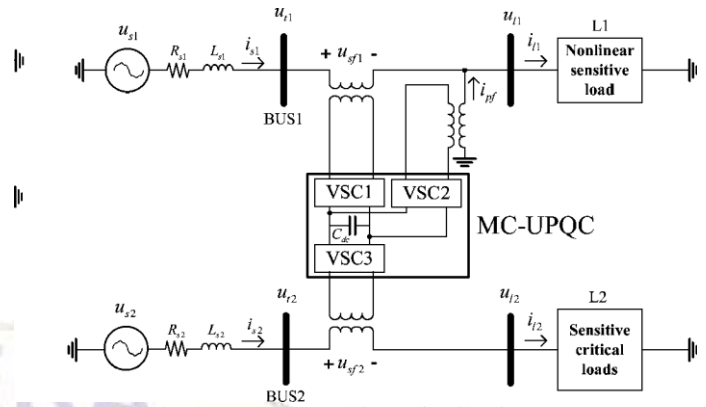

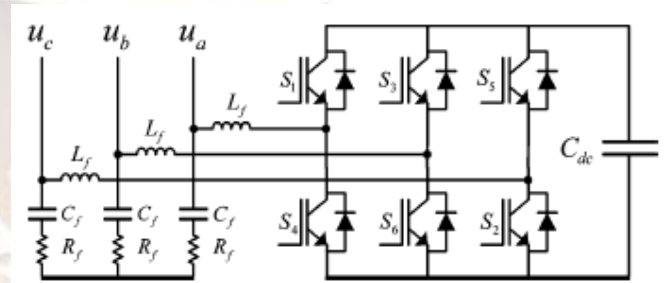Fig.2. Typical MC-UPQC used in a distribution system

Fig. 3. Schematic structure of a VSC

pass output filter (R_f, C_f) are connected to prevent the flow of switching harmonics into the power supply.

As shown in Fig. 2, all 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. 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})

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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.

C. Control Strategy

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 pulsewidth-modulation (SPWM) voltage control and hysteresis current control, respectively. Details of the control algorithm, which are based on the method [12], will be discussed later. Shunt-VSC: Functions of the shunt-VSC are:

1) to compensate for the reactive component of load L1 cur-rent;
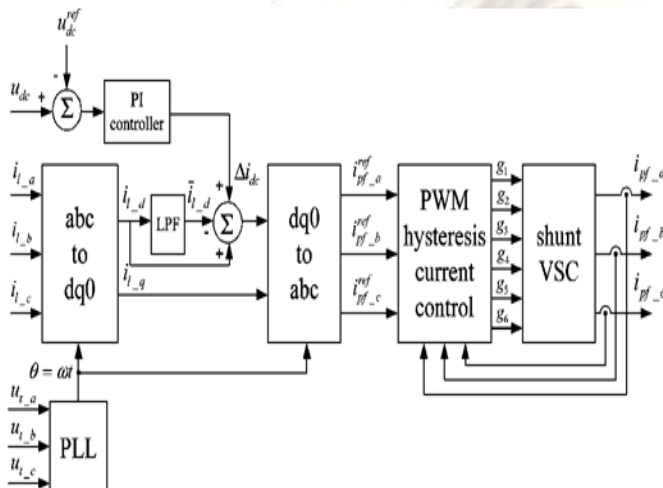

Fig.4. Control block diagram of the shunt VSC.

2) to compensate for the harmonic components of load L1 current;

3) to regulate the voltage of the common dc-link capacitor. Fig. 4 shows the control block diagram for the shunt VSC. The measured load current (i_{l_abc}) is transformed into the synchronous reference frame by using

$$i_{l\_dq0} = T_{abc}^{dq0}\, i_{l\_abc}.$$ (1)

where the transformation matrix is shown in (2), at the bottom of the page.

$$T_{abc}^{dq0} = \frac{2}{3}\begin{bmatrix} \cos(\omega t) & \cos(\omega t - 120°) & \cos(\omega t + 120°) \\ -\sin(\omega t) & -\sin(\omega t - 120°) & -\sin(\omega t + 120°) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}.$$ (2)

By this transform, the fundamental positive-sequence component, which is transformed into dc quantities in the and axes, can be easily extracted by low-pass filters (LPFs). Also, all harmonic components are transformed into ac quantities with a fundamental frequency shift

$$i_{l\_d} = \bar{i}_{l\_d} + \tilde{i}_{l\_d}$$ (3)

$$i_{l\_q} = i_{l\_q} + i_{l\_q}$$ (4)

where i_{l_d}, i_{l_q} are $d - q$ components of load current, are dc components, and i_{l_d}, i_{l_q} are the ac components of i_{l_d} and i_{l_q}.

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

$$i_{pf\_d}^{ref} = i_{l\_d}$$ (5)

$$i_{pf\_q}^{ref} = i_{l\_q}$$

(6)Consequently, the $d - q$ components of the feeder current are

$$i_{s\_d} = \bar{i}_{l\_d}$$ (7)
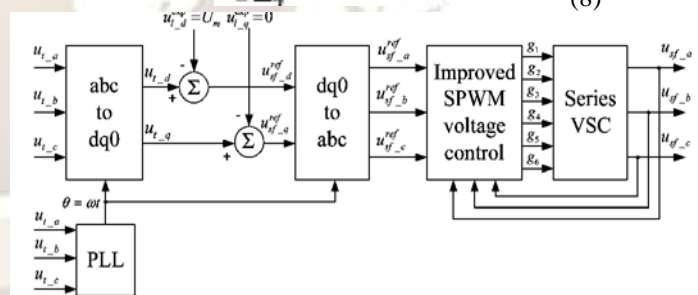
$$i_{s\_q} = 0.$$ (8)

Fig.5. Control block diagram of the series VSC.

This means that there are no harmonic and reactive components in the feeder current. Switching losses cause the dc-link capacitor voltage to decrease. Other disturbances, such as the sudden variation of load, can also affect the dc link. In order to regulate the dc-link capacitor voltage, a proportional-integral (PI) controller is used as shown in Fig. 4. The input of the PI controller is the error between the actual capacitor

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voltage (u_{dc}) and its reference value (u_{dc}^{ref}) The output of the PI controller (i.e., Δi_{dc}) is added to the component of the shunt-VSC reference current to form a new reference current as follows:

$$\begin{cases} i_{pf\_d}^{\text{ref}} = \tilde{i}_{l\_d} + \Delta i_{dc} \\ i_{pf\_q}^{\text{ref}} = i_{l\_q} \end{cases}.$$

9)

As shown in Fig. 4, the reference current in (9) is then transformed back into the *abc* reference frame. By using PWM hysteresis current control, the output-compensating currents in each phase are obtained

$$i_{pf\_abc}^{\text{ref}} = T_{dq0}^{abc} i_{pf\_dq0}^{\text{ref}}; \left(T_{dq0}^{abc} = T_{abc}^{dq0^{-1}}\right).$$

(10)

Series-VSC: Functions of the series VSCs in each feeder are:
1) to mitigate voltage sag and swell;
2) to compensate for voltage distortions, such as harmonics;
3) to compensate for interruptions (in Feeder2 only).The control block diagram of each series VSC is shown in Fig. 5. The bus voltage   is detected and then transformed into the synchronous reference frame using

$$u_{t\_dq0} = T_{abc}^{dq0} u_{t\_abc} = u_{t1p} + u_{t1n} + u_{t10} + u_{th}.$$

(11)

where

$$\begin{cases} u_{t1p} = [u_{t1p\_d} \quad u_{t1p\_q} \quad 0]^T \\ u_{t1n} = [u_{t1n\_d} \quad u_{t1n\_q} \quad 0]^T \\ u_{t10} = [0 \quad 0 \quad u_{00}]^T \\ u_{th} = [u_{th\_d} \quad u_{th\_q} \quad u_{th\_0}]^T \end{cases}.$$

(12)

u_{t1p}, u_{t1n} and u_{t10} are fundamental frequency positive-, negative-, and zero-sequence components, respectively, and is the harmonic component of the bus voltage.
According to control objectives of the MC-UPQC, the load voltage should be kept sinusoidal with a constant amplitude even if the bus voltage is disturbed. Therefore, the expected load voltage in

the synchronous $dq0$ reference frame ($u_{l\_dq0}^{\text{exp}}$) only has one value

$$u_{l\_dq0}^{\text{exp}} = T_{abc}^{dq0} u_{l\_abc}^{\text{exp}} = \begin{bmatrix} U_m \\ 0 \\ 0 \end{bmatrix}$$

(13) The compensating reference voltage in the synchronous reference frame $u_{l\_abc}^{\text{exp}}$ is defined as

$$u_{l\_abc}^{\text{exp}} = \begin{bmatrix} U_m \cos(\omega t) \\ U_m \cos(\omega t - 120°) \\ U_m \cos(\omega t + 120°) \end{bmatrix}.$$

(14)

where the load voltage in the *abc* reference frame($u_{sf\_dq0}^{\text{ref}}$)is defined as

$$u_{sf\_dq0}^{\text{ref}} = u_{t\_dq0} - u_{l\_dq0}^{\text{exp}}.$$

(15)

This means u_{t1p_d} in (12) should be maintained at U_m while all other unwanted components must be eliminated. The compensating reference voltage in (15) is then transformed back into the abc reference frame. By using an improved SPWM voltage control technique (sine PWM control with minor loop feedback) [8], the output compensation voltage of the series VSC can be obtained.

III. POWER-RATING ANALYSIS OF THE MC-UPQC

The power rating of the MC-UPQC is an important factor in terms of cost. Before calculation of the power rating of each VSC in the MC UPQC structure, two models of a UPQC are analyzed and the best model which requires the minimum power rating is considered. All voltage and current phasors used in this section are phase quantities at the fundamental frequency.
There are two models for a UPQC—quadrature compensation (UPQC-Q) and in phase compensation (UPQC-P). In the quadrature compensation scheme, the injected voltage by the series-VSC maintains a quadrature advance relationship with the supply current so that no real power is consumed by the series VSC at steady state. This is a significant advantage when UPQC mitigates sag conditions. The series VSC also shares the volt-ampere reactive (VAR) of the load along with the shunt-VSC, reducing the power rating of the shunt-VSC.
Fig.6 shows the phasor diagram of this scheme under a typical load power factor condition with and without a voltage sag. When

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the bus voltage is at the desired value $(U_l = U_t = U_0)$,he series-injected voltage (U_{sf}) is zero [Fig. 6(a)]. The shunt VSC injects the reactive component of load current   , resulting in unity input-power factor. Furthermore, the shunt VSC compensates for not only the reactive component, but also the harmonic components of the load current. For sag compensation in this model, the quadrature series voltage injection is needed as shown in Fig. 6(b). The shunt VSC injects I_c in such a way that
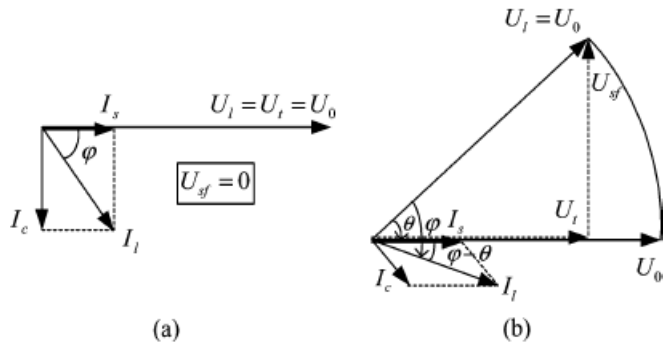

(a)   (b)

Fig.6.Phasor diagram of quadrature compensation.(a) Without voltage   sag.(b)   With   voltage   sag.
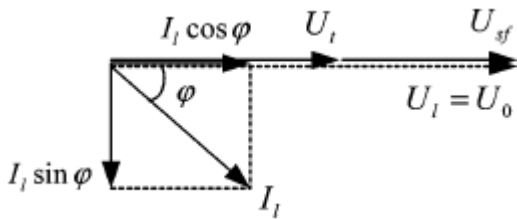

Fig.7.Phasor diagram of in phase compensation (supply voltage sag).

the active power requirement of the load is only drawn from the utility which results in a unity input-power factor. In an inphase compensation scheme, the injected voltage is in phase with the supply voltage when the supply is balanced. By virtue of in phase injection, series VSC will mitigate the voltage sag condition by minimum injected voltage. The phasor diagram of Fig. 7 explains the operation of this scheme in case of a voltage sag.
A comparison between inphase (UPQC-P) and quadrature (UPQC-Q) models is made for different sag conditions and load power factors in [13]. It is shown that the power rating of the shunt-VSC in the UPQC-Q model is lower than that of the UPQC-P, and the power rating of the series-VSC in the UPQC-P model is lower than that of the UPQC-Q for a power factor of less than or equal to 0.9. Also, it is shown that the total power rating of UPQC-Q is lower than that of UPQC-P where the VAR demand of the load is high.
As discussed in Section II, the power needed for interruption compensation in Feeder2 must be supplied through the shunt VSC in Feeder1 and the series VSC in Feeder2. This implies that power

ratings of these VSCs are greater than that of the series one in Feeder1. If quadrature compensation in Feeder1 and in phase compensation in Feeder2 are selected, then the power rating of the shunt VSC and the series VSC (in Feeder2) will be reduced. This is an important criterion for practical applications.
Based on the aforementioned discussion, the power-rating calculation for the MC-UPQC is carried out on the basis of the linear load at the fundamental frequency. The parameters in Fig. 6 are corrected by adding suffix "1," indicating Feeder1, and the parameters in Fig. 7 are corrected by adding suffix "2," indicating Feeder2. As shown in Figs. 6 and 7, load voltages in both feeders are kept constant at U_0 regardless of bus voltages variation, and the load currents in both feeders are assumed to be constant at their rated values (i.e., I_{01} and I_{02}, respectively)

$$U_{l1} = U_{l2} = U_0 \tag{16}$$

$$\begin{cases} I_{l1} = I_{O1} \\ I_{l2} = I_{O2} \end{cases} . \tag{17}$$

If the MC-UPQC is lossless, the active power demand sup-plied by Feeder1 consists of two parts:
1) the active power demand of load in Feeder1;
2) the active power demand for sag and interruption compensation in Feeder2.
Thus, Feeder1 current can be found as

$$U_{t1}I_{s1} = U_{t1}I_{l1}\cos\varphi_1 + U_{sf2}I_{l2}\cos\varphi_2 \tag{18}$$
$$(1-x_1)U_0I_{s1} = U_0I_{01}\cos\varphi_1 + x_2U_0I_{02}\cos\varphi_2 \tag{19}$$
$$(1-x_1)I_{s1} = I_{01}\cos\varphi_1 + x_2I_{02}\cos\varphi_2 \tag{20}$$
$$I_{s1} = \frac{I_{01}\cos\varphi_1}{(1-x_1)} + \frac{x_2I_{02}\cos\varphi_2}{(1-x_1)}. \tag{21}$$

From Fig. 6, the voltage injected by the series VSC in Feeder1 can be written as in (22) and, thus, the power rating of this converter (S_{VSC1}) can be calculated as

$$U_{sf1} = U_{t1}\tan\theta = U_0(1-x_1)\tan\theta \tag{22}$$
$$S_{VSC1} = 3U_{sf1}I_{s1} = 3U_0(1-x_1)\tan\theta$$
$$\times \left(\frac{I_{01}\cos\varphi_1}{1-x_1} + \frac{x_2I_{02}\cos\varphi_2}{1-x_1} \right). \tag{23}$$

The shunt VSC current is divided into two parts.
1) The first part (i.e.,) compensates for the reactive component (and harmonic components) of Feeder1 current and can be

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calculated from Fig. 6 as

$$I_{c1} = \sqrt{I_{l1}^2 + I_{s1}^2 - 2I_{l1}I_{s1}\cos(\varphi_1 - \theta)}$$
$$= \sqrt{I_{01}^2 + I_{s1}^2 - 2I_{01}I_{s1}\cos(\varphi_1 - \theta)} \quad (24)$$

where   is calculated in (21). This part of the shunt VSC current only exchanges reactive power (Q) with the system.

2) The second part provides the real power (P), which is needed for a sag or interruption compensation in Feeder2. Therefore, the power rating of the shunt VSC can be calculated as

$$S_{\text{VSC2}} = 3U_{l1}I_{\text{pf}} = 3\sqrt{Q^2 + P^2}$$
$$= 3\sqrt{(U_{l1}I_{c1})^2 + (U_{\text{sf2}}I_{l2}\cos\varphi_2)^2}$$
$$= 3U_0\sqrt{I_{c1}^2 + (x_2 I_{02}\cos\varphi_2)^2} \quad (25)$$

where   is calculated in (24).

Finally, the power rating of the series-VSC in Feeder2 can be calculated by (26). For the worst case scenario (i.e., interruption compensation), one must consider $x_2 = 1$ .Therefore

$$S_{\text{VSC3}} = 3U_{\text{sf2}}I_{l2} = 3x_2 U_0 I_{02}. \quad (26)$$
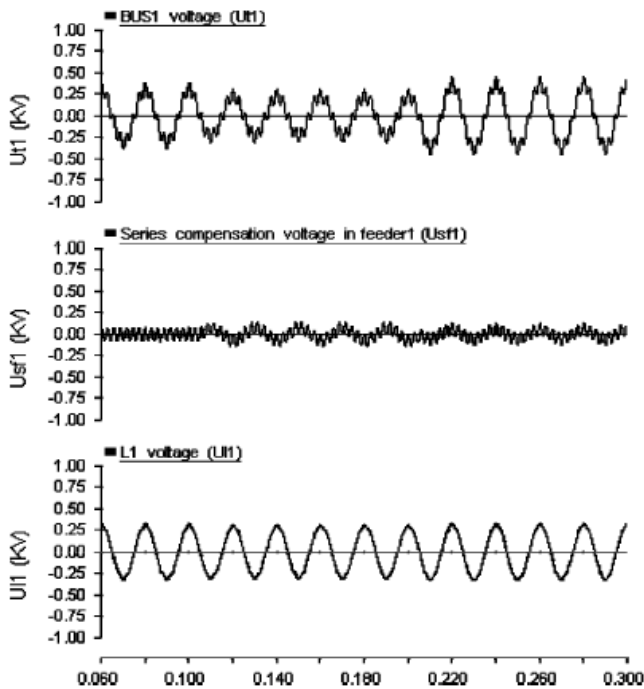

Fig.8.BUS1 voltage, series compensating voltage, and load voltage in Feeder1.

IV. SIMULATION RESULTS

The proposed MC-UPQC and its control schemes have been tested through extensive case study simulations using PSCAD/ EMTDC. In this section, simulation results are presented, and the performance of the proposed MC-UPQC system is shown.

A. Distortion and Sag/Swell on the Bus Voltage

Let us consider that the power system in Fig. 2 consists of two three-phase three-wire 380(v) (rms, L-L), 50-Hz utilities. The BUS1 (u_{t1}) voltage 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 BUS1 voltage contains25% sag between $0.1\ \text{s} < \text{t} < 0.2$ s and 20% swell between $0.2\,\text{s} < \text{t} < 0.3$ s. The BUS2 voltage contains 35% sag between $0.15\ \text{s} < \text{t} < 0.25$ s and 30% swell between $0.25\ \text{s} < \text{t} < 0.3$ s.The nonlinear/sensitive load L1 is a three-phase rectifier load which supplies an RC load of 10 Ω and 30 μF. Finally, the critical load L2 contains a balanced RL load of 10 Ω and 100mH.

The MC-UPQC is switched on at t=   0.02s. The BUS1 voltage, the corresponding compensation voltage injected by VSC1, and finally load L1 voltage are shown in Fig. 8. In all figures, only the phase   waveform is shown for simplicity.

Similarly, the BUS2 voltage, the corresponding compensation voltage injected by VSC3, and finally, the load L2 voltage are shown in Fig. 9. 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.

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. 10. The distorted nonlinear load current is compensated very well, and
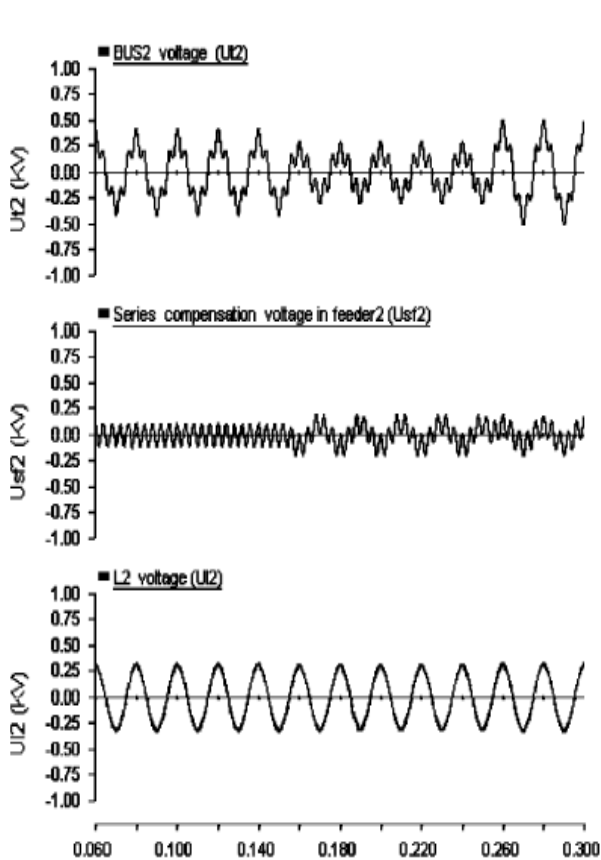
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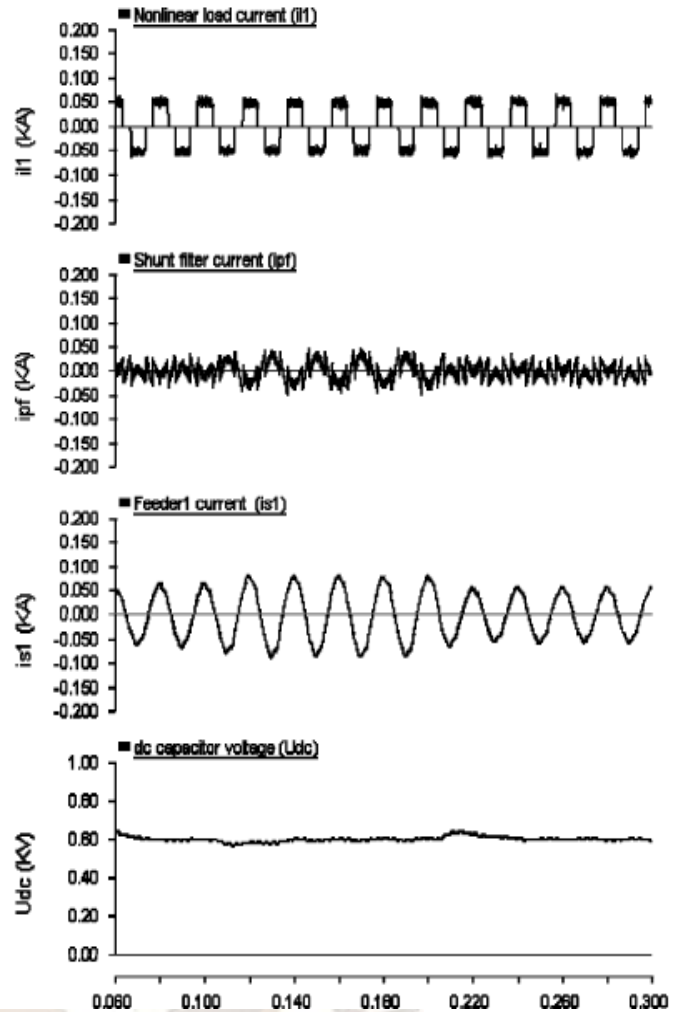Fig. 9.BUS2 voltage, series compensating voltage, and load voltage in Feeder2.

Fig.10. Nonlinear load current, compensating current, Feeder1 current, and capacitor voltage.the total harmonic distortion (THD) of the feeder current is reduced from 28.5% to less than 5%. Also, the dc voltage regulation loop has functioned properly under all disturbances, such as sag/swell in both feeders.

B. Upstream Fault on Feeder2

When a fault occurs in Feeder2 (in any form of L-G, L-L-G, and L-L-L-G faults), the voltage across the

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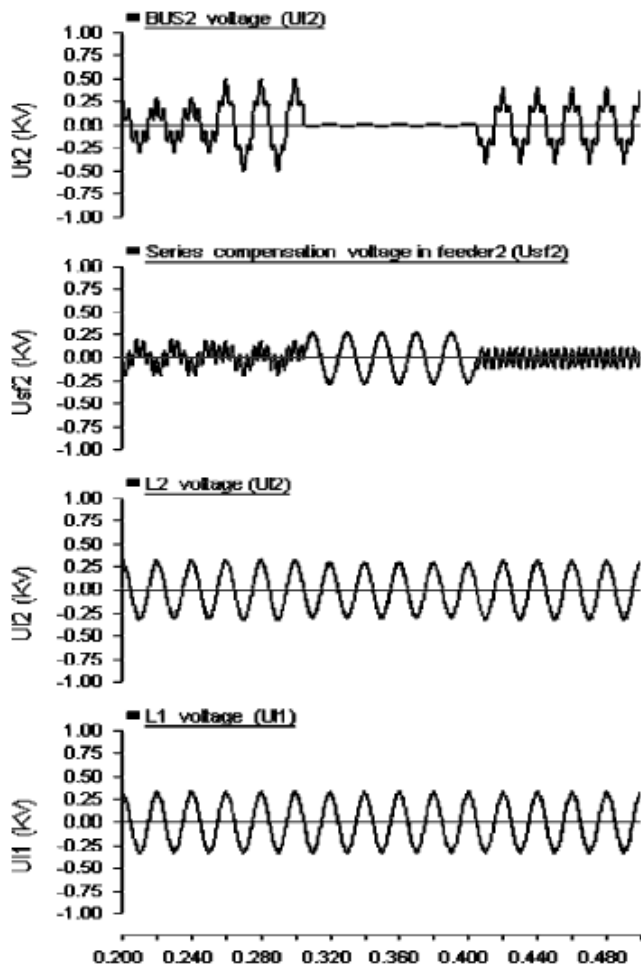**Vol. 2, Issue 1,Jan- Feb 2012, pp.212-221**

sensitive/critical

Fig. 11.   Simulation results for an upstream fault on Feeder2: BUS2 voltage, compensating voltage, and loads L1 and L2 voltages.

load L2 is involved in sag/swell or interruption. This voltage imperfection can be compensated for by VSC2.

In this case, the power required by load L2 is supplied through VSC2 and VSC3. This implies that the power semiconductor switches of VSC2 and VSC3 must be rated such that total power transfer is possible. This may increase the cost of the device, but the benefit that may be obtained can offset the expense.In the proposed configuration, the sensitive/critical load on Feeder2 is fully protected against distortion, sag/swell, and interruption. Furthermore, the regulated voltage across the sensitive load on Feeder1 can supply several customers who are also protected against distortion, sag/swell, and momentary interruption. Therefore, the cost of the MC-UPQC must be balanced against the cost of interruption, based on reliability indices,   such

as the customer average interruption duration index (CAIDI) and customer average interruption frequency index (CAIFI). It is expected that the MC-UPQC cost can be recovered in a few years by charging higher tariffs for the protected lines.The performance of the MC-UPQC under a fault condition on Feeder2 is tested by applying a three-phase fault to ground on Feeder2 between $0.3\,\text{s} < \text{t} < 0.4$s. Simulation results are shown in Fig. 11.

C. Load Change

To evaluate the system behavior during a load change, the nonlinear load L1 is doubled by reducing its resistance to half at t=0.5s. The other load, however, is kept unchanged. The system response is shown in Fig. 12. It can be seen that as load L1 changes, the load voltages and   remain undisturbed,
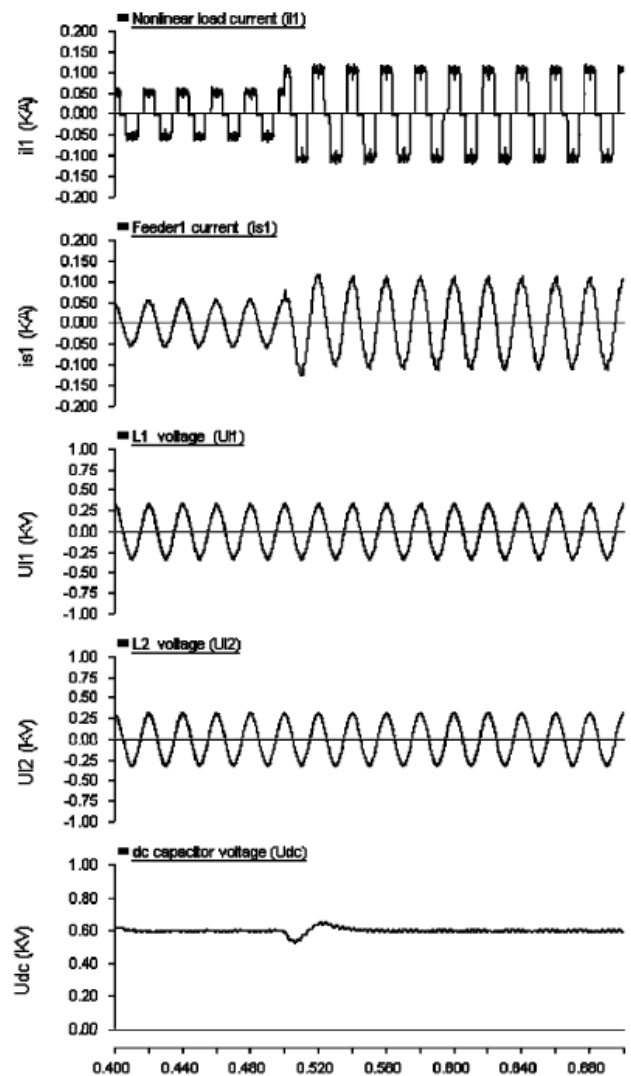

Fig.12. Simulation results for load change: nonlinear load current, Feeder1 current, load L1 voltage, load L2 voltage, and dc-link capacitor voltage.

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the dc bus voltage is regulated, and the nonlinear load current is compensated.

D. Unbalance Voltage

The control strategies for shunt and series VSCs, which are introduced in Section II, are based on the $d-q$ method. They are capable of compensating for the unbalanced source voltage and unbalanced load current. To evaluate the control system capability for unbalanced voltage compensation, a new simulation is performed. In this new simulation, the BUS2 voltage and the harmonic components of BUS1 voltage are similar to those given in Section IV. However, the fundamental component of the BUS1 voltage $(U_{t1,\text{fundaental}})$ is an unbalanced three-phase voltage with an unbalance factor (U_-/U_+) of 40%. This unbalance voltage is given by

$$U_{t1,\text{fundamental}} = \begin{bmatrix} 0.31\cos(\omega t + 46°) \\ 0.31\cos(\omega t - 106°) \\ 0.155\cos(\omega t - 210°) \end{bmatrix} \tag{27}$$

The simulation results for the three-phase BUS1 voltage, series compensation voltage, and load voltage in feeder 1 are shown in Fig. 13. The simulation results show that the harmonic components and unbalance of BUS1 voltage are compensated

Fig.13. BUS1 voltage, series compensating voltage, and load voltage in Feeder1 under unbalanced source voltage.

for by injecting the proper series voltage. In this figure, the load voltage is a three-phase sinusoidal balance voltage with regulated amplitude.

V. 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). Compared to a conventional UPQC, the proposed topology is capable of fully protecting critical and sensitive loads against distortions, sags/swell, and interruption in two-feeder systems. The idea can be theoretically extended to multibus/multi feeder systems by adding more series VSCs. 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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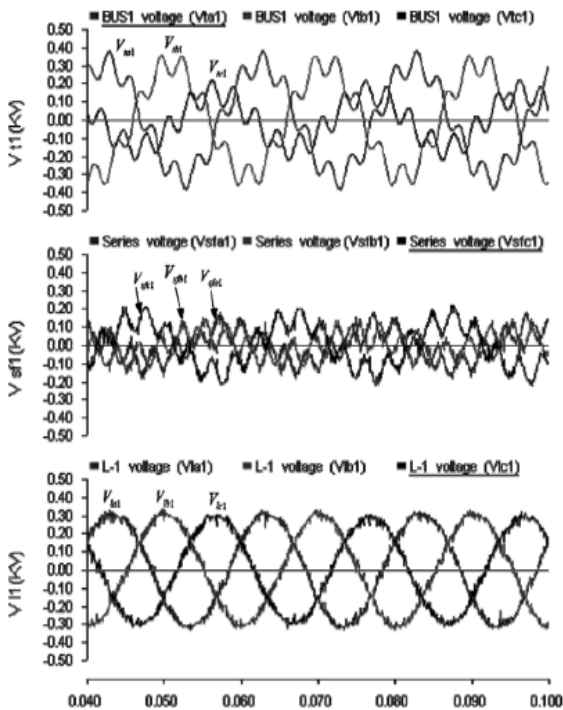
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