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MC-UPQC for Power Quality Control

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Abstract- The MC-UPQC is very important while compensating voltage sag, swell, interruption & also injecting currents into line to reduce the non-linear load currents and to compensate the reactive power which is generated by the loads. It also helps in supplying the pure sinusoidal wave to sensitive/critical loads. It also improves the power factor in the line. So this MC-UPQC is the good device for supplying the continuous power supply to consumers. In this we are using DVRs & DSTATCOMs. These consist of VSCs and are commonly shared by a DC link capacitor. Conventionally a PI controller is used to maintain the dc-link voltage at the reference value but the transient response of the conventional PI controller is very slow. So to improve the transient response of the DSTATCOM an energy based dc-link voltage controller is proposed. PWM techniques are used for generating the gate pulses which are given to IGBTS. Finally the main objective of the work is to improve the Power quality of the system and continuous power supply to consumers.

I. INTRODUCTION

This section contains about power quality and power quality problems and, FACTS controllers and custom power devices and voltage source converters and MC-UPQC and MATLAB and simulation results of this MCUPQC. Electric power distribution network becomes more increasingly important and plays an essential role in power system planning. This type of power systems has a major function to serve distributed customer loads along a feeder line therefore under competitive environment of electricity market service of electric energy transfer must not be interrupted and at the same time there must provide reliable, stable and high quality of electric power. The three phase four-wire distribution systems are facing severe power quality problems such as poor voltage regulation, high reactive power, load unbalancing, excessive neutral current, poor power factor etc [1]. Three phase four -wire distribution systems are the distribution systems used in commercial buildings, office buildings, hospitals etc.

Most of the loads in these locations are non-linear loads and some are sensitive loads are mostly unbalanced load in the distribution system. The voltage regulation is also poor in the distribution system due to the unplanned expansion and the installation of different types of loads in the existing distribution system [2]. There are mitigation techniques for power quality problems in the distribution system. There are different custom power devices to mitigate the above power-quality problems by injecting voltages/currents or both into the system. In this section main objective of the paper is discussed and organization of the thesis is presented.

Multi-Converter Unified Power Quality Conditioning System (MCUPQC)

A new unified power-quality conditioning system (MC-UPQC), capable of compensating 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 [3]. 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 MATLAB/SIMULINK.

II. PROPOSED MC-UPQC SYSTEM

MC-UPQC is the Multi Converter Unified Power Quality conditioning system. The name stands itself it applied to several feeders. In our present configuration two adjacent feeders are connected by a MC-UPQC. It injects voltages and currents in the feeders. So a time two adjacent feeders are protected from the faults. Its Circuit Configuration is shown below.

The single-line diagram of a distribution system with an MC-UPQC is shown in Fig 1.

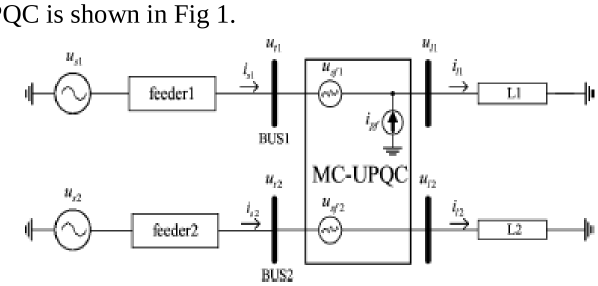

Figure 1: Single-line diagram of a distribution system with an MC-UPQC.

As shown in this figure (1), 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 Ut_1 and Ut_2respectively. The shunt part of the MC-UPQC is also connected to load L1 with a current of i_{L1}. Supply voltages are denoted by Us_1 and Us_2 while load voltages are U_{L1} and U_{L2}Finally, feeder currents are denoted by i_{s1} and i_{s2}load currents are i_{L1} and $i_{L2.}$ Bus voltages Ut_1 and Ut_2 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 economic losses or human damages.

AC electrical loads where the voltage and current waveforms are sinusoidal. The current at any time is proportional to voltage. Linear Loads are: power factor improvement capacitors, heaters etc.
Applies to those ac loads where the current is not proportional to the voltage. Foremost among loads meeting their definition are gas discharge lighting having saturated ballast coils and Thyristor (SCR) controlled loads. The nature of non-linear loads is to generate harmonics in the current waveform. This distortion of the current waveform leads to distortion of the voltage waveform. Under these conditions, the voltage waveform is no longer proportional to the current. Non Linear Loads are: computer, laser printers, rectifier, electronic ballast, refrigerator, TV etc.

MC–UPQC Structure

The internal structure of the MC–UPQC is shown in Fig (2).

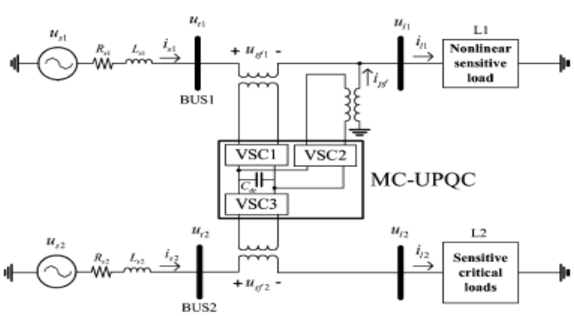

Figure 2: Typical MC-UPQC used in a distribution system.

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 withBUS1 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).

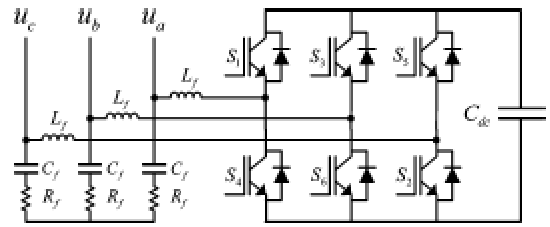

Figure 3: Schematic structure of a VSC

The commutation reactor L_f and high- pass output filter R_f, C_f are connected to prevent the flow of switching harmonics into the power supply. 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 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 andVSC3) operate as voltage controllers while the shunt VSC (i.e., VSC2) operates as a current controller.

In this section schematic diagram of UPQC and its designing, control objectives, functions are discussed and also what are MCUPQC and MCUPQC single line diagram and structure and how this MCUPQC connected between two adjacent feeders, their operation and functions of MCUPQC are discussed.

III. CONTROL STRATEGY

In this section we are discussing about control objectives of MCUPQC. The control strategy mainly based on the voltage source converters. 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. Details of the control algorithm, which are based on the d–q method, will be discussed later. Control strategy includes the controlling techniques of MC-UPQC. It is controlled by using the voltage source converters [4]. A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the

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voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. The converter is normally but based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics.

In this we are using two types of VSCs namely Series Voltage Source converter and Shunt Voltage Source converter. The structure of VSC consists of IGBTs. These are operated by using PWM techniques. These VSCs operates both rectifiers and inverters based on the requirement of operation. Finally these VSCs inject voltages into distribution lines.

Voltage Source Converter

The VSC is used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics.

The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power;
2. Correction of power factor; and
3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

The most advanced solution to compensate reactive power is the use of a Voltage Source Converter (VSC) incorporated as a variable source of reactive power. These systems offer several advantages compared to standard reactive power compensation solutions. Reactive power control generated by generators or capacitor banks alone normally is too slow for sudden load changes and demanding applications, such as wind farms or arc furnaces. Compared to other solutions a voltage source converter is able to provide continuous control, very dynamic behavior due to fast response times and with single phase control also compensation of unbalanced loads. The ultimate aim is to stabilize the grid voltage and minimize any transient disturbances.

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics.

The effectiveness of the DSTATCOM in correcting the voltage sag depends on the value of Zt□or fault level of the load bus. When the shunt injected current Is□ is kept in quadrature with V_L, the desired voltages correction can again be achieved without injecting any active power into the system. On the other hand, when the value of I_{sh} is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

Voltage magnitude is one of the major factors that determine the quality of power supply. Loads at distribution level are usually subject to frequent voltage sags due to various reasons. Voltage sags are highly undesirable for some sensitive loads, especially in high-tech industries. It is a challenging task to correct the voltage sag so that the desired load voltage magnitude can be maintained during the voltage disturbances.

The DSTATCOM can be used to correct the voltage sag at distribution level. A DSTATCOM is a shunt device that generates an ac voltage, which in turn causes a current injection into the system through a shunt transformer. The load voltage and injected current determine the power injection of the DSTATCOM. For lower voltage sags, the load voltage magnitude can be corrected by injecting only reactive power into the system. However, for higher voltage sags, injection of active power, in addition to reactive power, is essential to correct the voltage magnitude.

DSTATCOM is capable of generating or absorbing reactive power but the active power injection of the device must be provided by an external energy source or energy storage system.

Control Strategy for Shunt VSC

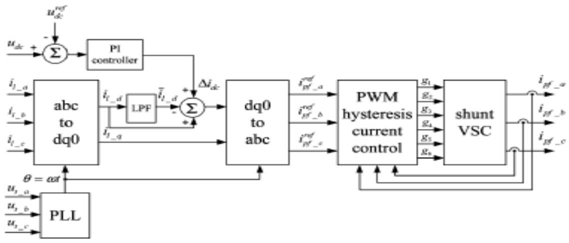

Figure 4: shows the control block diagram for the shunt VSC.

Shunt-VSC: Functions of the shunt-VSC are:

1) To compensate for the reactive component of load L1 current;
2) To compensate for the harmonic components of load L1current;
3) To regulate the voltage of the common dc-link capacitor.

Control Strategy for Series VSC

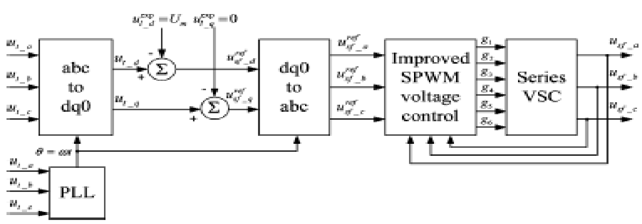

Figure 5: control Block diagram of Series VSC

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).

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 [5]. 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.

When the bus voltage is at the desired value ($U_l = U_t = U_0$), the series-injected voltage (U_{sf}) is zero. The shunt VSC injects the reactive component of load current $\mathbf{I_c}$, 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 I_c. The shunt VSC injects $\mathbf{I_c}$ in such a way that the active power requirement of the load is only drawn from the utility which results in a unity input-power factor. In an in phase 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. explains the operation of this scheme in case of voltage sag.

A comparison between in phase (UPQC-P) and quadrature (UPQC-Q) models is made for different sag conditions and load power factors. 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 above Sections, the power needed for interruption compensation in Feeder2 must be supplied through the shunts 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 is 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.

In this section the control strategies of MCUPQC with the use of VSC consists of series, shunt voltage source converters and PWM techniques are discussed. The VSCs used in MCUPQC has several functions to compensate voltage, current, reactive power, Power factor, etc. These are through several equations theoretically. The power rating analysis of the MC-UPQC also discussed.

IV. SIMULATION RESULTS

To verify the performance of proposed MC-UPQC, simulation was carried out in MATLAB software. The performance characteristics are shown in following section.

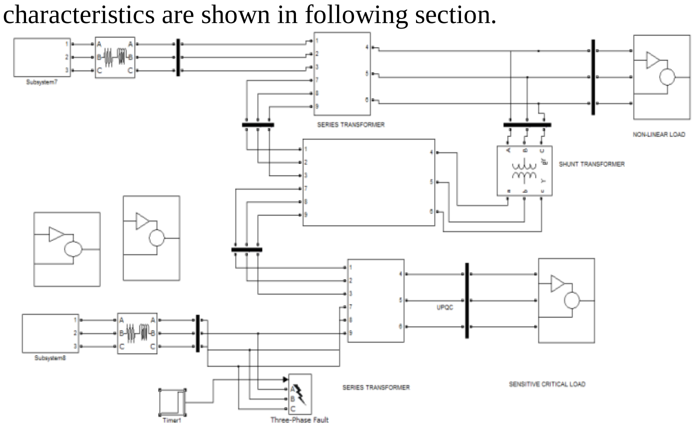

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Figure 6: Simulink model of MC-UPQC with unbalanced load system

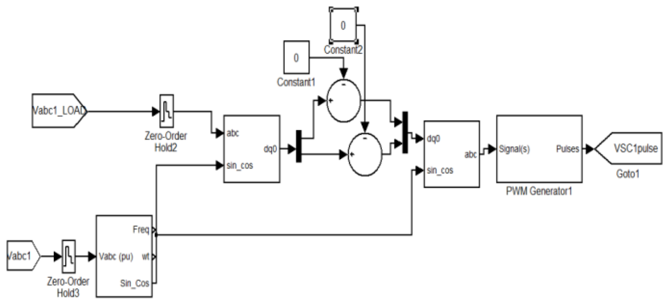

Figure 7: simulation model of control of series voltage source converter

Distortion and Sag/Swell on the Bus Voltage

Let us consider that the power system in fig consists of two three-phase three wire 380v, 50-HZ utilities. The BUS1 voltage contains the seventh-order harmonic with a value of 20%, and the BUS2 voltage contains the fifth-order harmonic with a value of 35%. The BUS1 voltage contains 25% sag between 0.1s<t<0.2s and 20% swell between 0.2s<t<0.3s. The BUS2 voltage contains 35% sag between 0.15s<t<0.25s and 30% swell between 0.25<t<0.3s. The nonlinear/sensitive load L1 is a three-phase rectifier load which supplies an RC load of 10 and 30F. Finally, the critical load L2 contains a balanced RL load of 10 and 100MH.

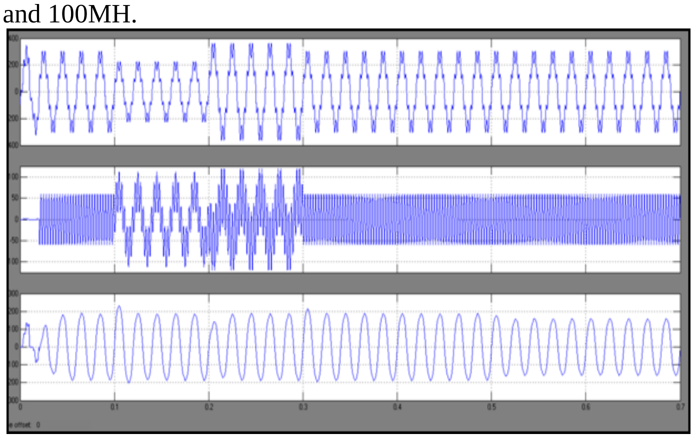

Figure 8: bus voltage, series compensating voltage, and load voltage in feeder1.

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 in all figures, only the phase a 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 .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.

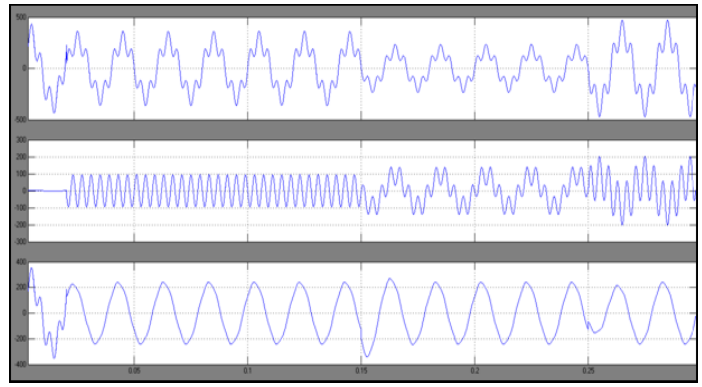

Figure 9: bus2 voltage, series compensating voltage, and load voltage in feeder2.

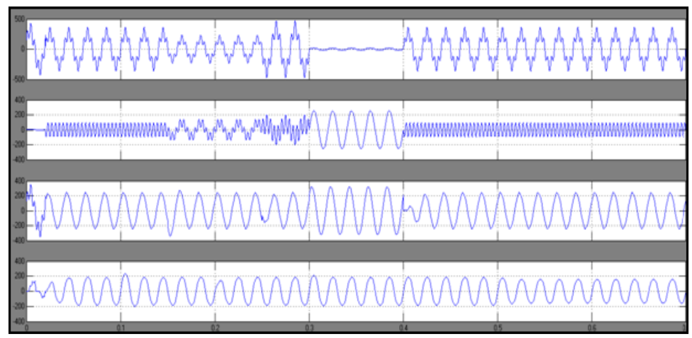

Figure 10: simulation results for an upstream fault on feeder2:bus2 voltage, compensating voltage and L1and L2 voltages.

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 nonlinear load current is compensated very well, and 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.

Up Stream Fault on Feeder2

When a fault occurs in feeder2 the voltage across the sensitive/critical loadL2 is involved in sag/swell or interruption. This voltage imperfection can be compensated for by VSC2.

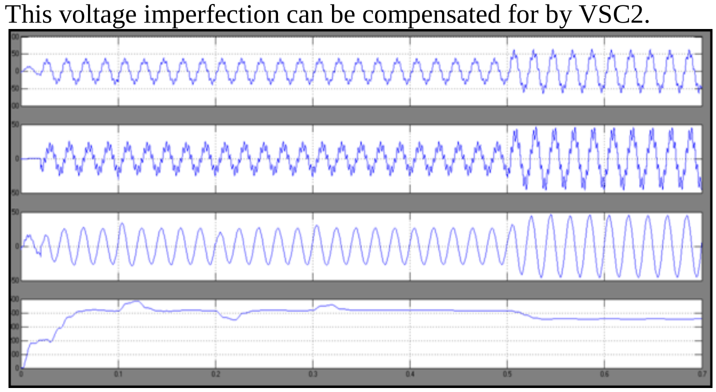

Figure 11: simulation result nonlinear load current, compensating current, feeder1and capacitor voltage

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 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 and customer average interruption frequency index. 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 0.3s <t < 0.4s. Simulation results are shown

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 L1 changes, the load voltages ut1 and ut2 remain undisturbed, the dc bus voltage is regulated, and the nonlinear load current is compensated.

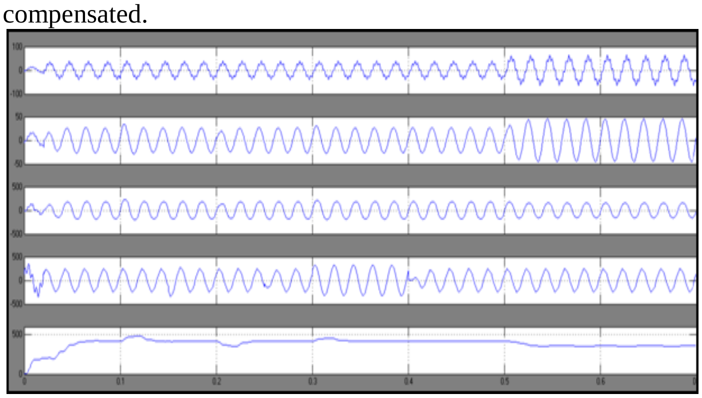

Figure 12: simulation results for load change: nonlinear load current, feeder1 current, load L1 voltage, and load L2 voltage, and dc-link capacitor voltage

Unbalance Voltage

The control strategies for shunt and series VASCs, which are introduced in section III, 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 bBUS1 Voltage is an unbalanced three-phase voltage with an unbalance factor of 40%.

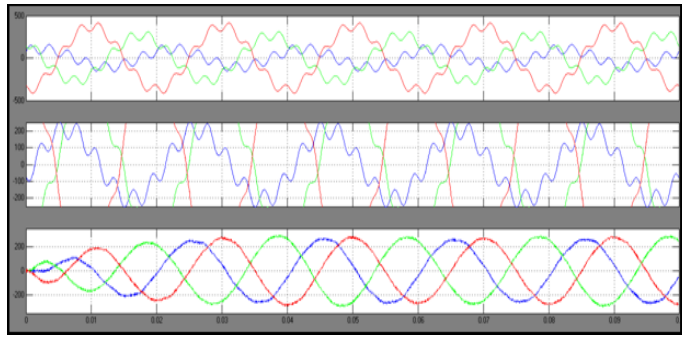

Figure 13: bus1 voltage, series compensating voltage, and load voltage in feeder1 under unbalanced source voltage.

The simulation results for the three-phase BUS1 voltage, series compensation voltage, and load voltage in feeder1 are shown in fig .the simulation results show that the harmonic components and unbalance of BUS1 voltage are compensated for by injecting the proper series voltage. In this figure, the load voltage is a three-phase sinusoidal balance voltage with regulated amplitude.

CONCLUSION

Finally 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 multi-bus/multi-feeders systems by adding more series VSC. 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 interruption 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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