Enhancement of Power Quality using Multi-Converter Unified Power Quality Conditioner

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Abstract

A new unified power-quality conditioning system (MC-UPQC) is presented in this paper. The response of the Multi converter unified power quality conditioner, for induction motor load is studied. MC-UPQC is capable of simultaneous compensation for voltage and current in multibus/multifeeder systems on the distribution side. In this configuration, one shunt voltage-source converter (shunt VSC) and two series VSCs exist. This system can be applied to express feeders which directly connect to non-linear/sensitive and critical loads, 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. In order to regulate the DC-link capacitor voltage, conventionally, a proportional controller (PI) is used to maintain the DC-link voltage at the reference value. The control strategies used for series and shunt voltage source converters are sinusoidal pulse-width modulation voltage control and hysteresis current control respectively. The performance of the proposed configuration has been verified through simulation studies using MATLAB/SIMULATION on a two-bus/two-feeder system.

Keywords: Power quality (PQ), unified power-quality conditioner (UPQC), voltage-source converter (VSC), proportional controller (PI).

1. Introduction

Along with the rapid development of technology and national economy, the demands of electric energy largely increase; correspondingly the power quality becomes more and more important. Power quality issues have become a serious concern by both electric industry and consumers.

Power quality problems can be defined as:
'Any power problem that results in failure or misoperation of customer equipment manifests itself as an economic burden to the user, or produces negative impacts on the environment.'[1]- [2]
The basic problems of power quality [1] are
• Power Factor
• Harmonic Distortion
• Voltage Transients
• Voltage Sags or Dips
• Voltage Swells

The AC and DC variable speed drives utilized in industries are significant contributors to total harmonic current and voltage distortion. [2].

The fifth harmonic voltage distortion causes serious problems in three phase motors as it a negative harmonic. When applied to induction motor it produces negative torque [2].The seventh harmonic creates a rotating field beyond the motors synchronous speed. The resulting torque pulsations cause wear and tear on coupling and bearings [3]. Another major power quality issue is voltage sag which is caused due to abrupt increase in the loads such as motor starting [4].Voltage sag when last longer than a cycle, many AC contactors will fall out disconnecting the motor from the supply.

Another aspect of power quality issue is voltage swell. This is caused due to line to ground faults making the unfaulted phases to depend on the zero sequence impedance [5].

The provision of both DSTATCOM and DVR can control the power quality of the source current and the load bus voltage. The primary function of the DVR is to rapidly boost up the load side voltage in the event of a disturbance in order to avoid any power disruption to

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that load [6] where as the DSTATCOM can compensate for distortions and unbalance in a load such that a balanced sinusoidal current flows through the feeder [7]. DSTATCOM can also regulate the voltage of a distribution bus [8]. A combination of DVR and DSTATCOM is termed as Unified Power Quality Conditioner (UPQC).An extensive study has been made and results have in obtained using PSCAD/EMTDC software in reference [9].

2. MC-UPQC System

In this paper MC-UPQC results are analysed using MATLAB software and a three phase induction motor is used as the non-linear load L1.

MC-UPQC is a new connection for a unified power quality conditioner (UPQC), capable of simultaneous compensation for voltage and current in multibus/multifeeder systems. It consists of a shunt voltage-source converter (shunt VSC) and two series VSCs, all converters are connected back to back on the DC side and share a common DC-link capacitor.

The aims of the MC-UPQC are:

A. To regulate the load voltage (u*l1*) against sag/swell and distortions in the system to protect the Non-Linear/sensitive load L1 i.e. the three phase induction motor.

B. To regulate the load voltage (u*l2*) against sag/swell and distortions in the system caused due to upstream fault on feeder2 to protect the sensitive / critical load L2.

C.To compensate for the reactive and harmonic components of nonlinear load current (i*l1*).

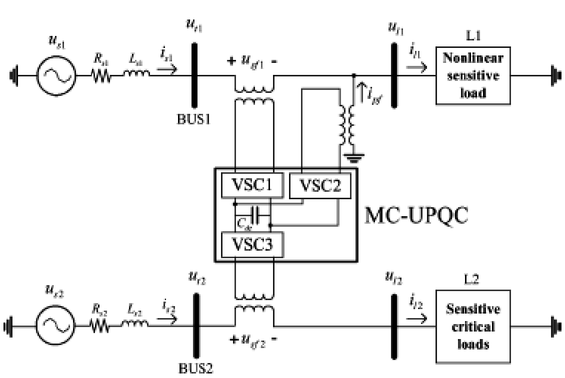

Fig.1: Typical MC-UPQC used in a distribution system.

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 ut1 and ut2, respectively. The shunt part of the MC-UPQC is also connected to load L1 with a current of *il1*.Supply voltages are denoted by *us1* and *us2* while load voltages are *ul1* and *ul2*. Finally, feeder currents are denoted by *is1* and *is2* and load currents are *il1* and *il2*. Bus voltages *ut1* and ut2 are distorted and may be subjected to sag/swell. The load L1 is a three phase induction motor 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 include production industries and critical service providers, such as medical centres, airports, or broadcasting centres where voltage interruption can result in severe economical losses or human damages.

3. Problem Formulation

A Unified Power Quality Conditioner (UPQC) consisting of two voltage source converters (VSCs) that are connected to a common DC bus. One is connected in shunt with the distribution feeder. Among the other two VSCs, one is connected in series with the same feeder while the other one is connected to the adjacent feeder. The DC- links of all VSCs are supplied through a common DC capacitor.

Four cases have been taken up to analyse the performance of UPQC.

1. Sag/swell and distortion on the bus voltage in feeder-1.
2. Upstream fault on feeder 2
3. Load change
4. Current compensation in feeder-1

4. Analysis of UPQC

MC-UPQC consists of three voltage source converters (VSCs) that are connected to a common DC bus.VSC1 is connected in series with BUS1 and VSC3 is connected in series with BUS 2at the end of feeder 2. VSC2 is connected in shunt with the induction motor load at the end of feeder 1.

The converters consisting of IGBTs are used as they are fast acting switches.IGBTs are efficient for medium power and low switching frequency applications.

Commutation reactor is used to limit the increase of current on the mains side and also prevents the flow of switching harmonics into the power supply, along with the high pass filter.

4.1 Series VSCs:

The function of series VSC is to mitigate voltage sag and swell, voltage harmonics and current compensation during interruption. The control algorithm used is based on d-q method. The control block of series VSC is shown in fig.2. It consists of abc to dq0 transformation block which computes the three phase quantities to the direct axes, quadrature axes and zero sequence voltages, in the rotating reference frame using Park's transformation.

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

Where

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

The controlling is based on comparison of a voltage reference and measured terminal voltage $\boldsymbol{u_{t\text{-}abc}}$. The PLL block is used to synchronise three phase terminal voltages on a set of frequency. The resultant signals are again transformed back to three phase quantities. This will be a vectorised signal consisting of three phase sinusoidal quantities. These are given to the PWM generator which generates pulses for the converter. The converter produces the three phase voltage signals $\boldsymbol{u_{sf\text{-}abc}}$ which is free from distortions and is fed to the non-linear load.

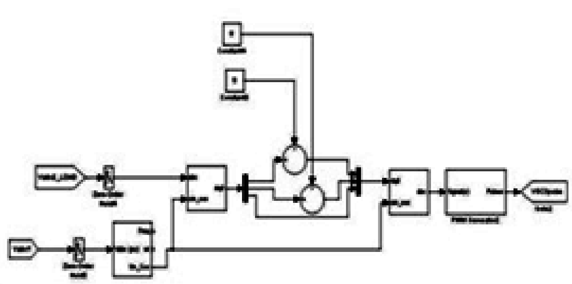

Fig.2 Control block of series VSC

4.2 Shunt VSC:

The function of shunt VSC is to compensate for the reactive and the harmonic components of the load currents of non-linear load. It should also regulate the voltage of common DC-link capacitor. Here the three phase load currents are converted to dq0 quantities and harmonics are eliminated to obtain three phase vectorised currents. These currents are used as carrier signals in the PWM hysteresis current control method to generate pulses for the shunt converter which produces distortions less currents for the load. PI controller is used maintain the DC-link voltage at the reference value $\boldsymbol{u_{dc\text{-}ref}}$.

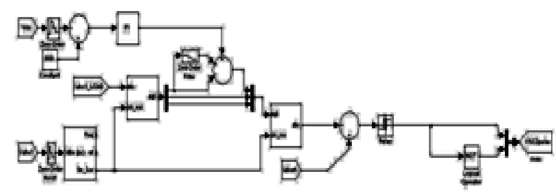

Fig.3 Control block of shunt VSC

4.3 Induction Motor Load:

Induction motor finds application in production industries. It requires pure sinusoidal AC supply for proper operation and for a larger lifetime. The fifth harmonic voltage distortion causes serious problems in three phase motors as it a negative harmonic. It produces negative torque which attempts to drive the motor in a reverse direction and slows it rotation. Motor draws more current to offset the reverse torque and regain its normal operating speed. This results in over current in the motor. The seventh harmonic creates a rotating field beyond the motors synchronous speed. The UPQC presented in this paper is capable of providing distortion less three phase input to the induction motor. The simulation block for UPQC is shown in fig4. The simulation results obtained in MATLAB/SIMULATION show the effectiveness of the system.

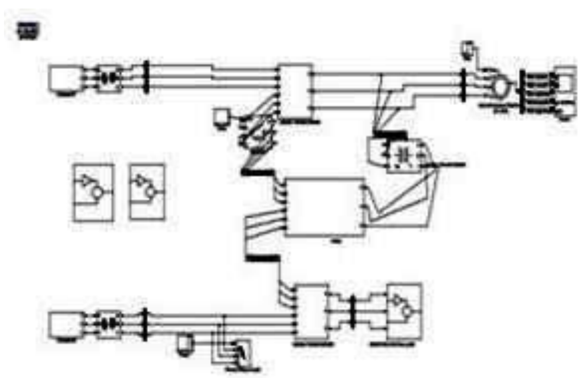

Fig.4 The simulation block of UPQC

5. Simulation Results

5.1. Sag/Swell and Distortion on the Bus Voltage in Feeder-1

Let us consider that the power system in Fig. 1 consists of two three-phase three-wire 380(v) (RMS, L-L), 50-Hz utilities. The BUS1 voltage (ut1) contains the seventh-order harmonic with a value of 22%, and the BUS2 voltage (ut2) 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 0.25s<t<0.3s.

The load L1 is a three-phase Induction motor load with configuration mechanical input torque (Tm), squirrel-cage rotor type with a reference frame and the machine ratings of nominal power 50H.P ,400V line-line voltage with frequency 50HZ. The critical load L2 contains a balanced RL load of 10Ω and 100mH. The MC–UPQC is switched on at t=0.02s.

The simulink model for distribution system with MC- UPQC is shown in figure 4. The BUS1 voltage, the corresponding compensation voltage injected by VSC1, and finally load L1 voltage are shown in Figure 5. Similarly, the BUS2 voltage, the corresponding compensation voltage injected by VSC3, and finally, the load L2 voltage are shown in figure 6

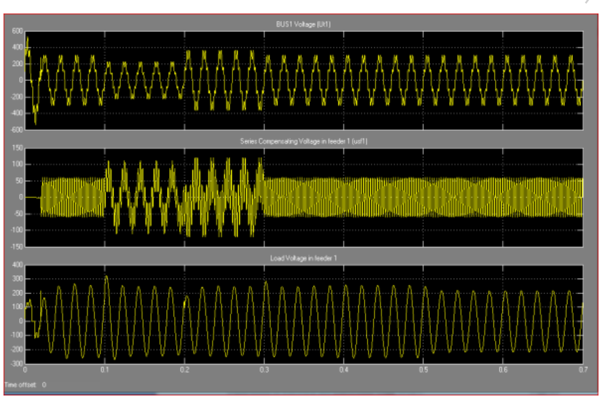

Fig 5. Simulation Result for BUS1 voltage, series compensating voltage, and load voltage in Feeder1.

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. 5. The distorted 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%.

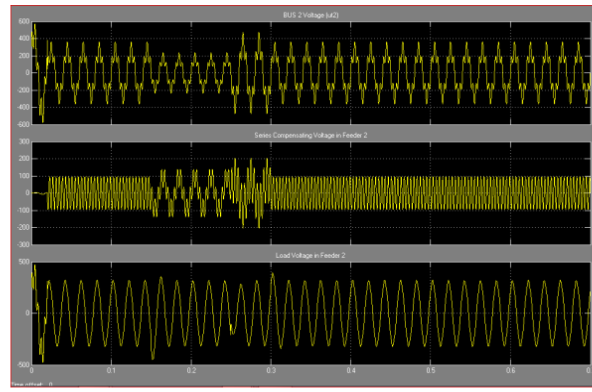

Fig 6.Simulation Result for BUS2 voltage, series compensating voltage, and load voltage in Feeder2.

Also, the DC voltage regulation loop has functioned properly under all disturbances, such as sag/swell in both feeders.

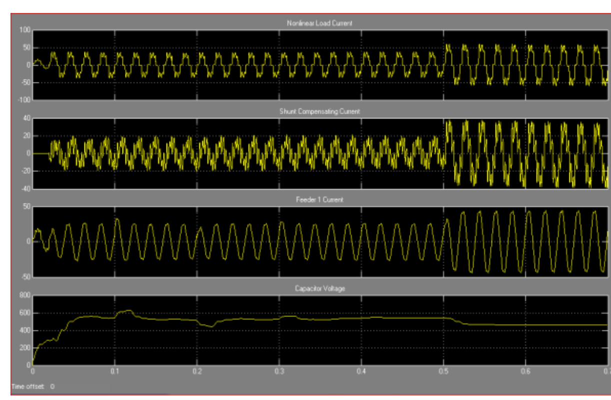

Fig 7.Simulation Result for Nonlinear load current, compensating current, Feeder1 current, and capacitor voltage.

5.2. 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 sensitive/critical 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. 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<0.4 s. Simulation results are shown in Fig.8

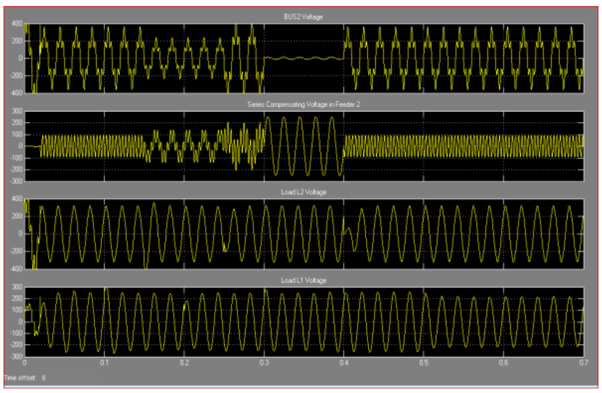

Fig 8.simulation results for an upstream fault on Feeder2: BUS2 voltage, compensating voltage, and loads L1 and L2 voltages.

5.3. Load Change

To evaluate the system behavior during a load change, the nonlinear load L1 is doubled by reducing its resistance to half at 0.5 s. The other load, however, is kept unchanged. In this case load current and source currents are suddenly increased to double and produce distorted load voltages (*Ul1* and U*l2*) as shown in Fig 9.

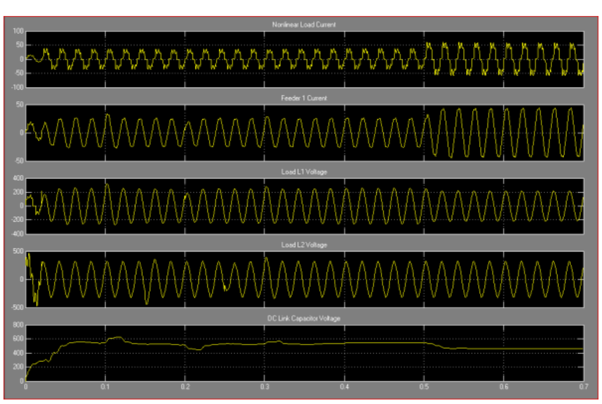

Fig 9.Simulation results for load change: nonlinear load current, Feeder1 current, load L1 voltage, load L2 voltage, and dc-link capacitor voltage

6. Conclusion

The present topology illustrates the operation and control of Multi Converter Unified Power Quality Conditioner (MC-UPQC). The system is extended by adding a series VSC in an adjacent feeder. The device is connected between two feeders coming from different substations. A non-linear/sensitive Induction motor load L-1 is supplied by Feeder-1 while a sensitive/critical load L-2 is supplied through Feeder-2. The performance of the MC-UPQC has been evaluated under various disturbance conditions such as voltage sag/swell in either feeder, fault and load change in one of the feeders. The MC-UPQC can mitigate voltage sag in Feeder-1 and in Feeder-2 for long duration. The reactive power compensation is provided and current is also regulated. UPQC enables sharing of power compensation capabilities between two adjacent feeders which are not connected. The analysis is done using MATLAB software.

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