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Optimal Design and Control Implementation of Unified Power Quality Conditioner

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Abstract

A simplified control algorithm for a three-phase, four-wire unified power quality conditioner (UPQC) is presented to compensate for supply voltage distortions/unbalance, supply current harmonics, the supply neutral current, the reactive power and the load unbalance as well as to maintain zero voltage regulation (ZVR) at the point of common coupling (PCC). The UPQC is realized by the integration of series and shunt active filters (AFs) sharing a common dc bus capacitor. The shunt AF is realized using a three-phase, four leg voltage source inverter (VSI) and the series AF is realized using a three-phase, three leg VSI. A dynamic model of the UPQC is developed in the MATLAB/SIMULINK environment and the simulation results demonstrating the power quality improvement in the system are presented for different supply and load conditions.

Keywords: Active Filter, Harmonics, Reactive Power, Unbalance, UPQC, Voltage Regulation

I. INTRODUCTION

The main objective of electric utility companies is to supply their customers with uninterrupted sinusoidal voltage of constant magnitude. However this is becoming increasingly difficult to do, because the size and number of non-linear and poor power factor loads such as adjustable speed drives, computer power supplies, furnaces and traction drives are increasing rapidly. Due to their nonlinear nature, these solid state converters cause excessive neutral currents in three phase four wire systems. Moreover, in the case of the distribution system, the overall load on the system is seldom found to be balanced. In the past, the solutions to mitigate these identified power quality problems [1] were through using conventional passive filters. But their limitations such as, fixed compensation, resonance with source impedance and the difficulty in tuning time dependence of filter parameters have ignited the need for active and hybrid filters [2]–[4]. The rating of active filters is reduced through augmenting them with passive filters [5], [6] to form hybrid filters, which reduce overall cost. Also they can provide better compensation than either passive or active filters. If one can afford the cost, then a hybrid of two active filters provides the best solution and thus it is known as a unified power quality conditioner (UPQC) or universal active filter. Presents a 3-phase, 4-wire UPQC configuration suitable for power distribution systems and a simple control algorithm for its control. The series AF is controlled to maintain voltage regulation and to eliminate supply voltage sag/swell, harmonics and unbalance from the load terminal voltage. The shunt AF is controlled to alleviate the supply current from harmonics, negative sequence current, reactive power and neutral current. The dc bus voltage is held constant by the shunt active filter. The performance of the proposed system is demonstrated through simulated waveforms and the harmonic spectra of supply currents and load voltages with and without UPQC. UPQC consists of two IGBT based VSC, one shunt and one series cascaded by a common DC bus. The main components of a UPQC are series and shunt power converters, DC capacitors, low-pass and high-pass passive filters, and series and shunt transformers. The key components of this system are as follows. 1) Two inverters —one connected across the load which acts as a shunt APF and other connected in series with the line as that of series APF. 2) Shunt coupling inductor L is used to interface the shunt inverter to the network. It also helps in smoothing the current wave shape. 3) A common dc link that can be formed by using a capacitor or an inductor. 4) An LC filter that serves as a passive low-pass filter and helps to eliminate high-frequency switching ripples on generated inverter output voltage. 5) Series injection transformer that is used to connect the series inverter in the network. A suitable turn ratio is often considered to reduce the voltage and current rating of series inverter. 6) The integrated controller of the series and shunt APF of the UPQC to provide the compensating voltage reference Vc and compensating current reference Ic.

II CONTROL SCHEME OF SERIES FILTER

A simple algorithm is developed to control the series and shunt filters. The series filter is controlled such that it injects voltages (vca; vcb; vcc), which cancel out the distortions and/or unbalance present in the supply voltages (vsa; vsb; vsc), thus making the voltages at the PCC (vla; vlb; vlc) perfectly balanced and sinusoidal with the desired amplitude. In other words, the sum of the supply voltage and the injected series filter voltage makes the desired voltage at the load terminals.

CONTROL SCHEME OF SHUNT FILTER

The control algorithm for a shunt AF consists of the generation of 3-phase reference supply currents and it is depicted in Fig. 3. This algorithm uses supply in-phase, 120_ displaced three unit vectors computed using eqn. (1). The amplitude of the reference supply current (I_ sp) is computed as follows. A comparison of the average and the reference values of the dc bus voltage for the shunt AF results in a voltage error, which is fed to a proportional integral (PI) controller and the output of the PI controller is taken as the reference amplitude of the supply currents. The three in-phase reference supply currents are computed by multiplying their amplitude (I_ sp) and in phase unit current vectors

SRF Control Technique

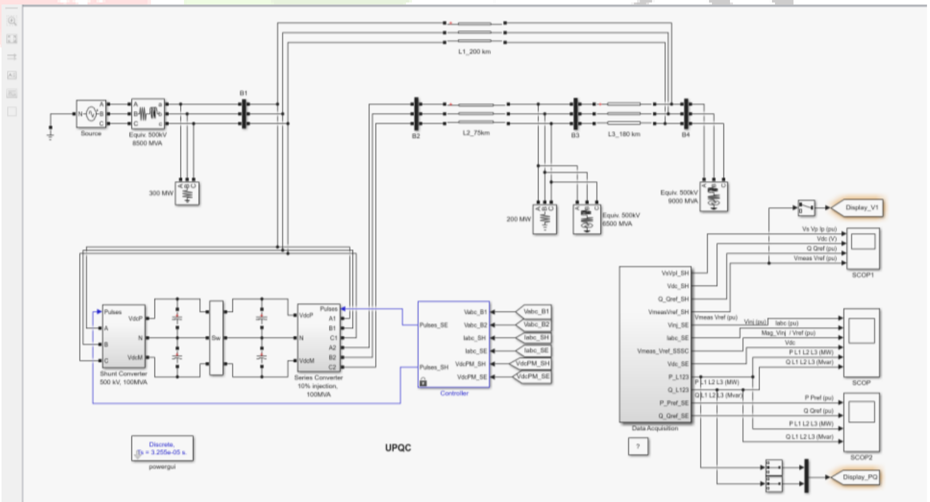
In the SRF-based APF applications in three-phase four wire (3P4W) systems, voltage and current signals are transformed into the conventional rotating frame (d−q−0). In the SRF method, the transformation angle (ωt) represents the angular position of the reference frame which is rotating at a constant speed in synchronism with the three-phase ac voltage.

III. OBJECTIVES

1. Series inverter - The inverters connected in series to the supply known as the series active filter. This inverter behaves as a voltage source line which eliminates a voltage interruption.
2. Shunt inverter - The inverter connected in shunt to the supply line is known as shunt active filter. It eliminates the current related harmonics also minimize the reactive current in the load circuit.
3. DC link - The capacitor or inductor can be used as common DC link. the capacitor is used as DC link, which supplies the DC voltage.
4. LC filter - The output of the series active filter produces high switching ripples. The LC filter minimizes the ripples in a system. The LC filter acts as the low-pass filter.
5. Lsh Filter - The Lsh filter act as a high-pass filter. The ripples during switching mode are minimized by Lsh filter.
6. Injection transformer - The series injection transformer connected to series convertor.

IV. SIMULATION RESULTS

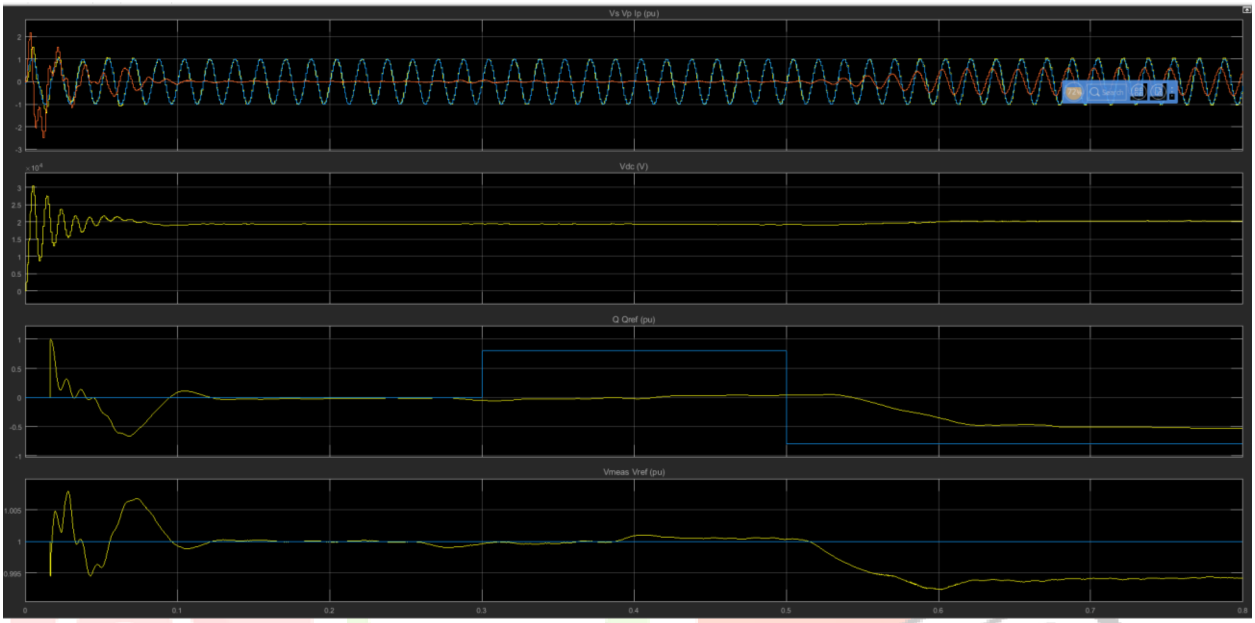
Simulation results for the proposed UPQC-based 3P4W topology are shown in Fig .MATLAB/Simulink is used as a simulation tool. The distorted voltage profile is shown in Fig. The UPQC should maintain the voltage at load bus at a desired value and free from distortion. The plant load is assumed to be the combination of a balanced three-phase diode bridge rectifier followed by an *R*–*L* load, which acts as a harmonic generating load, and three different single-phase loads on each phase, with different load active and reactive power demands. The resulting load current profile shown in Fig.



Description

A Unified Power Flow Controller (UPQC) is used to control the power flow in a 500 kV transmission system. The UPQC located at the left end of the 75-km line L2, between the 500 kV buses B1 and B2, is used to control the active and reactive powers flowing through bus B2 while controlling voltage at bus B1. It consists of two 100-MVA, three-level, 48-pulse GTO-based converters, one connected in shunt at bus B1 and one connected in series between buses B1 and B2. The shunt and series converters can exchange power through a DC bus. The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2. This pair of converters can be operated in three modes:

- **Unified Power Flow Controller (UPQC)** mode, when the shunt and series converters are interconnected through the DC bus. When the disconnect switches between the DC buses of the shunt and series converter are opened, two additional modes are available:
- Shunt converter operating as a **Static Synchronous Compensator (STATCOM)** controlling voltage at bus B1
- Series converter operating as a **Static Synchronous Series Capacitor (SSSC)** controlling injected voltage, while keeping injected voltage in quadrature with current.



Simulation

- **Power control in UPQC mode**
- The GUI allows you to choose the operation mode (UPQC, STATCOM or SSSC) as well as the Pref/Qref reference powers and/or Vref reference voltage settings. Also, in order to observe the dynamic response of the control system, the GUI allows you to specify a step change of any reference value at a specific time.
- the operation mode is set to "UPQC (Power Flow Control)". The reference active and reactive powers are specified in the last two lines of the GUI menu. Initially, Pref= +8.7 pu/100MVA (+870 MW) and Qref=-0.6 pu/100MVA (-60 Mvar). At t=0.25 sec Pref is changed to +10 pu (+1000MW). Then, at t=0.5 sec, Qref is changed to +0.7 pu (+70 Mvar). The reference voltage of the shunt converter (specified in the 2nd line of the GUI) will be kept constant at Vref=1 pu during the whole simulation (Step Time=0.3*100> Simulation stop time (0.8 sec). When the UPQC is in power control mode, the changes in STATCOM reference reactive power and in SSSC injected voltage.

V. CONCLUSION

The effectiveness of the UPQC has been demonstrated in maintaining three-phase balanced sinusoidal constant load voltages, harmonic elimination, power factor correction, load balancing and supply neutral current compensation. Supply currents and load voltage harmonic levels are maintained. This topology would be very useful to expand the existing three phase three wire system to three phase four wire system where UPQC is installed to compensate the different power quality problems. The MATLAB/Simulink based simulation results show that the source currents and load voltages are perfectly balanced and are free from distortion by applying both control techniques of the UPQC is reduced due to elimination of a fourth leg compared to three-phase four-leg VSI based three phase four wire UPQC.

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