

Design of a Dynamic Model of the Unified Power Quality Conditioner and its Operation Control

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Abstract— This paper presents a 3-phase unified power quality conditioner (UPQC) to compensate voltage fluctuation and current distortion in the power utility side. The UPQC compensates for any unbalanced or distorted three-phase supply voltages and load currents in a power distribution network. In this paper, UPQC and its control strategies are described. Hysteresis current controller is used for obtaining the gate pulses from the reference current and voltage signal. A dynamic model of the UPQC is developed in Simulink. The simulation results validate the performance of the proposed model and its operation control.

Keywords—unified power quality conditioner; Simulink; hysteresis current controller;

I. INTRODUCTION

The power distribution network contains many non-linear loads which introduce harmonics in line voltage and current. With the development of technology, more sensitive loads, such as computers, communication and medical equipments are used widely, and therefore power quality has become a significant issue to both customers and the utility companies. The operations of these equipments are very much affected by input voltage disturbances, and therefore, the elimination or mitigation of disturbances propagated from the distribution system is absolutely essential to improve the operational reliability of these loads.

Different types of disturbances are introduced in the supply system. The maximum allowable limit of the disturbance is given as – 10% voltage sag or swells, 5% total harmonic distortion and 10% voltage unbalance [1] as per IEEE-519 and IEC-555 [2]. The main objective is to provide power to the load following these above guidelines. Power electronics based FACTS devices [3] are used in distribution system to improve the quality and reliability of power supplied. These devices include Static Var Compensator (SVC), Dynamic Static Compensator (DSTATCOM) [4], Dynamic Voltage Regulator (DVR) Unified Series-Shunt Compensator (USSC) [5] and Unified Power Quality Conditioner (UPQC).

The UPQC is a relatively new member of the custom power device family. It contains both shunt and series compensators. Thus, it can handle any supply voltage and load current problems when installed in a power distribution

network. Since PQ (power quality) problem arises either because of supply voltage distortion or because of load current distortion, any PQ issues can be tackled by UPQC.

II. CONFIGURATION OF PROPOSED UPQC

The UPQC is a power electronics based compensator which works on active filtering [6] technique. The UPQC is used for simultaneous voltage fluctuation, harmonic distortion and power quality disturbance mitigation. In this paper, we have emphasized mainly on elimination of voltage fluctuation and harmonic distortion of voltage and current in the utility side. Though the active filters used in UPQC can be either voltage-source converters or current source converters, but the voltage-source converters are commonly used. It is a combination of Shunt (SHUC) and Series (SERC) Compensators, joined together back to back with the help of a DC link capacitor as shown in Fig.1. The SERC operates as a controlled voltage source and compensates for any voltage disturbance in the network. The SHUC works as a controlled current source and compensates for reactive or harmonic elements in the load.

The UPQC system is inherently complex in nature and various sophisticated control strategies [7], [8] are used to achieve the desired performance. Separate independently functioning control blocks are used for SHUC and the SERC. These two filters are connected to each other through a common DC link bus, which can be controlled by regulating the DC link voltage with the help of shunt control block.

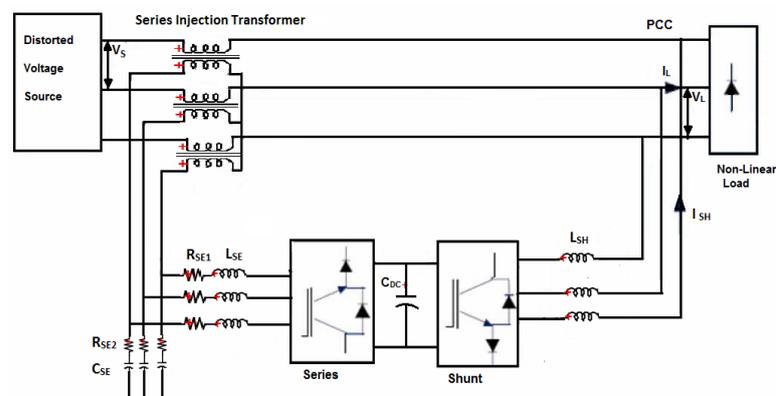


Fig. 1. Schematic Diagram of UPQC

A. Series Control Block

The SERC of the UPQC acts as a controlled voltage source. The voltage at the point of common coupling (PCC) is always regulated at a predetermined value.

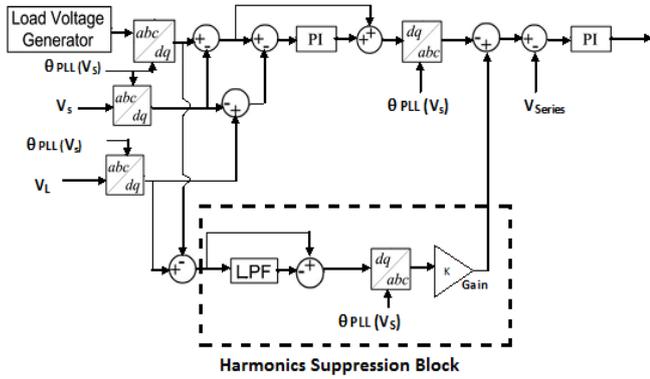


Fig. 2. Schematic diagram of series control block

Whenever there is a harmonics distortion in the waveform or a slight deviation from its fundamental value, the load voltage is regulated to its predetermined value with the help of series controller. It's another function is to provide a constant load voltage under voltage sag condition, by injecting a sizeable amount of injection voltage to keep the load voltage constant. First, the 3 phase supply voltage, the load voltage and ideal load voltage generator is transformed to synchronous d-q-0 frame. During sag, the source voltage V_s is subtracted from the reference load voltage and forms the forward path. Further, a feedback path is added by subtracting the load voltage V_L from its reference value which is fed to a PI controller to force the steady state error to zero, thus keeping the load voltage constant to its reference value [9]. For harmonics compensation, the load voltage is subtracted from its reference value in the synchronous d-q-0 frame. The fundamental frequency components, which appear as DC when transformed to d-q, are filtered out. The harmonic components of voltage are multiplied with a suitable gain and reference harmonic compensating voltage is obtained. This voltage added with sag compensating voltage is then subtracted from the measured series voltage and fed to a PI controller. The output of the PI controller forms the series reference voltage which is sent to hysteresis current controller to obtain gate pulses for the series active filter.

This damps the propagation of voltage harmonics in the distribution line as well as maintains the load voltage at the desired value. The overall control block representation realized is shown in Fig.2.

B. Shunt Control Block

The SHUC of the UPQC acts as a controlled current source which supplies the necessary current component at the PCC such that the source current at that point is always sinusoidal and at unity power factor. The overall block representation of the shunt current controller is given in Fig.3.

The load current at the point of common coupling is measured and converted to d-q components. The fundamental

frequency components when transformed to d-q are filtered out and the harmonic components of current are extracted. The shunt active filter then injects the same magnitude of harmonics but with the opposite polarity so that the harmonic distortions in the source current are cancelled out and remains distortion free. Thus, the source current always remains sinusoidal even if any non-linear load is connected.

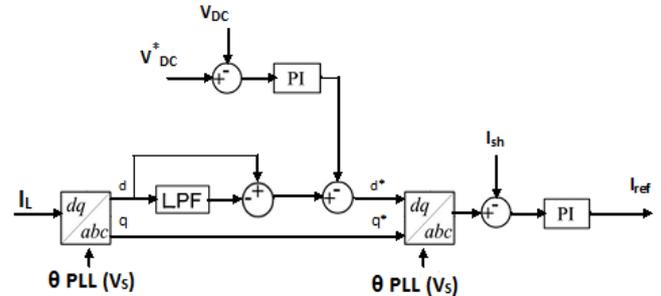


Fig. 3. Schematic diagram of shunt control block

The value of DC-link voltage depends on voltage level of the point of connection and has to be higher than the peak value of the voltage at the point of connection so that it can compensate for the reactive and harmonic currents of the load. In parallel, the difference between the dc link voltage and its constant reference value is fed to the d axis of current through a PI controller, thus forcing the error to be zero every time the DC voltage deviates from its normal value [9]. The sum of outputs obtained from the filter and the PI regulator is then compared with measured shunt current through a PI controller to obtain the shunt reference current.

The reference current generated is converted to gate signals for the shunt inverter by application of a suitable modulation technique. A hysteresis current controller is used to control the source current as it is an attractive choice because of its simplicity and robustness. The threshold upper limit and lower limit are formed by adding and subtracting appropriate offset values to the input signal. The reference current is now compared with the specified thresholds to generate the switching pulses for the shunt converter.

TABLE I. SYSTEM PARAMETERS

Parameters	Value
Source line voltage rating	230 V, 50 Hz
DC-link Capacitor (C_{DC})	6800 μ F
DC-link Voltage (V_{DC})	300 V
L_{SE}, R_{SE1}	3 mH, 0.01 Ω
C_{SE}, R_{SE2}	120 μ F, 1 Ω
L_{SH}	2 mH

III. SIMULATION RESULTS

In this section, the performance of our proposed UPQC is studied. The DC link voltage is maintained at 300V. In the first case, a distorted 3-phase source voltage is generated by deliberately introducing 10% of 5th and 10% of 7th order harmonics in the source voltage resulting in a THD of 14.25%. This distortion is largely blocked from propagating to the load, on activating the UPQC. The load voltage is given in Fig.4 and is seen to be unaffected by the distortion in the source voltage. Thus a balanced sinusoidal voltage of the desired value is obtained at the load with a mere THD of 0.73%.

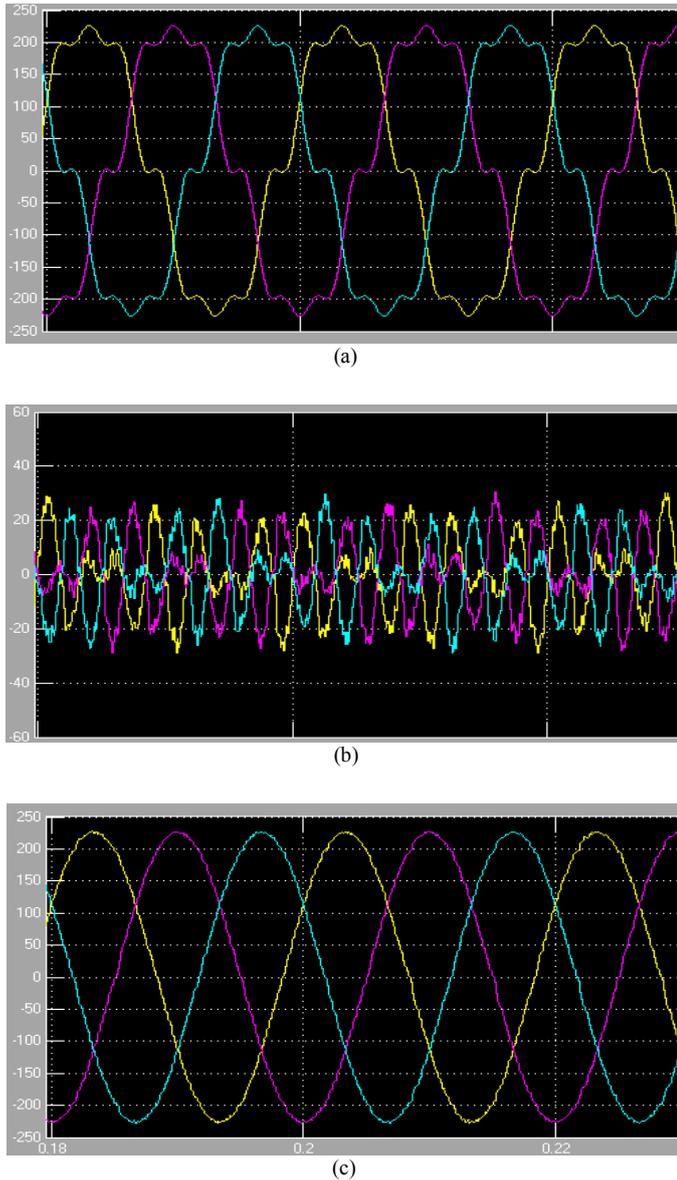


Fig. 4. Simulation results for distorted voltage supply (a) Source voltage waveform (b) Series Injection voltage waveform (c) Load voltage waveform

Due to the non-linear load, both the load current and the source current is heavily distorted, but with the help of shunt compensator, a uniform sinusoidal current is drawn from the

source as intended. Fig. 5 shows the source current, the shunt injection current and the load current.

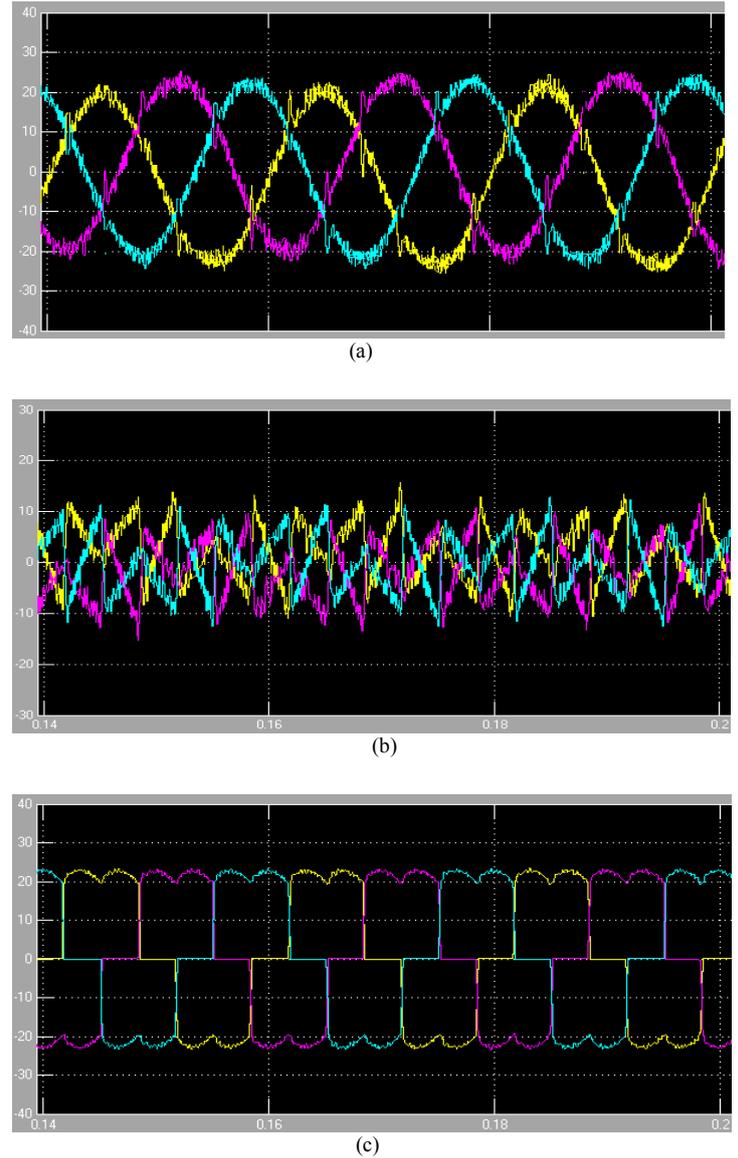
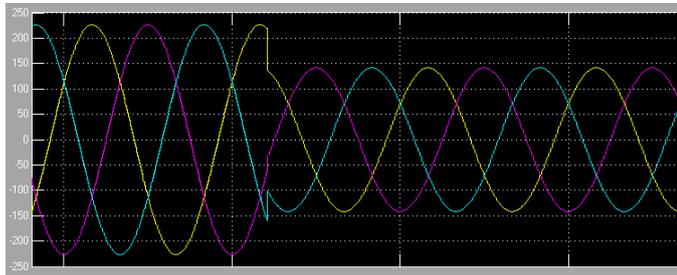


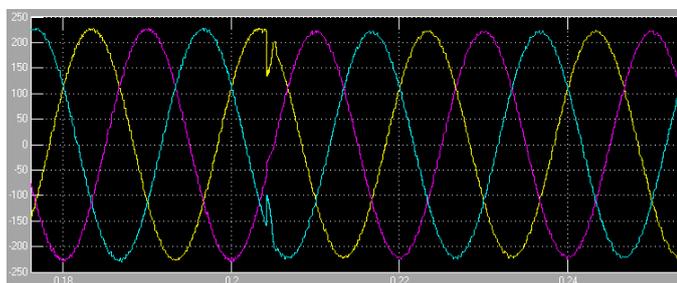
Fig. 5. Simulation results for current waveform due to non-linear load (a) Source current waveform (b) Shunt Injection current waveform (c) Load current waveform

In another case, voltage sag is considered where the line voltage is stepped down to 140V from 230V (40 % sag). During voltage sag, the series compensator injects the amount of deficient voltage into the transmission lines and the sag is therefore compensated with the required amount, thus the system voltage is regulated at a constant predetermined value. During this period, the source voltage decreases and the shunt inverter supplies the required constant power to the load. The voltage injected by the series compensator is in phase with the source and load voltage by consuming a proportional active power from the DC link. The DC link voltage is again brought back to its nominal value of 300V by the shunt compensator,

which draws a proportional active current during voltage sag. Thus, the source current increases and the magnitude of this new source current is determined by the shunt controller. This increased source current is taken up by the shunt controller terminals of the UPQC, whose injection current has a prominent fundamental component along with the harmonic components.



(a)



(b)

Fig. 6. Simulation results for source voltage sag (a) Source voltage waveform (b) Load current waveform

This increased power, which is drawn due to higher shunt current by the SHUC, is given out as an injected voltage to the deficient supply voltage by the series compensator, thus keeping the load voltage and power unchanged at a constant value.

Fig.6 shows the correspondingly sagged source voltage and the uniform load voltage after sag compensation.

IV. CONCLUSION

This paper offers a new model of UPQC with proper shunt and series control, by which harmonics, reactive power, and voltage sags, swells and imbalance are compensated promptly within the allowable limits. Ability of all three systems for the

current harmonic cancellation and line voltage harmonics, and sag conditioning has been studied in this paper and the corresponding simulation results are presented. The total harmonic distortion (THD) of the source current and the load voltage is brought down well within IEEE specifications. This newly proposed UPQC is therefore seen to be effective in improving the power quality at the point of installation, while using less complex series and shunt control without compromising its performance.

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