Performance Analysis of UPQC for Non-Linear Load by Using MATLAB

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***Abstract* - In this paper, a simplified control algorithm for a three-phase, 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 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.**

***IndexTerms* - Active Power Filter (APF), UPQC, Harmonics Voltage Sag, Voltage Swell, Power Quality.**

I. INTRODUCTION

The main objective of electrical utility corporations is to produce their customers with uninterrupted sinusoidal voltage of constant magnitude. But this can be turning into more and more difficult to do, as a result of the size and number of non-linear and poor power factor loads like adjustable speed drives, computer power supplies, furnaces and traction drives are increasing speedily. As a result of 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 load on the system is rarely found to be balanced.

In the past, the solutions to mitigate these known power quality issues [1] were through using typical passive filters. however their limitations like, fixed compensation, resonance with supply impedance and therefore the problem in calibration time dependence of filter parameters have ignited the necessity for active and hybrid filters [2]–[4]. The rating of active filters is reduced through augmenting them with passive filters [5], [6] to create hybrid filters that reduce overall value. Additionally they'll offer higher compensation than either passive or active filters. If one will afford the price, then a hybrid of two active filters provides the most effective solution and therefore it's referred to as a unified power quality conditioner (UPQC) or universal active filter. Therefore, the development of hybrid filter technology has been from a hybrid of passive filters to a hybrid of active filters to supply an economical solution and best compensation [7]–[12].

Recently a lot of attention is being paid on mitigation of voltage sags and swells using UPQC. The swells aren't as common as sags; however the consequences of a swell are often a lot of damaging than sag. For instance, the excessive overvoltage throughout swell condition might cause breakdown of components or equipments. The common reason behind voltage sag and swell is sharp change of line current flowing through the supply impedance.

This paper presents a 3-phase UPQC configuration suitable for power distribution systems and a simple control algorithm for its control. The series APF is controlled to maintain voltage regulation and to eliminate supply voltage sag/swell, harmonics and unbalance from the load terminal voltage. The shunt APF is controlled to alleviate the supply current from harmonics, negative sequence current, reactive

II. SYSTEM CONFIGURATION

The best protection for sensitive loads from sources with inadequate quality is shunt-series connection i.e. unified power quality conditioner (UPQC). Recent analysis efforts are created towards utilizing unified power quality conditioner (UPQC) to solve nearly all power quality issues for example voltage sag, voltage swell, voltage outage and over correction of power issue and unacceptable levels of harmonics in the current and voltage the fundamental configuration of UPQC is shown in Figure-1.

The major parts of the UPQC is

- Series Active Power Filter
- Shunt Active Power Filter
- DC link Capacitor
- High Pass Filter
- Low Pass Filter
- Series Transformer

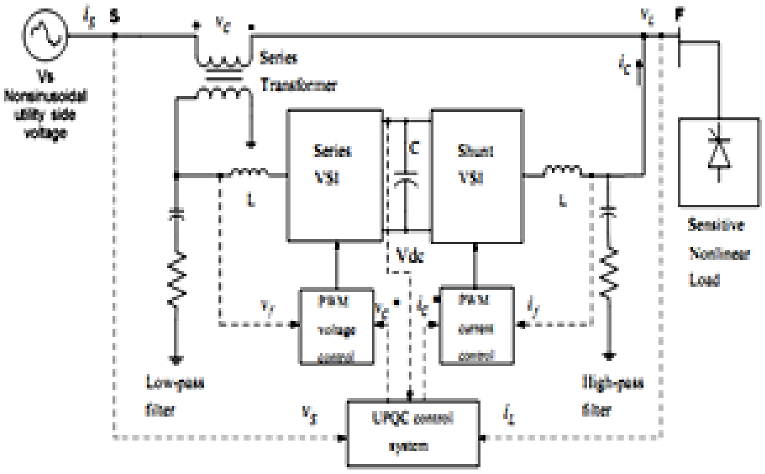

Figure 1 Basic Block of UPQC

The voltage at PCC could also be or might not be distorted looking on the other non-linear loads connected at PCC. Also, these loads might impose the voltage sag or swell condition throughout their switching ON and/or OFF operation. The UPQC is put in so as to shield a sensitive load from all disturbances. It consists of two voltage source inverters connected back to back, sharing a common dc link. One inverter is connected parallel with the load. It acts as shunt APF, helps in compensating load harmonic current, reactive current and maintain the dc link voltage at constant level. The second inverter is connected in series with the line using series transformers, acts as a controlled voltage source maintaining the load voltage sinusoidal and at desired constant voltage level.

As shown in Figure 1 V_S, V_C, V_L, I_C is the supply voltage, series compensation voltage, and load voltage and shunt compensation current respectively. The source voltage may contain negative, zero as well as harmonic component. The system (utility) voltage at pint S can be expressed as:

$$V_S = V_{1p}(t) + V_{1n}(t) + \sum_{k=2}^{\infty} V_k(t) \qquad [1]$$

Where V_{1p} is the fundamental frequency positive sequence components, V_{1n} is the fundamental frequency negative sequence components respectively. The last term of equation represents the harmonic content in the voltage and θ_{1p}, θ_{1n} and θ_k are the corresponding voltage phase angles.

Usually, the voltage at the load of point of common coupling (PCC) is expected to be sinusoidal with fixed amplitude V_L:

$$V_L = V_L \sin(\omega t + \theta_{1p}) \qquad [2]$$

Hence the series inverter will need to compensate for the following components of voltage:

$$V_C = (V_L - V_{1p})\sin(\omega t + \theta_{1p}) - V_{1n}(t) - \sum_{k=2}^{\infty} V_k(t) \qquad [3]$$

In the subsequent sections, it will be shown how series-APF can be designed to operate as a controlled voltage source whose output voltage would be automatically controlled using the above described logic.

To provide load reactive power demand and compensation of the load harmonic and negative sequence currents, the shunt-APF acts as a controlled current source and its output component should include harmonic and negative sequence components in order to compensate these quantities in the load current. The distorted non-linear load current can be expressed as:

$$i_L = I_{1p}\sin(\omega t + \delta_{1p}) + i_{1n}(t) + \sum_{k=2}^{\infty} i_k(t) \qquad [4]$$

It is usually desired to have a certain phase angle (displacement power factor angle), ϕ_L between the positive sequence voltage and current at the load terminal.

$$\left.\begin{array}{l} \phi_L = \delta_{1p} - \theta_{1p} \\ or \\ \delta_{1p} = \theta_{1p} + \phi_L \end{array}\right\} \qquad [5]$$

Substituting equation [5] into equation [4] and simplifying yields

$$i_L = I_{1p}\sin(\omega t + \theta_{1p})\cos\phi_L + I_{1p}\cos(\omega t + \theta_{1p})\sin\phi_L + i_{1n}(t) + \sum_{k=2}^{\infty} i_k(t) \qquad [6]$$

In order to compensate harmonic current and reactive power demand, the shunt active filter should produce the following current:

$$i_C = I_{1p}\cos(\omega t + \theta_{1p})\sin\phi_L + i_{1n}(t) + \sum_{k=2}^{\infty} i_k(t) \qquad [7]$$

Then the harmonic, reactive and negative sequence current will not flow into power source. Hence, the current from the source terminal will be:

$$i_S = i_L - i_C = I_{1p}\sin(\omega t + \theta_{1p})\cos\phi_L \quad [8]$$

There are also some switching losses in the converter, and hence the utility must supply a small overhead for the capacitor leakage and converter switching losses in addition to the real power of the load. The total current supplied by the source is therefore

$$i_S = i_S + i_{Sl} \quad [9]$$

III. EASE OF USE

A simple algorithm is developed to control the series filters. The control strategy is based on the extraction of Unit Vector Templates (UVT) from the distorted supply. Figure 2 shows the block diagram of the controlling of series active filter.

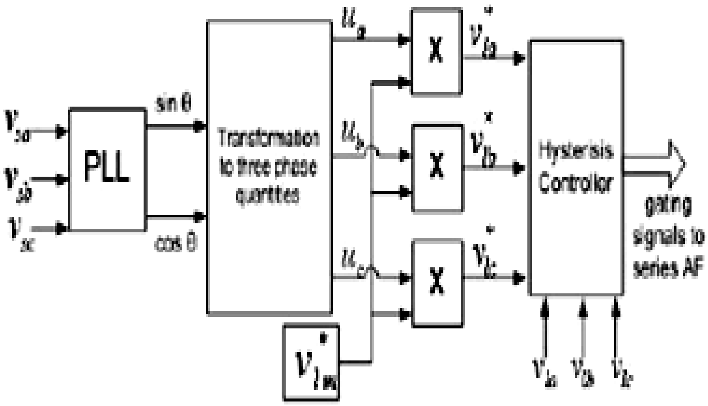

Figure 2 Controllers for Series Active Power Filter

The series filter is controlled such that it injects voltages that wipe out the distortions and/or unbalance present within the provide voltages therefore creating the voltages at the load terminal perfectly balanced and sinusoidal with the specified amplitude. Three phase distorted/unbalanced supply voltages are detected and given to the PLL that generates angle (ωt) varying between 0 and 2π radian, synchronized on zero crossings of the fundamental (positive-sequence) of phase A. The detected supply voltage is multiplied with an acceptable value of gain before being given as an input to the PLL. The angle output from the PLL is used to compute the supply in phase, 120^0 displaced three unit vectors. The series filter is controlled such that it injects voltages (v_{Ca}, v_{Cb}, v_{Cc}) which cancel out the distortions and/or unbalance present in the supply voltages (v_{Sa}, v_{Sb}, v_{Sc}) thus making the voltages at the load terminal (v_{La}, v_{Lb}, v_{Lc}) perfectly balanced and sinusoidal with the desired amplitude. The computed three in-phase unit vectors are then multiplied with the desired peak value of the PCC phase voltage (v_{lM}) which becomes the three-phase reference load voltages as from equation [10].

$$\begin{bmatrix} v_{La}^* \\ v_{Lb}^* \\ v_{Lc}^* \end{bmatrix} = [v] \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad [10]$$

To generate injected voltages, supply voltage signals are compared with these reference signals and these signals are then given to the hysteresis controller along with the sensed series APF output voltages.

IV. CONTROL OF SHUNT ACTIVE POWER FILTER

The control process of a shunt active power filter must estimate the current reference waveform for each phase of the inverter, preserve the dc voltage constant, and produce the inverter gating signals. Also the compensation effectiveness of an active power filter depends on its aptitude to follow the reference signal calculated to compensate the distorted load current with a minimum error and time delay. The shunt component of UPQC can be controlled in two ways

- Tracking the Shunt Converter Reference Current
- Tracking the Supply Current

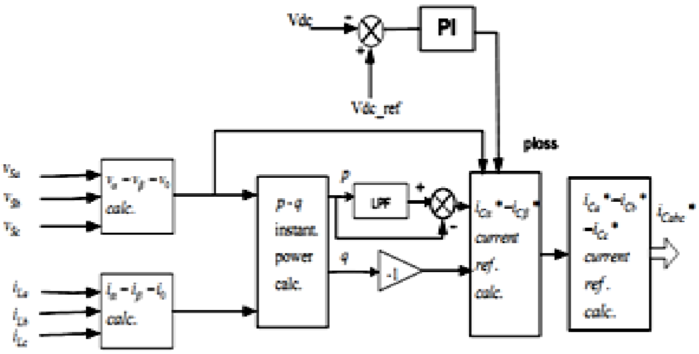

Figure 3 Controller for Shunt Active Power Filer

The concept of instantaneous active and reactive powers and its application for shunt active filter reference currents generation was created by Akagi.

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. 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.

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V. SIMULATION RESULT

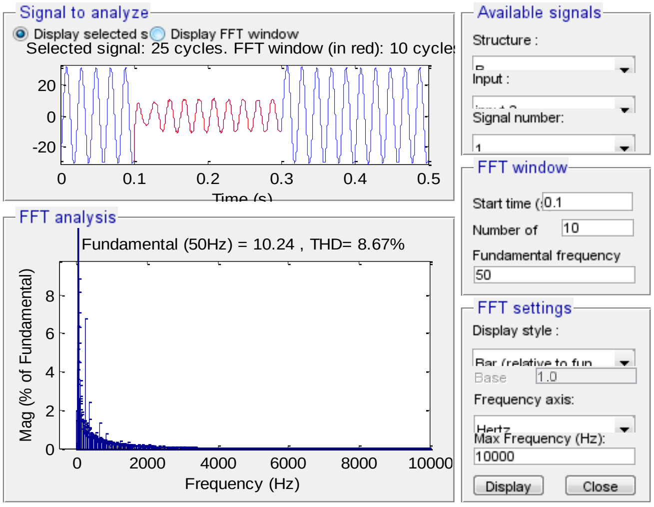
The performance of unified power quality conditioner (UPQC) is present in this section to evaluate the proposed control strategy. The simulation models have been developed in MATLAB/SIMULINK environment. The models have been operated for non-linear load as well as unbalanced load. In order to introduce non-linear load a three phase diode bridge with RL load on dc side is used. For unbalanced load we connect three variable resistors as a load. The simulation results under voltage sag and swell condition are presented. Additionally, the simulation result under distorted voltage condition is also presented. The shunt active power filter compensates current disturbances and also maintains the dc link voltage to reference value. While series active power filter compensates voltage related problems for maintaining required load voltage. The whole simulation is run for 0.5 sec.

The system parameters used are as follows:

Supply: Voltage and frequency Vs= 400 Vrms, f= 50 Hz,
Load: 3 phase ac line inductance 2 mH
3 phase dc inductance and resistor Ldc3=10mH, Rdc3=30 ohm
DC Link Capacitor C = 6800 µF
Shunt APF: Filter resistor and capacitor: 5 ohm, and 10 µF
Ac line inductance: 3.5 mH
Series APF: Filter resistor and capacitor5 ohm and 20 µF
Ac line inductance: 1.5 mH

Figure 4.1 to 4.3 shows the FFT analysis of the Shunt APF.

Figure 4.4 to 4.6 shows the FFT Analysis of Series APF


Selected signal: 25 cycles. FFT window (in red): 10 cycle

Fundamental (50Hz) = 10.24 , THD= 8.67%

Signal number: 1

Start time (: 0.1

Number of 10

Fundamental frequency 50

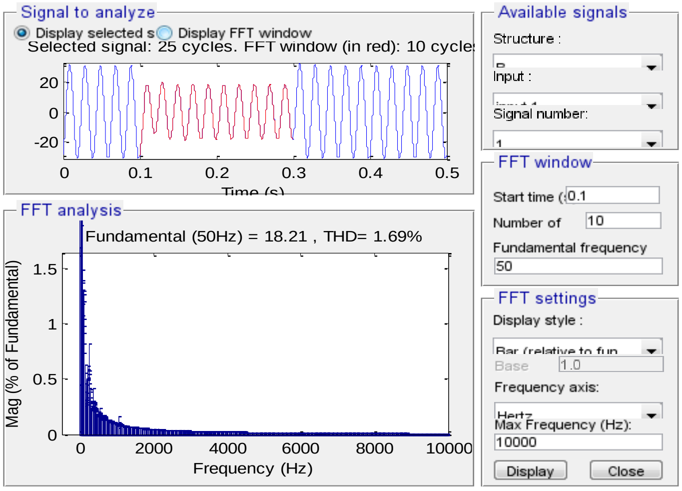
Display style : Bar (relative to fun

Base 1.0

Frequency axis: Hertz

Max Frequency (Hz): 10000

Figure 4.1 FFT Analysis of Source Current with compensation SAPF


Selected signal: 25 cycles. FFT window (in red): 10 cycle

Fundamental (50Hz) = 18.21 , THD= 1.69%

Signal number: 1

Start time (: 0.1

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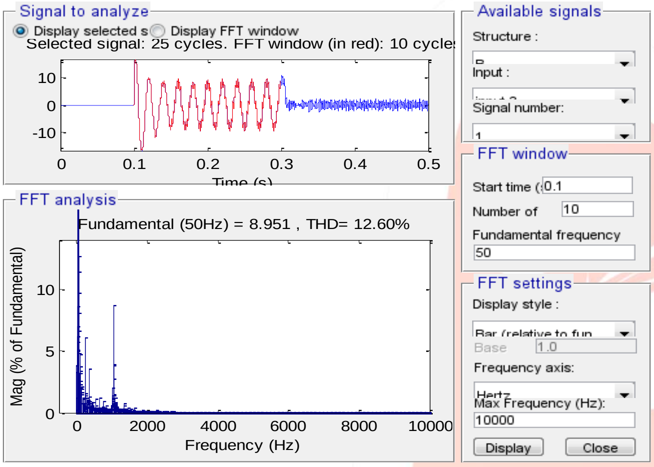
Max Frequency (Hz): 10000

Figure 4.2FFT Analysis of Load Current with compensation SAPF


Selected signal: 25 cycles. FFT window (in red): 10 cycle

Fundamental (50Hz) = 8.951 , THD= 12.60%

Signal number: 1

Start time (: 0.1

Number of 10

Fundamental frequency 50

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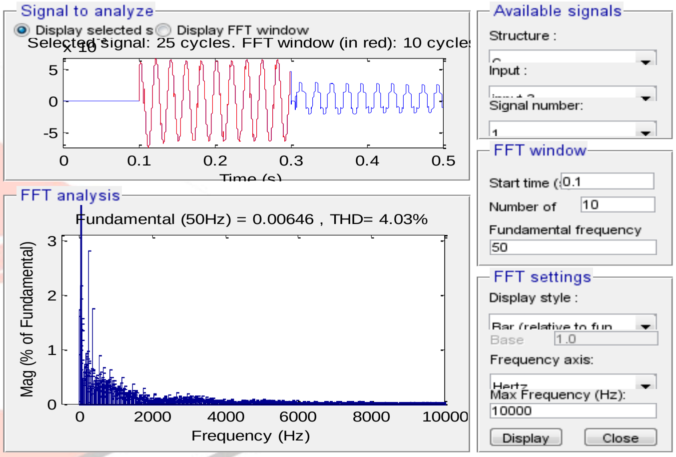
Frequency axis: Hertz

Max Frequency (Hz): 10000

Figure 4.3 FFT Analysis of Compensation current of SAPF


Selected signal: 25 cycles. FFT window (in red): 10 cycle

Fundamental (50Hz) = 0.00646 , THD= 4.03%

Signal number: 1

Start time (: 0.1

Number of 10

Fundamental frequency 50

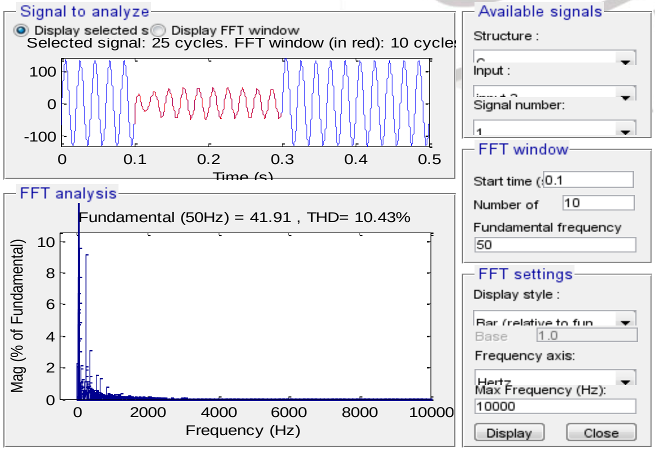
Display style : Bar (relative to fun

Base 1.0

Frequency axis: Hertz

Max Frequency (Hz): 10000

Figure 4.4 FFT Analysis of Source Voltage with Series APF


Selected signal: 25 cycles. FFT window (in red): 10 cycle

Fundamental (50Hz) = 41.91 , THD= 10.43%

Signal number: 1

Start time (: 0.1

Number of 10

Fundamental frequency 50

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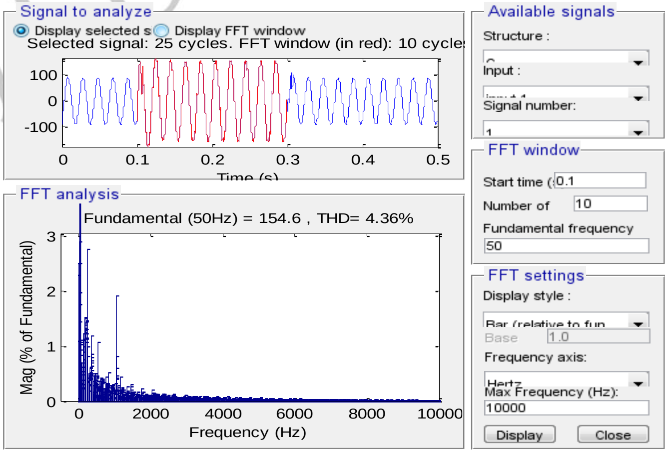
Frequency axis: Hertz

Max Frequency (Hz): 10000

Figure 4.5 FFT Analysis of Load Voltage with Series AP


Selected signal: 25 cycles. FFT window (in red): 10 cycle

Fundamental (50Hz) = 154.6 , THD= 4.36%

Signal number: 1

Start time (: 0.1

Number of 10

Fundamental frequency 50

Display style : Bar (relative to fun

Base 1.0

Frequency axis: Hertz

Max Frequency (Hz): 10000

Figure 4.6 FFT Analysis of Compensation of VOLTAGE

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