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Comparison of Control Algorithm of Fourier analysis over d-q theory of Single-Phase UPQC

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Abstract:- Single phase unified power quality conditioner (UPQC) consists of series and shunt active power filter (APF) with common dc- capacitor. Series converter acts as voltage source converter and shunt converter acts as current source converter. Use of non-linear loads results in voltage and current harmonics. These harmonics can be eliminated by using single phase UPQC. So that, which also improves the power quality at the point of common coupling (PCC). This paper presents control methods of single –phase d-q theory and fourier analysis of single-phase UPQC. The two control methods are studied, analyzed and simulation models are developed for two methods using MATLAB software. The simulated results show that for distorted supply power quality is improved and the total harmonic distortion of source current are compared for two control methods.

Keywords:- Active Power Filter, Harmonics, Power Factor Correction, Power Quality, UPQC,**THD**

I. INTRODUCTION

The power electronic loads in industry causes an increasing deterioration of the power system voltage and current waveforms. As a result, harmonics are generated from power converters or nonlinear loads[7]. This causes the power system to operate at low power factor, low efficiency, increased losses in transmission and distribution lines, failure of electrical equipments, and interference problem with communication system. So, there is a great need to mitigate these harmonic and reactive current components. Active Power filters are a viable solution to these problems. The continuous usage of non-linear loads injects current and voltage harmonic components into the power system and increases reactive power demands and power system voltage fluctuations. The amount of distortion in the voltage or current waveform is quantified by means of an index called the total harmonic distortion (THD). One of the effective approaches is to use a unified power quality conditioner (UPQC) at PCC to protect the sensitive loads. A UPQC is a combination of shunt and series APFs, sharing a common dc link [5-12]. It is a versatile device that can compensate almost all power quality problems such as voltage harmonics, voltage unbalance, voltage flickers, voltage sags & swells, current harmonics, current unbalance, reactive current, etc.

To control a single-phase UPQC different control strategies[2] are reported some of these are based on single phase p-q theory, adaptive interference cancellation theory, detection of fundamental at zero crossing using digital control, multi variable regulator (MVR) and neural network etc. In this paper two control algorithms namely single-phase d-q theory, and fourier analysis have been proposed and compared for the shunt APF and series APF of UPQC.

II. SINGLE PHASE UPQC CIRCUIT CONFIGURATION

Fig.1 shows the proposed single-phase, two-wire UPQC connected to a power system feeding a combination of linear and non-linear load. An R-L load is considered as a linear load and a single-phase diode bridge rectifier drawing constant dc current is considered as the non-linear load. It consists of series APF and shunt APF, in which series APF is used as a voltage controller and shunt APF used as a current controller. The dc link of both active filters is connected to a common dc link capacitor. The series filter is connected between the supply and load terminals using a single phase transformers with turn's ratio of 5:1. In addition to injecting the voltage, this transformer is used to filter the switching ripple content in the series active filter. A small capacity rated R-C filter is connected in parallel with the secondary of the series transformer to eliminate the high switching ripple content in the series active filter injected voltage. The voltage source inverter for both the active filter are implemented with IGBTs (Insulated gate Bipolar Transistors). The implemented control algorithm consists mainly of the computation of reference of fundamental source current (i*s) and load voltage (vl*) respectively. The values of the circuit parameters and load under consideration are given in Appendix.

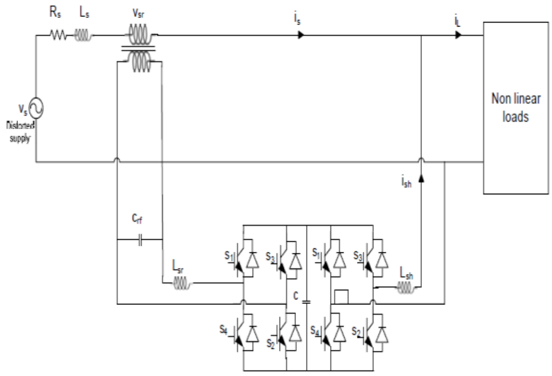


Fig1. Detailed configuration of UPQC

III. CONTROL SCHEME FOR SERIES APF

The control scheme of series APF is to generate reference voltage signals at PCC. By using non linear loads supply voltage is distorted. The series APF filter is controlled such that it injects required voltages, which cancel out the distortions present in the supply voltage, thus making the voltage at PCC perfectly sinusoidal with the desired amplitude.

A. Control of Series APF using Single-phase d-q theory

The reference load voltage is extracted by using an imaginary variable of load voltage leaded by 90^o with respect to the sensed load voltage. The series APF filter is controlled such that it injects required voltages, which cancel out the distortions present in the supply voltage, thus making the voltage at PCC perfectly sinusoidal. The block diagram for the control strategy for the series APF is shown in Fig. 3.

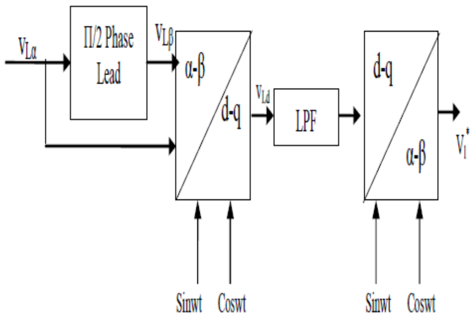


Fig2. Control scheme of series APF using d-q theory

B. Control of Series APF using Fourier analysis

The magnitude and phase angle of load voltage are calculated. The reference load voltage can be obtained as per the block diagram shown in Fig.3. In each control algorithm the sensed (V_L) load voltage and reference load voltage (V_L^*) are compared in a hysteresis voltage controller to generate the switching signals to the switches of the series APF. The series APF compensates voltage harmonics by injecting out of phase harmonic voltage so that, making load voltage distortion free.

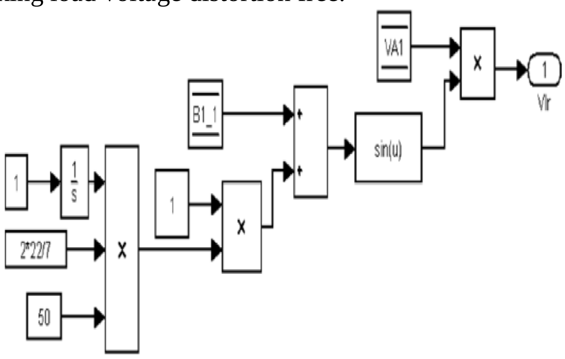


Fig4. Control scheme of series APF using Fourier analysis

IV. CONTROL SCHEME OF SHUNT APF

The control algorithm for shunt APF is to make the source current sinusoidal and in phase at PCC.

A. Control scheme of Shunt APF using Single-phase d-q theory

Without using any transformation matrix a single phase system can be represented directly in α-β frame. In this approach an imaginary variable, orthogonal to α, is generated from the original variable voltage/current by shifting it by 90° .The original signal along with the imaginary signal thus can be considered as equivalent representation of a single-phase system in orthogonal α-β frame. Using the concept of single phase p-q theory, the load current in α-β frame can be represented as:

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \begin{bmatrix} i_L(wt+\phi) \\ i_L\left(wt+\phi+\frac{\pi}{2}\right) \end{bmatrix} \quad \text{------------------ (1)}$$

This approach of using an imaginary variable is further extended to represent the single-phase system in d-q frame. The variable in α-β frame can be converted to d-q frame representation of single-phase system using eqn.(4) as follows:

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} Sin(w_1 t) & -Cos(w_1 t) \\ Cos(w_1 t) & Sin(w_1 t) \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad \text{------------- (2)}$$

In eqn. (2) iLd and iLq are the d and q components of the load current. The iLd and iLq of the load current have two components first one DC component and second one AC component. The DC component of these load currents can be extracted with a set of moving average filter with a time equal to half of the cycle time of supply frequency. The AC and DC components can be easily extracted from i_{Ld} and i_{Lq} using low pass filter (LPF) and high pass filter (HPF), respectively. Therefore required reference d-q components are as follows:

$$\begin{bmatrix} i^*_{Ld} \\ i^*_{Lq} \end{bmatrix} = \begin{bmatrix} i_{LDCD} \\ 0 \end{bmatrix} \quad \text{--------------------------------------- (3)}$$

Where i_{LDCD} is DC component of iLd.

The reference source current signals in α-β frame can be generated by replacing iLd and ILq with iLd*and iLq* in eqn(2) and taking its inverse transform using eqn.(4) as follows:

$$\begin{bmatrix} i^*_{S\alpha} \\ i^*_{S\beta} \end{bmatrix} = \begin{bmatrix} Sin(w_1 t) & Cos(w_1 t) \\ -Cos(w_1 t) & Sin(w_1 t) \end{bmatrix} \begin{bmatrix} i_{LDCD} + I_{loss} \\ 0 \end{bmatrix} \quad \text{----------------- (4)}$$

The i*sβ is an imaginary component of the source current, which can be discarded for power factor correction. I_{Loss} is the output of DC bus voltage PI controller for self supporting DC bus of the UPQC The block diagram for the reference current using single-phase d-q theory is shown in Fig. 6.

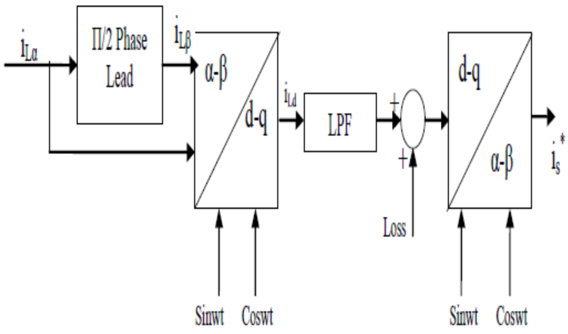


Fig 5. Control scheme of shunt APF using d-q theory

B. Control scheme of Shunt APF using Fourier Analysis

As per Fourier series a non-sinusoidal signal can be expressed as a sum of sinusoidal signal of various frequencies. Based on this the distorted utility voltage and load current can be expressed as:

$$v_s(t) = \sum_{n=1}^{k} V_n \sin(nwt + \theta_n) \quad \text{----------------- (5)}$$

$$i_L(t) = \sum_{n=1}^{k} I_n \sin(nwt + \phi_n) \quad \text{---------------- (6)}$$

Where $v_s(t)$ and $i_L(t)$ are the instantaneous source voltage and load current, Vn and In are the maximum voltage of nth order utility voltage and load current, θn and Φn are the phase angle of nth-order utility voltage and load current. The reference source current for current harmonics along with reactive power compensation will be expressed as:

$$i_s^*(t) = I_1 Sin(wt + \theta_1) \quad \text{----------------------- (7)}$$

Where,

$$I_1 = I_1 Cos\Phi_1 + I_{Loss} \quad \text{----------------------- (8)}$$

The MATLAB model to extract reference source current is depicted in Fig. 5. The ILoss is the component of source current required to maintain the DC link of the back to back connected VSIs of UPQC. In all proposed control algorithms for the shunt APF of single-phase UPQC, the sensed (is) source current and reference source currents (i*s) are compared in a hysteresis current controller to generate the switching signals to the switches of the shunt APF which makes the supply currents sinusoidal and in phase with the voltage at PCC.

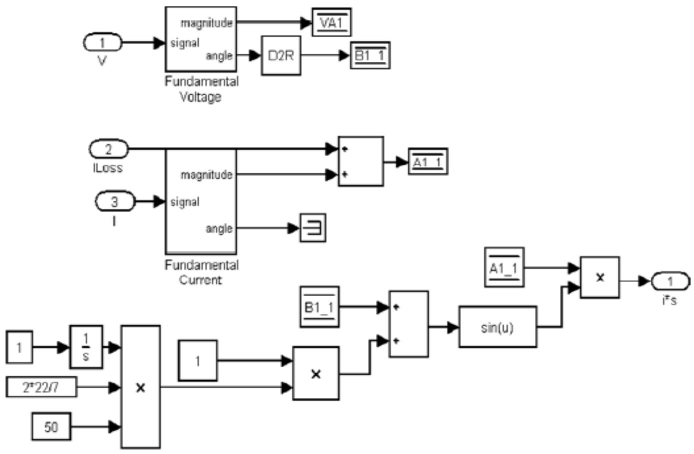


Fig 6. Control scheme of shunt APF using fourier analysis

V. SIMULATION RESULTS

In the simulation environment, the operating conditions and the circuit constants are set as follows:
Supply voltage: 220 V RMS, 50Hz.
Supply impedance: 50μH, 0.01Ω.
DC link capacitance value: 4700μF.
DC link voltage: 325 V
Ripple filter parameter: 0.01Ω, 0.5m H, 0.1Ω, 0.5mH.
Transformer: 250MVA, 58KV/12KV.
Linear load: 15 Ω, 50mH, Non-linear load: Single-Phase Rectifier Load on dc side R=10Ω and La=25mH.

A. Matlab model for non linear load without UPQC:

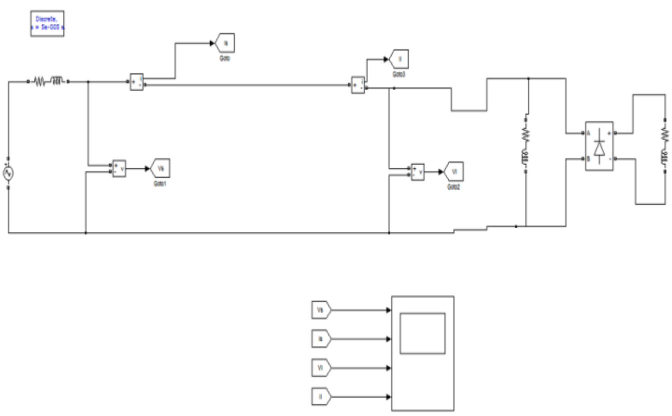


Fig 7 Matlab model of non linear load without UPQC

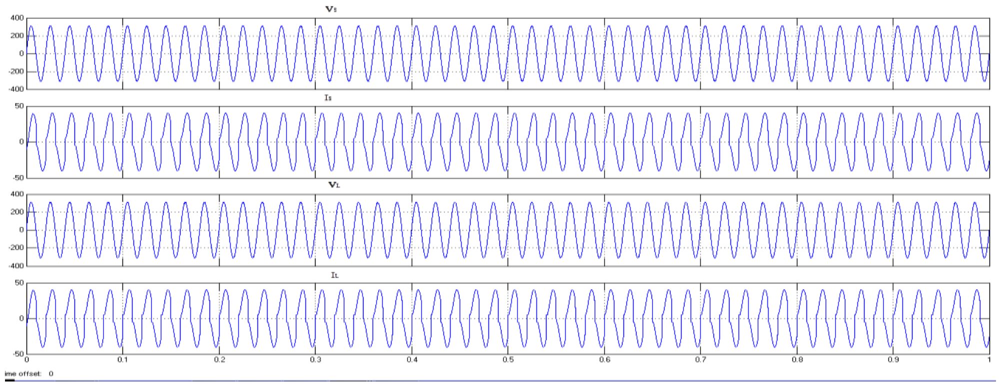


Fig 8 Performance of linear and non linear load without UPQC

B. Simulation model of single phase UPQC with single phase d-q theoryand fourier analysis

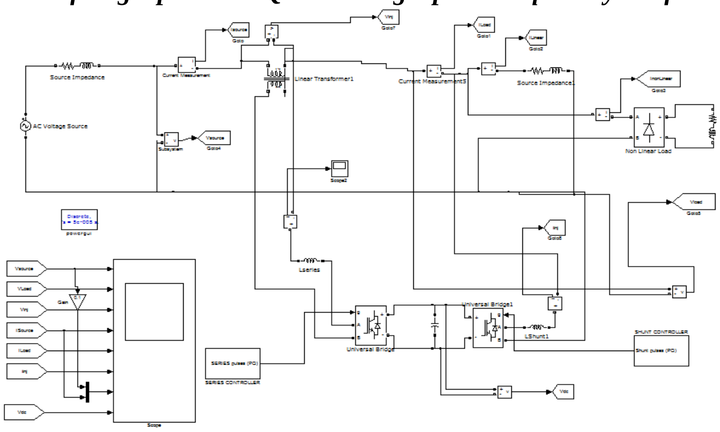


Fig.9 Matlab model of single phase UPQC

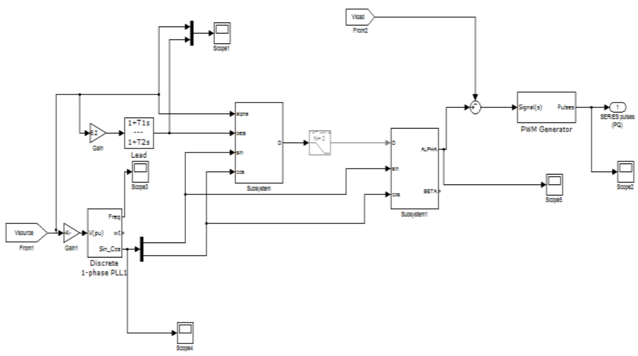


Fig.10 . Matlab model of control scheme of series APF using single phase d-q theory

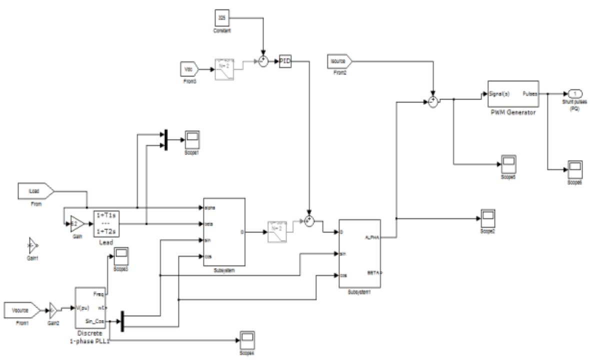


Fig.11 Matlab model of control scheme of shunt APF using single phase d-q theory

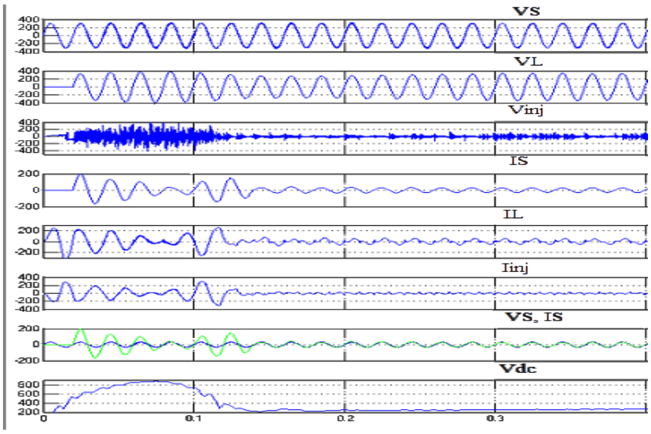


Fig 12. Dynamic response of UPQC with single-phase d-q theory

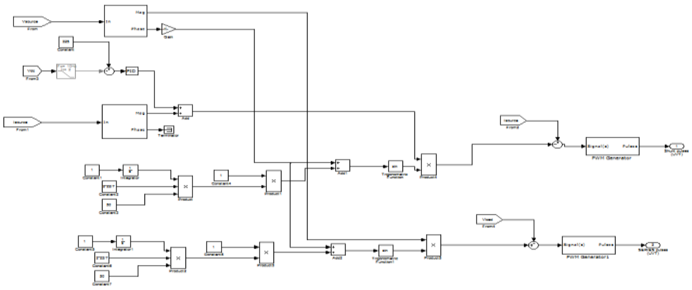


Fig. 13 Matlab model of control scheme of series and shunt APF using fourier analysis

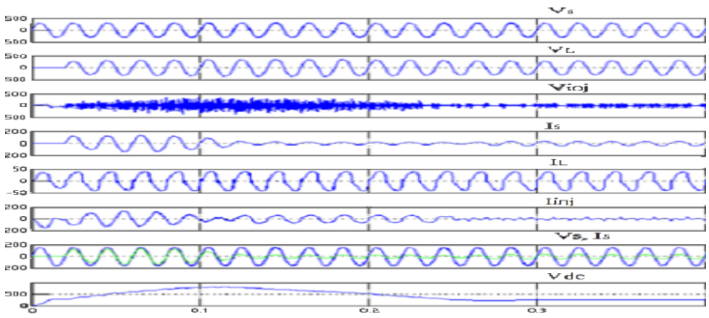
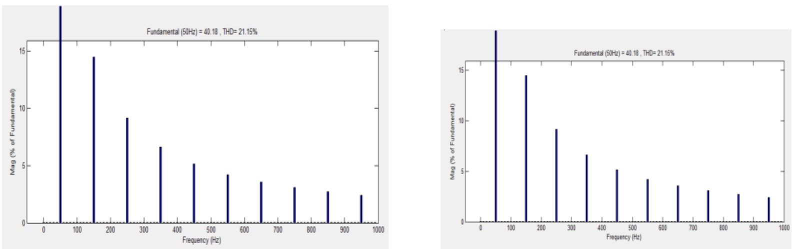


Fig 14. Dynamic response of UPQC using Fourier analysis

Above figs shows matlab models of single phase UPQC using d-q theory and fourier analysis. From above fig it is observed that source current and load voltage are made sinusoidal by injecting voltage(V_{inj}) and current(I_{inj}). Hence source current becomes sinusoidal with source voltage. It is observed that the DC link voltage of the back to back connected VSI is maintained to the reference value.

C. THD analysis:

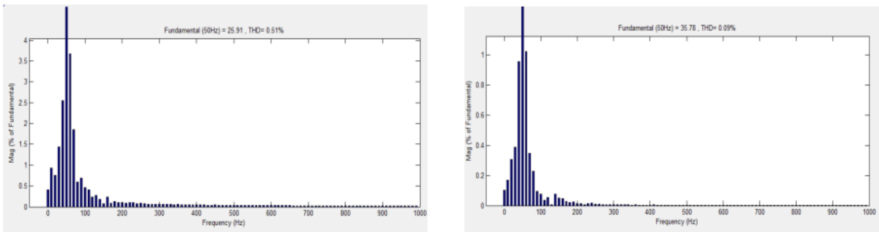
FFT analysis



(a) **(b)**

Fig 15 a)Harmonic analysis of source current without UPQC
b) Harmonic analysis of load current without UPQC

The above analysis show that the THD of source current and load current without connecting UPQC is 21.15%



(a) (b)

Fig a) Harmonic analysis of source current with d-q theory
b) Harmonic analysis of source current with fourier analysis

The above analysis shows THD of single phase UPQC by using single phase d-q theory which is reduced to 0.59% and by using fourier analysis is 0.09%.

***D. Comparative Analysis*:**

Parameter Control Strategies	Source Current	
	RMS (A)	THD (%)
Without compensation	28.58	21.15
Compensation using d-q theory	26.10	0.59
Compensation using Fourier analysis	26.12	0.09

Above table shows comparitive analysis of THD of single-phase UPQC, in which w3ithout connecting UPQC THD of source current is 21.15% and by using single-phase d-q theory THD is 0.59% and by using fourier analysis it is 0.09%.

VI. CONCLUSION

The proposed single-phase UPQC is analysed and studied for two control methods single-phase d-q theory and fourier analysis. For the proposed single phase UPQC the effectiveness of fourier analysis over single-phase d-q theory have been validated and compared for power-factor correction, current and voltage harmonic mitigation. Simulation results of single phase UPQC using MATLAB are verified. From the simulation results it is found that the performance for voltage harmonic mitigation is almost same for both control algorithms, while the performance of Fourier analysis approach was found best for current harmonic mitigation. Supply currents harmonics levels are maintained below IEEE-519 standards.

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