Synchronous Reference Frame Control of Unified Power Quality Conditioner

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Abstract : This study has been undertaken to investigate the determinants of stock returns in Karachi Stock Exchange (KSE) using two assets pricing models the classical Capital Asset Pricing Model and Arbitrage Pricing Theory model. To test the CAPM market return is used and macroeconomic variables are used to test the APT. The macroeconomic variables include inflation, oil prices, interest rate and exchange rate. For the very purpose monthly time series data has been arranged from Jan 2010 to Dec 2014. The analytical framework contains**.**

I. INTRODUCTION

SRF controlling method for the operation of UPQC model is very similar to instantaneous reactive power theory method. A major feature this algorithm pursues is that only load current is essential here for the generation of reference current and hence disturbances present in source or distortionspresent in voltage have will leave no negative impact to the performance of the designed UPQC system. In the given proposed SRF method for UPQC we have optimized the system without using transformer voltage, load, and filter current measurement, .This reduces numbers of measurements are and thereby improving system performance.

In this approach signals of current & voltage are first sensed and then transformed to a certain rotating frame ($d-q-0$). Here, the transformation angle (ωt) is representing angular position of proposed reference frame .This ωt is rotating at constant speed and is synchronized with the 3-Ø ac voltage. Under the set condition of nonlinear load, load reactive currents and harmonic current is found by PLL algorithms. After this, currents having same magnitude but with reverse phase is produced and injected to the proposed system for compensating neutral current, harmonics, and reactive power. In the stationary reference frame as discussed , $\alpha-\beta-0$ coordinates are stationary, while in the SRF, $d-q-0$ coordinate is rotating in synchronism with supply voltages.

II. I_d & I_q Components Definition

From the proposed SRF theory "d" coordinate component of current namely i , is corresponding to positive-sequence and this component is always in phase with voltage. The "q" coordinate component of current namely iq is found to be perpendicular to the id component of the current, This $iq$is called negative sequence reactive current. The "0" coordinate component of current is found to be orthogonal to both id & iq and we name it as zero sequence component of the current. If iq is found to be negative, the load will be pursuing inductive reactive power and if it is positive. then it will be having a capacitive reactive power. In the proposed nonlinear power systems, i_d & i_q components will have both oscillating components ($\tilde{\imath}_d$ & $\tilde{\imath}_q$) and average components ($\bar{\imath}_d$ & $\bar{\imath}_q$), as mentioned in the below equations.

$$i_d = \bar{\imath}_d + \tilde{\imath}_d \; \& \; i_q = \bar{\imath}_q + \tilde{\imath}_q \qquad (1.1)$$

In both the coordinates the oscillating part responds to oscillating component & the average part responds to active current($\bar{\imath}_d$) and reactive current ($\bar{\imath}_q$).Hence wherever APF applications are made in operation our objective will be to separate the fundamental positive sequence component so that harmonics can be eliminated or removed.

III. Modified Phase Locked Loop

For high distortion and system with more unbalance the conventional PLL will give low performance and the transformation angle (ωt) will not vary perfectly linearly with time as desired. A modified PLL can be used under those highly distorted situation under which UPQC filtering operation and results can be improved to a better quality. A simple schematic structure to design modified PLL is shown below:-

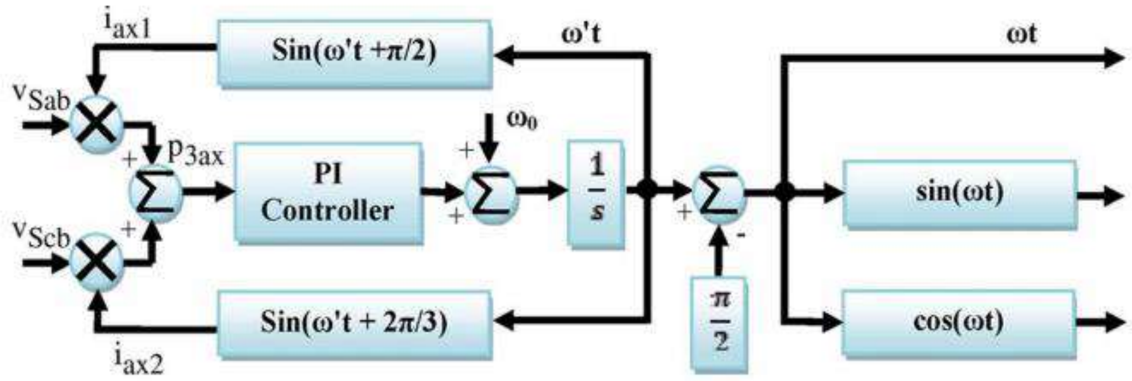

Fig 1.1 PLL block diagram

First we calculate the 3-∅ instantaneous source line voltages V_{sab} & V_{scb}. This measured line voltages is multiplied with auxiliary (i_{ax1} & i_{ax2}) feedback currents of unity amplitude, in which one will lead leads 120° from the other to achieve auxiliary instantaneous active power ($p3ax$). This is passed through a P-I controller. The referred fundamental angular frequency ($\omega_0 = 2\pi f$) is added to result of P-I controller for the purpose to stabilize output. The result is then passed through an integrator block to get auxiliary transformation angle (ωt).The resultant produced ωt leads 90° to system's fundamental frequency; and hence −90° is added to integrator output for getting system fundamental frequency. When this instantaneous power $p3ax$ reaches zero or gets low frequency oscillation then PLL is said to reach a stable operating point. Also the output ωt will reach fundamental positive sequence component of lien voltage.

IV. Reference-Voltage Signal Generation for Series APF

The control algorithm for series APF in UPQC model involves the calculations of reference voltage which has to be injected by the series transformer which it performs by comparing the component of positive sequence of source voltage with the load voltages. The supply voltage issensed and then it is transformed into *d-q-0* frame of reference by the following transformation matrix:-

$$\begin{bmatrix} V_{so} \\ V_{sd} \\ V_{sq} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \sin(\omega t) & \sin(\omega t - 120°) & \sin(\omega t + 120° \\ \cos(\omega t) & \cos(\omega t - 120°) & \cos(\omega t + 120° \end{bmatrix} \quad (1.2)$$

V_{sd} & V_{sd} are the instantaneous components in the new SRF and both of them has got oscillating ($\tilde{V}_{sd}$ & $\tilde{V}_{sq}$) as well as average components ($\bar{V}_{sd}$ & $\bar{V}_{sq}$) in them. The oscillating part includes within it harmonic and negative sequent part of the utility voltage due to non-linear load. The average part has within it the positive sequence voltage component.

Hence we can say that :-

$$V_{sd} = \overline{V_{sd}} + \widetilde{V_{sd}} \quad (1.3)$$

The harmonic part is separated by passing the d-component voltage V_{sd} via LPF. The output of this LPF is only the average component $\overline{V_{sd}}$ The zero and negative components namely V_{sq} & V_{s0} of source voltage is terminated or made to zero for compensating harmonics of load voltage, and unbalance. The reference load voltage is calculated by passing the new set of components of d-q-0frame via a inverse transformation which converts it again to the original a-b-c reference frame. This inverse transformation called Inverse Parks transformation is shown below:-

$$\begin{bmatrix} V_{la}^{*} \\ V_{lb}^{*} \\ V_{lc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \sin(\omega t) & \cos(\omega t) \\ \frac{1}{\sqrt{2}} & \sin(\omega t - 120°) & \cos(\omega t - 120°) \\ \frac{1}{\sqrt{2}} & \sin(\omega t + 120°) & \cos(\omega t + 120°) \end{bmatrix} \begin{bmatrix} 0 \\ \overline{V_{sd}} \\ 0 \end{bmatrix} \quad (1.4)$$

The resultant reference voltages $(V_{la}^*, V_{lb}^* \& V_{lc}^*)$ as above and actual sensed load voltages (V_{la} , V_{lb} & V_{lc}) are compared and then passed via a sinusoidal pulse width modulation(PWM) for controlling switching or gate signals for the series filter operation of IGBT used and to fight against and remove all problems related with voltage namely, harmonics in voltage, sag/swell, voltage unbalance at the PCC. The whole idea of generating reference voltage for series APF operation in UPQC model is depicted below:-

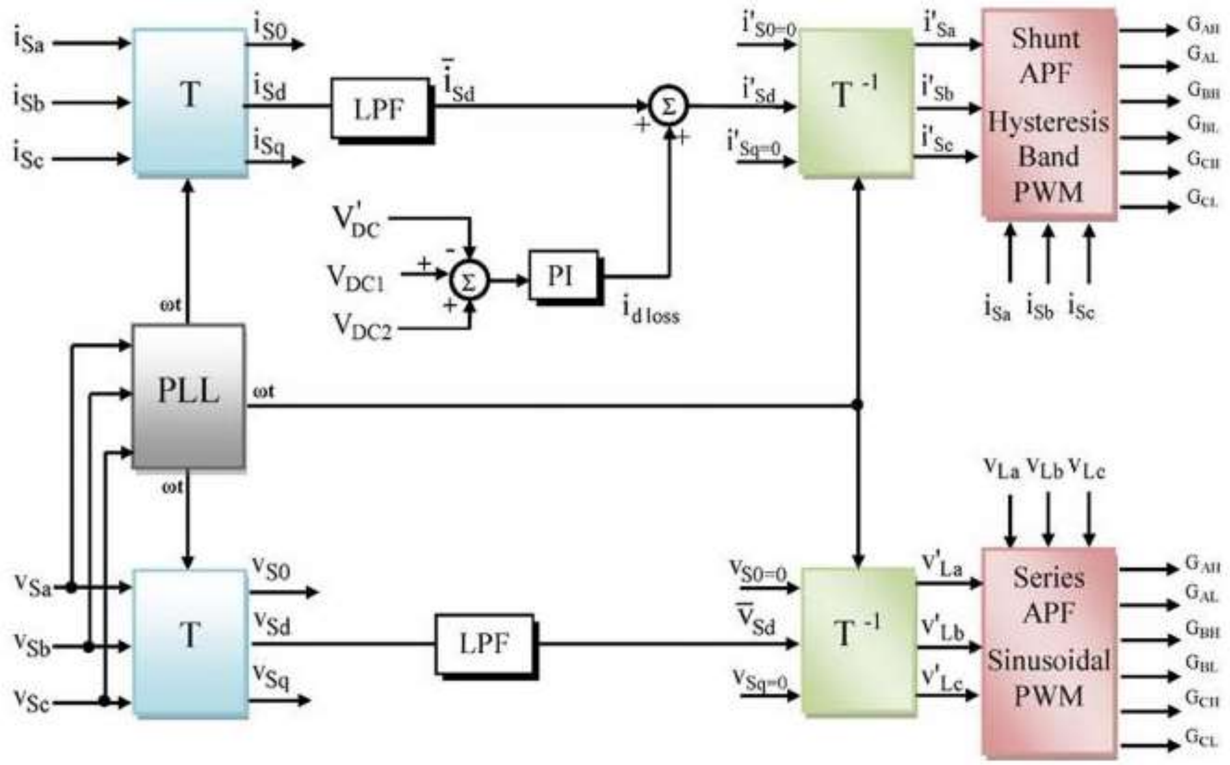

Fig 1.2 SRF control for UPQC operation

V. Reference-Source-Current Signal Generation for Shunt APF

The shunt APF as discussed in chapter 2 is useful for avoiding the problems related with the current harmonics generated in our UPQC model with nonlinear load and also takes care for reactive power compensation. The sensed source current are transformed to $d-q-0$ coordinates by the same Parks transformation equation as given in 1.2, where the angular frequency (ωt) comes from modified PLL discussed under section 1.3

$$\begin{bmatrix} i_{s0} \\ i_{sd} \\ i_{sq} \end{bmatrix} = T \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \quad (1.5)$$

T is the Parks transformation matrix given in eqn 1.2

The new transformed instantaneous source current in *d-q-0* frame namely i_{sd} & i_{sq} again includes in it both oscillating components ($\tilde{i}_{sd}$ & $\tilde{i}_{sq}$) and average components ($\bar{i}_{sd}$ & $\bar{i}_{sq}$) as well. Oscillating component will contain in it a combination of harmonic and negative sequence component whereas the average component is including only positive sequence current component which corresponds to reactive current. The zero sequence part namely i_{s0} will appear under unbalanced load conditions. In our SRF method average component of positive-sequence ($\bar{i}_{sd}$) in

the *d*-axis and the zero- and negative-sequence component (i_{s0} & i_{sq}) in the 0- and *q*-axes of the

source currents, in for compensating harmonics and unbalances produced in the non-linear load.

Series APF injects active power in the power system for compensating the active power losses of the UPQC power circuit, which results in regulation of dc-link voltage across capacitor. A part of active power is taken from the power system by shunt APF to make dc-link voltage constant. For this task, the voltage of dc-link is compared with a set reference value (V_{dc}), and then passed via a PI controller whose output is the required active current (i_{dloss}). The d-component of source current i.e i_{sd} is passed via a LPF to get its average component i.e ($\overline{i_{sd}}$). Now this average component and required active current i.e i_{dloss} are added to get fundamental reference component. The whole phenomenon can be seen in Fig 1.2

$$i'_{sd} = \overline{i_{sd}} + i_{dloss} \quad (1.6)$$

The negative sequence and zero component of source current is set to zero to compensate, distortion, harmonics, and reactive power in source current. . The reference source current is produced by inverse Parks transformation as mention below:-

$$\begin{bmatrix} i'_{sa} \\ i'_{sb} \\ i'_{sc} \end{bmatrix} = T^{-1} \begin{bmatrix} 0 \\ i'_{sd} \\ 0 \end{bmatrix} \quad (1.7)$$

Where, T^{-1} is inverse Parks transformation as given in eqn 1.4

Both the measured and reference source current are compared now and passed via hysteresis band current controller for getting the gating signals for operation of shunt APF in the given UPQC model and thereby eliminating all the current related problem from the system.

VI. Results

UPQC is a equipment which is formed by combining series APF and Shunt APF together. UPQC removes both problems which are caused due to voltage and current harmonics. UPQC mitigate the problems of source voltage unbalance and make load side voltage completely balanced and it also mitigate the problems which is caused due to load current harmonics and make current drawn from source completely sinusoidal. In table-1.1 system parameters of UPQC are given

Table-1.1- System Parameters used for UPQC

Supply Voltage	326 V
Line Frequency	50 Hz
Line impedance	R_s=0.01 Ω, L_s=0.01 mH
Series Transformer Turns ratio	1:1
Load impedance	R_L= 30 Ω, L_L= 1 mH
DC Capacitance	2200 μF
DC capacitor voltage	700 V

Current harmonic compensation and voltage sag mitigation

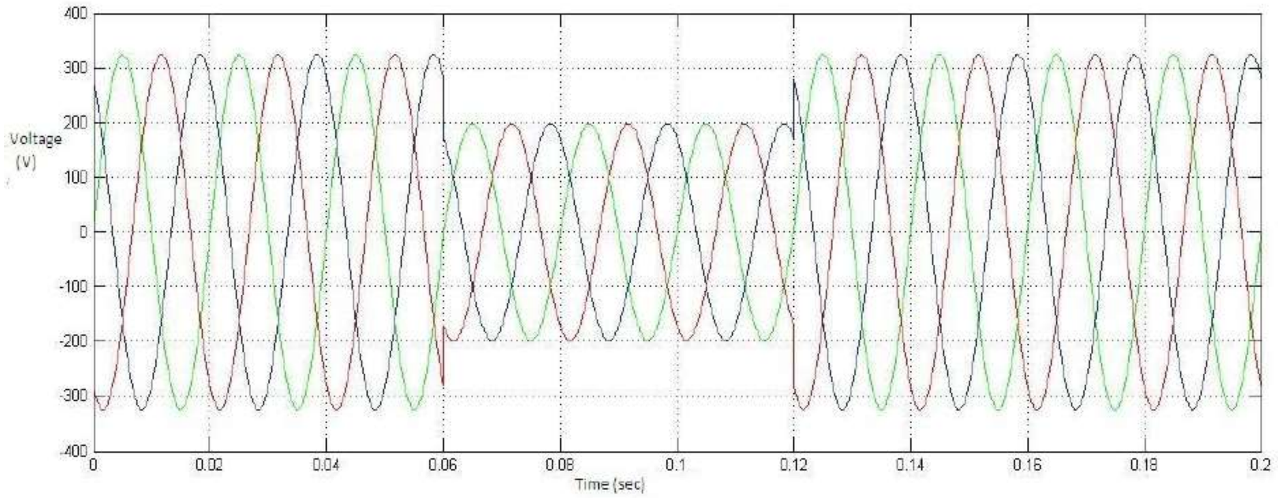

Fig.1.3 Source voltage during sag of UPQC

In fig.1.3 source voltage of UPQC during sag is shown. Total simulation time is 0.2 sec. The voltage dip is from 0.06 sec to 0.12 sec. It is due to presence of faults in the system. Due to sag the voltage from 0.06 sec to 0.12 sec is 200 V.

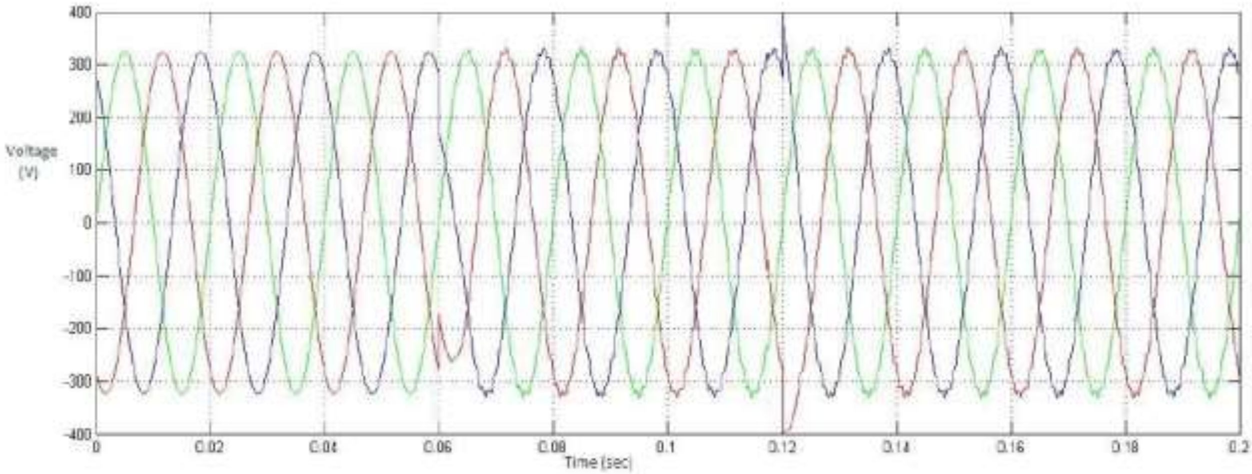

Fig.1.4Load voltage during sag after application of UPQC

In Fig.1.4 load voltage of UPQC is shown. After operation of UPQC the sag from time 0.06 sec to 0.12 sec is removed. UPQC removes the voltage sag problems. The total load voltage becomes sinusoidal and gains its original magnitude which is 326 V.

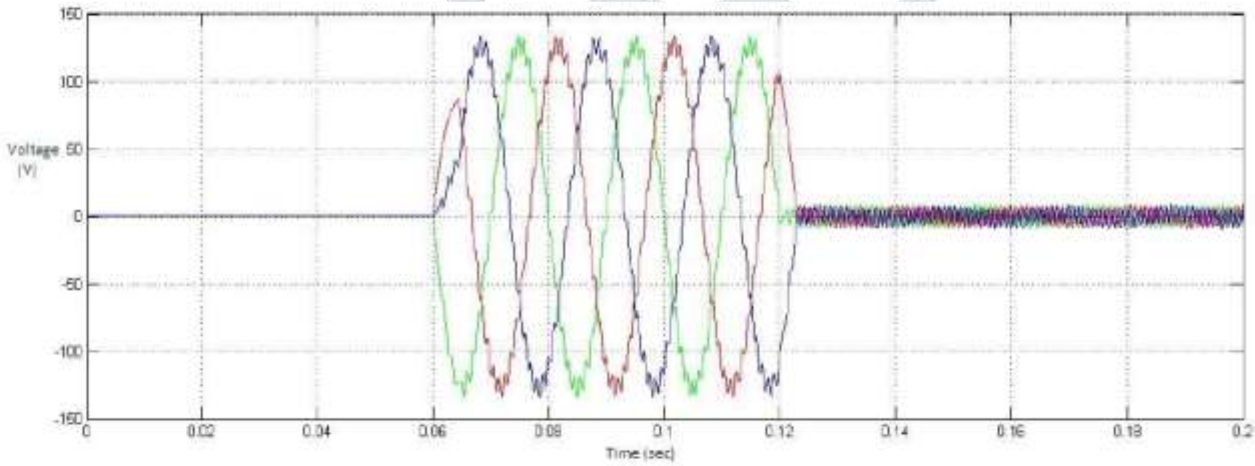

Fig. 1.5 Injected Voltage of UPQC during sag

Fig.1.5 shows the injected voltage of UPQC during sag. The voltage is injected form 0.06 sec to 0.12 sec so that the load voltage becomes completely balanced.

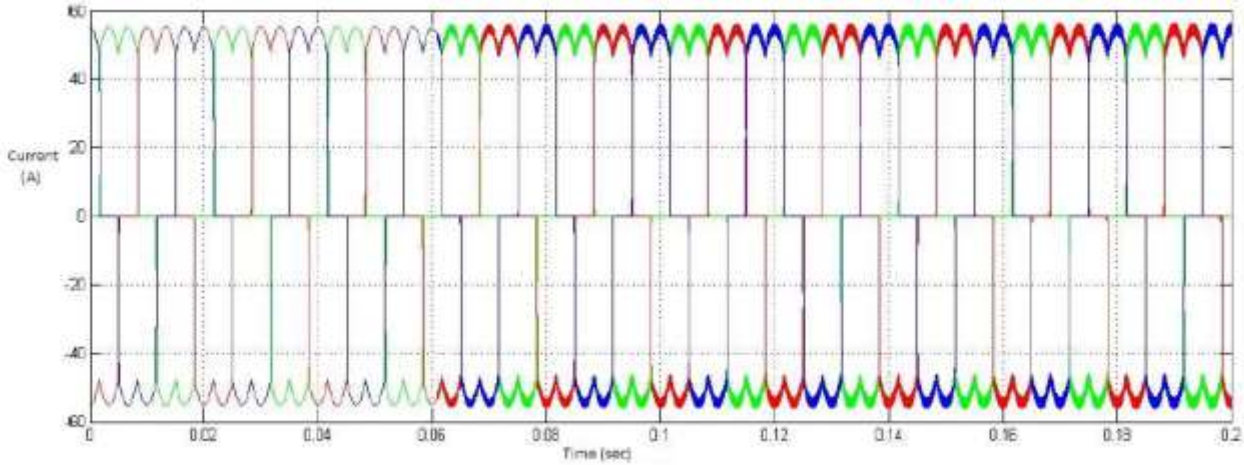

Fig. 1.6 Load current of UPQC during sag

In Fig.1.6 load current of UPQC during sag is shown. The load current of UPQC is contains harmonics and is non-linear due to presence of non-linear load.

VII. CONCLUSIONS

Reliability of supply and power are the two important factors of any power delivery system today. Nowadays, consumers want not only the suuply, but the quality of supply is important to them. So it is necessary to solve the power quality problems. To solve this problem we are using different methods. In this paper we just introduced a device known as UPQC to solve the voltage and current related problems. From the analysis, SRF theory is efficient method to correct the abnormality in the voltage and current and also help to maintain the load voltage balanced and constant.

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