POWER QUALITY IMPROVEMENT BY USING ACTIVE POWER FILTERS

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***Abstract*—Filtering of harmonics in a power system is playing major role due to the usage of non-linear and unbalanced loads. For the elimination of harmonics, requires active power filters. The controlling of active power filters are done by using conventional PI controllers and proportional resonant controllers. But in this context proportional resonant controllers are used to control the harmonics present in the power system.**

***Index Terms*-- Shunt active power filter (APF), 2^{nd} harmonic, control methods, proportional integral control (PI), Proportional resonant control (PR), unbalanced and nonlinear load**

I. INTRODUCTION

Day by day our needs are increased in terms of power. Requirement will make burden on power quality. Now a day most of the loads are nonlinear due to usage of power electronic devices like semiconductor devices used in rectifiers and inverters, switching power supply and other power electronic converters. To overcome above problems shunt APF is recognized as cost effective solution for compensating harmonics in low and medium power applications.

In general PI controllers are playing major role for controlling shunt APF. For three phase Systems synchronous frame PI controllers can be used but it requires computational burden in case of multiple frame transformations. To overcome above we are preferred to use Proportional resonant controller, which is having similar frequency response characteristics. PR controllers are used for reference tracking in the stationary reference frame. The basic functionality of a PR controller is to introduce infinite gain at a selected resonant frequency for eliminating steady state error at that frequency.

Conceptually, an integrator whose DC gain forces the DC steady state error to zero in the same way resonant portion of the PR controller whose AC gain (GI) forces the AC steady error to zero. Due to above advantages go for PR control method.

Under an unbalanced load the fundamental positive and negative-sequence components will present in to the system. The interaction of positive and negative sequence component of switching functions and AC currents of the APF produces 2^{nd} harmonic ripple on the DC link of the APF, which will inject 3^{rd} harmonic component in the AC currents of the APF and line currents. In addition nonlinear load will inject high harmonic components in to the load current. The interaction of positive and negative sequence switching functions and high harmonic AC currents of the APF produces high order even harmonics on the DC link voltage of the APF, which create high order odd harmonics in to the APF AC currents. It

will lead to deterioration of performance of the system. It will provide more stress on the dc link capacitor, which will reduce life cycle of the dc link capacitor [1-3].

Some methods are proposed in the papers [1], [5] and [6] to improve performance of the system. Methods, which are proposed in the above papers, are used to eliminate only the 3^{rd} harmonic of APF AC current, thus to reduce the distortion of the line current but high harmonics cannot be reduced, Moreover the even harmonics on the DC link side still exist

By using conventional positive sequence control method we cannot eliminate 2^{nd} harmonic voltage completely from the DC link voltage. Proposed method in the paper [2] can eliminate 2^{nd} harmonic voltage completely from the DC link. But the controller is complex.

To overcome above disadvantages of the control method and series harmonics at both DC side and AC side of the APF, PR Control method is proposed in this paper. This method is implemented with simple controller. PR filters can also be used for generating the harmonic command reference precisely in an active power filter, especially for single-phase systems, where d–q transformation theory is not directly applicable. Another advantage associated with the PR controllers and filters is the possibility of implementing selective harmonic compensation without requiring excessive computational resources.

The remainder of the paper is organized as follows section 2 describes mathematical modeling of active power filter, section 3 presents control strategy. Finally, the simulation results and conclusion are given in section 4.

II. MATHEMATICAL MODEL

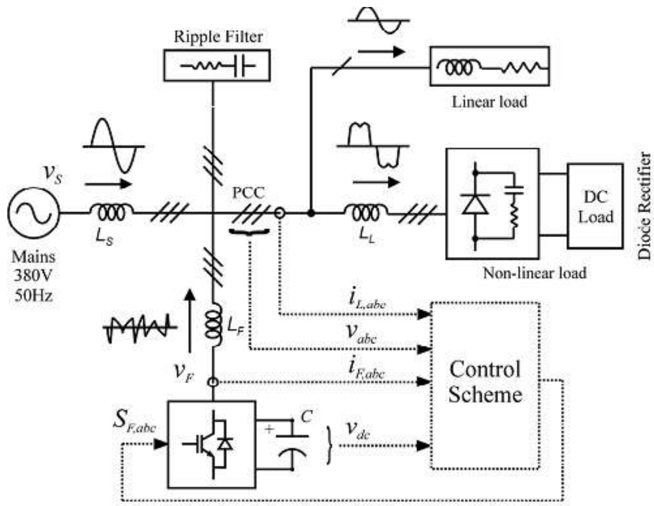

Fig.1 Basic current harmonic scheme of an unbalanced load using a shunt APF.

Under unbalanced load i_{dq}^{+1*}, i_{dq}^{-1*} are conjunction vector positive and negative sequence components of APF currents in the rotating synchronous frame, respectively d_{dq}^{+1}, d_{dq}^{-1} are vector of switching function positive and negative sequence in the rotating synchronous frame, respectively.

DC link voltage contains the 2nd harmonic , the output of the PI controller of DC link voltage, i.e., the reference current for APF current loop, can be given as (DC item is neglected).

$$\vec{i}_d^{\,*} = A_2\varepsilon_2 \sin(2\omega_e t + \beta_i) = \frac{A_i}{2}(e^{j(2\omega_e t+\beta_i)} - e^{-j(2\omega_e t+\beta_i)}) \qquad (1)$$

Where $A_i = A_2\mathcal{E}_2$, $\mathcal{E}_2$is the error of the voltage control loop and subscript "*" means reference value.

From equation (1) it can be seen that 2nd harmonic component still exist in reference current, which we are getting from output of the PI controller. The output of the APF current compensator is obtained as

$$\vec{v}_{dq} = A_v \sin(2\omega_e t + \beta_v) = \frac{A_v}{2}(e^{j(2\omega_e t+\beta_v)} - e^{-j(2\omega_e t+\beta_v)}) \qquad (2)$$

Transforming equation (2) into the form in αβ stationary frame, equation (2) is written as

$$\vec{v}_{\alpha\beta} = \vec{v}_{dq} e^{j\omega_e t} = \frac{A_v}{2}(e^{j(3\omega_e t+\beta_v)} - e^{-j(\omega_e t+\beta_v)}) \qquad (3)$$

In equation (3) the 3rd harmonic component appears in the APF current such harmonic results in a 4th harmonic on the DC link voltage and DC link current of the APF, which causes high order harmonic in the APF AC currents. These harmonic flows into the line and deteriorates the performance of the system.

In addition under the nonlinear load, load current contains not only the fundamental negative sequence component, but also high order harmonics $6k \pm 1$, where k = 0, 1, 2…… interaction of these high order harmonics and fundamental negative and positive sequence components leads to a series of high harmonics 2k, k = 0,1,2….. at DC link, e.g., 2nd ,4th ,6th …..

Three phase proportional resonant (PR) transfer functions are used for the separation of positive and negative sequence components. In general proportional integral transfer functions are used for the separation of positive and negative sequence components but it requires transformation from stationary reference frame (αβ) to synchronous reference frame (dq), which will increase the computational effort. Therefore we use PR transfer functions in terms of stationary reference frame. Here we have to do reverse transformation from dq to αβ.

The inverse transformation can be performed by using the following 2×2matrix:

$$G_{\alpha\beta}(s) = \frac{1}{2}\begin{bmatrix} G_{dq1} + G_{dq2} & jG_{dq1} - jG_{dq2} \\ -jG_{dq1} + jG_{dq2} & G_{dq1} + G_{dq2} \end{bmatrix} \qquad (4)$$

Where $G_{dq1} = G_{dq}(s+j\omega)$

$G_{dq2} = G_{dq}(s+j\omega)$

Given that $G_{dq}(s) = K_p + K_i/s$ and $G_{dq}(s) = K_p + K_i/(1 + (s/\omega_c))$, the equivalent controllers in the stationary frame for compensating for positive-sequence feedback error are therefore expressed as:

$$G_{\alpha\beta}^{+}(s) = \frac{1}{2}\begin{bmatrix} K_p + \frac{2K_i s}{s^2+\omega^2} & -\frac{2K_i\omega}{s^2+\omega^2} \\ \frac{2K_i\omega}{s^2+\omega^2} & K_p + \frac{2K_i s}{s^2+\omega^2} \end{bmatrix} \quad (5)$$

$$G_{\alpha\beta}^{+1} \approx \frac{1}{2}\begin{bmatrix} K_p + \frac{2K_i\omega_c s}{s^2+2\omega_c s+\omega^2} & \frac{2K_i\omega}{s^2+2\omega_c s+\omega^2} \\ -\frac{2K_i\omega}{s^2+2\omega_c s+\omega^2} & K_p + \frac{2K_i\omega_c s}{s^2+2\omega_c s+\omega^2} \end{bmatrix} \quad (6)$$

Similarly, for compensating for negative sequence feedback error, the required transfer functions are expressed as:

$$G_{\alpha\beta}^{-}(s) = \frac{1}{2}\begin{bmatrix} K_p + \frac{2K_i s}{s^2+\omega^2} & 0 \\ 0 & K_p + \frac{2K_i s}{s^2+\omega^2} \end{bmatrix} \quad (7)$$

$$G_{\alpha\beta}^{-1} \approx \frac{1}{2}\begin{bmatrix} K_p + \frac{2K_i\omega_c s}{s^2+2\omega_c s+\omega^2} & -\frac{2K_i\omega}{s^2+2\omega_c s+\omega^2} \\ \frac{2K_i\omega}{s^2+2\omega_c s+\omega^2} & K_p + \frac{2K_i\omega_c s}{s^2+2\omega_c s+\omega^2} \end{bmatrix} \quad (8)$$

Comparing equations (4) and (5) with (6) and (7). It is noted that the diagonal terms of $G_{\alpha\beta}^{+}(s)$ and $G_{\alpha\beta}^{-}(s)$ are identical, but there non-diagonal terms are opposite in polarity. This is inversion of polarity can be viewed as equivalent to the reversal of rotating direction between the positive – and negative- sequence synchronous frames.

Combining both the equations, the resulting controllers for compensating for both positive- and negative- sequence feedback errors are as expressed as:

$$G_{\alpha\beta}(s) = \frac{1}{2}\begin{bmatrix} K_p + \frac{2K_i s}{s^2+\omega^2} & 0 \\ 0 & K_p + \frac{2K_i s}{s^2+\omega^2} \end{bmatrix} \quad (9)$$

$$G_{\alpha\beta}^{-1} \approx \frac{1}{2}\begin{bmatrix} K_p + \frac{2K_i\omega_c s}{s^2+2\omega_c s+\omega^2} & 0 \\ 0 & K_p + \frac{2K_i\omega_c s}{s^2+2\omega_c s+\omega^2} \end{bmatrix} \quad (10)$$

Equations (3- 10) are getting from [3]

In this paper I have used equations (5) and (7) for separation of positive- and negative-sequences in the PR control method.

III. CONTROL STRATEGY

Our control strategy is to eliminate 2^{nd} harmonic at the DC link voltage of the APF under an unbalanced load condition.

As from above analysis, the fundamental negative sequence component is the reason for production of high harmonics in the line current as well as DC side of the APF. Therefore, we have to be diminished the fundamental negative sequence component of APF, thereby, cancel the harmonics in the system. In order to realize this object, we have to maintain quadrature component of fundamental positive sequence reference current, which is the output of PI controller of voltage control loop, and both the direct and quadrature component of fundamental negative sequence reference current must be zero.

$i_d^{+1*} = 0$ and $i_{dq}^{-1*} = 0$ (7)

This is the basis for a PR control method of the APF. The new control method block diagram for the APF system is shown in Fig.3. It is having two control loops in the overall system. Outer loop is the voltage control loop, which regulates the DC link voltage of the APF to the reference value. The inner loop includes the fundamental current controller and high harmonic controller. In case of conventional positive sequence control method and DC link voltage control method PI controller is used in fundamental current controller and PR controller is used in high harmonic current controller.

In case of PR control method PR controller is used in both the fundamental sequence current controller and high harmonic current controller. This control method will reduce the complexity of the circuit. The PR control method is compared with the conventional control method and DC link voltage control method. The DC link voltage control method block diagram is given in Fig.2 combining [1] with [2].

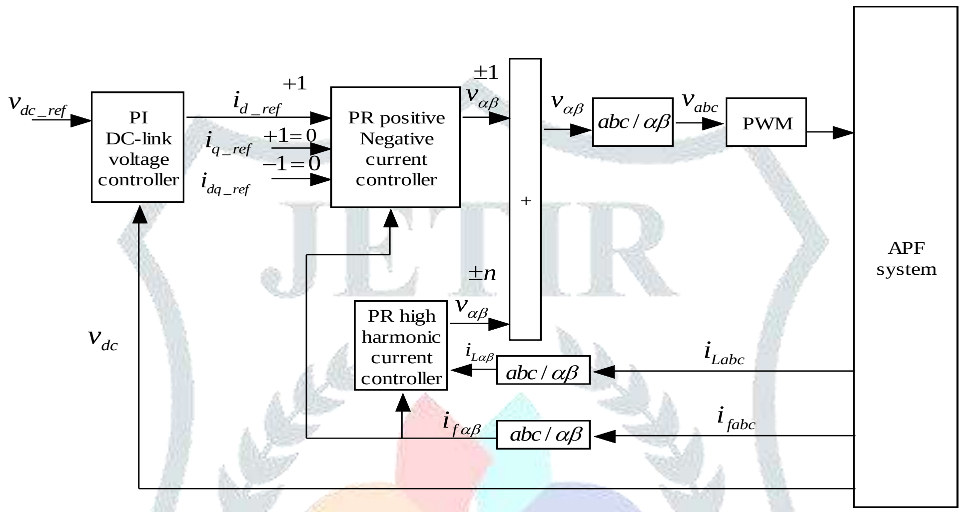

Fig.2 Model of Proposed PR control method.

IV. SIMULATION RESULTS AND COMPARISION

Simulation results of PR control method are compared with the conventional positive sequence control method and DC link voltage control method. Here we are comparing THD (total harmonic Distortion), 3rd harmonics and 2nd, 4th, 6th harmonic components at the DC link. Almost we are getting same results for both DC link Voltage control method and PR control method.

The simulation results of the APF are shown in Table I.

TABLE I

PARAMETERS OF THE APF

Parameters	Value	Parameters	Value
l_{sa}	0.29mH	r_{sa}	91mΩ
C_{dc}	100μF	U_{dc_ref}	700V
l_a	3 mH	ra	1mΩ

Proportional Resonant (PR) control method:

PR controllers are used for the controlling of both positive and negative sequences. From the Fig.3, Fig.4 and Fig.5, we can see line current DC link voltage and compensating current. Fig.6 (a) and (b) will show THD of line current and harmonic content of DC link voltage.

The AC current THD and ripple of DC link voltage of the three controllers are shown in Table II

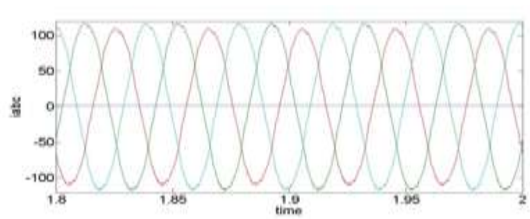

Fig. 3 Line current.

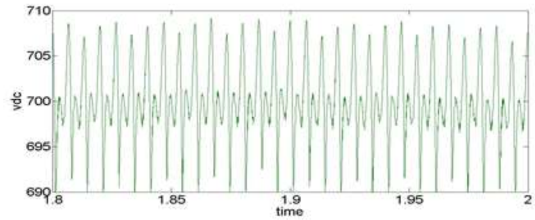

Fig. 4 DC link voltage.

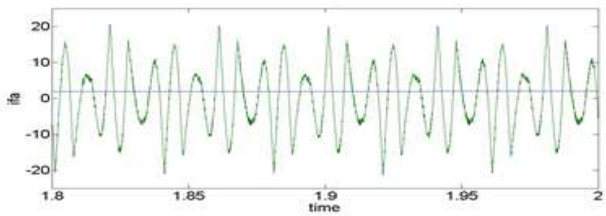

Fig. 5 Compensating current.

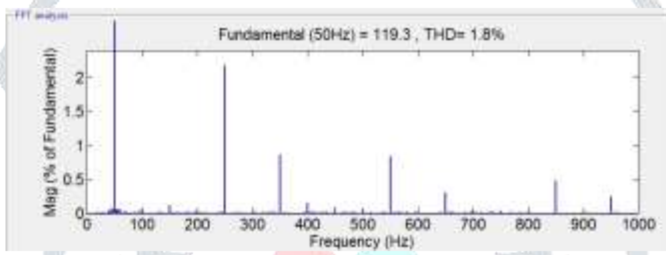

Fig. 6 (a) THD of line current

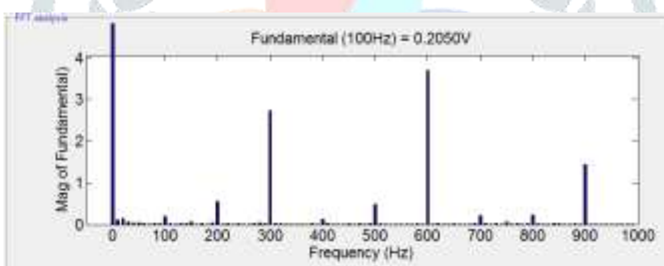

Fig. 6 (b) Harmonic content of DC link voltage.

TABLE II

	PR control
AC current THD	1.8%
3rd harmonic current	0.0962A
Ripple of DC voltage (V)	1) 0.2050V 2) 0.5928V 3) 2.95V

V. CONCLUSION

In this paper, PR control method is discussed based on THD and 3rd harmonic component of line current and ripple of DC link voltage. The simulation results reveal that distortions caused by the 3rd order harmonics on the line current and by 2nd ripple on the DC link are nullified. The PR control method is implemented more simply and cost a few. This method should not use for power factor correction.

VI. References

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