Power Quality Improvement by Active Shunt Filter with Hysteresis Current Controller

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Abstract This paper envisages the method to improve power quality of utility grid. Power drawn by nonlinear and unbalanced load contains higher order of harmonics components which in turns increases the total harmonics distortion level of supply current. We have used active shunt filter to improve the power quality with the help of hysteresis current controller. The p-q theory has been used to calculate the reference current to be compared with the load current drawn. With the help of hysteresis controller the gate triggering pulses for voltage source inverter used as active shunt filter have been generated. In our work Clarke's transformation matrix has been used for conversion of three phase voltage and current into two-axis α-β component. The whole system has been simulated in MATLAB software with a specific objective to improve the quality of power by reducing total harmonics distortion level and we have achieved that goal.

Keywords Power quality · Nonlinear and unbalanced load · Active shunt filter (ASF) · P-Q theory · Hysteresis current controller · Total harmonic distortion (THD)

1 Introduction

Rapid industrialization and consumer's demand of power has increased the generation capacity with a significant consideration of power quality issue. The use of nonlinear load and electronics devices such as computer, electronic bulb, inverter, etc., is a common trend in today's society [1–5]. As the repercussion these types of load inject harmonics components in the transmission line which pollutes the supply power and degrades the power quality [1–10]. As a result several disturbances

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such as excessive vibration of motor, damage of capacitor, appliances deterioration, excessive heat formation, etc., happen frequently [1]. So here the term good power and bad power come in today's power dispatch scenario. By the term good power we mean the frequency of supply current should be 50 Hz and the deviation should be in the range of $\pm 5\%$. Besides this the voltage profile should be in the desired level. There should be neither swell nor sag of the supply voltage and the supply waveform should be pure sinusoidal. But today's load profile does not permit to maintain such supply profile due to the inherent nonlinear characteristics of loads. To mitigate this so many methods are applied with the help of advanced power electronics based technologies like Dynamic Voltage Restorer (DVR), Static compensator (STATCOM), Unified Power Flow Controller (UPFC), Passive filter like LC, LCL, etc. [9, 10]. Here we have a novel approach to improve the power quality and minimize the THD by using active shunt filter. The drawback of passive filter is resonance problem [1]. Besides this the components in passive filter show aging problem. They are bulky and require more space [2]. Active filter is free from such type of problem and shows good performance in respect of speed and accuracy [2]. So many techniques are employed to control the current of active shunt filter like sinusoidal PWM [1], Fuzzy algorithm based current controller [5], etc. With the increase in switching speed of PWM the power waveform is also improved but switching loss is increased. Advanced method like adaptive fuzzy hysteresis band current controller has been proposed by [5] which minimize the uncertainty of system. In this paper we have simulated hysteresis current controller based active shunt filter with our main focus to improve supply current waveform with low THD profile.

2 Active Shunt Filter

A pictorial representation of active shunt filter is provided in Fig. 1 The basic structure of active power filter consists of a voltage source inverter [1, 4, 5].

The voltage source inverter is controlled by current. Its main function is to inject compensating current to the supply side in phase opposition to the harmonics components of load current. It injects compensating current in accordance with the current drawn by nonlinear and unbalanced load and cancels the harmonics introduced by nonlinear load. It also enables source to deliver only active power by injecting reactive power demand and maintains supply current sinusoidal [8–10]. In Fig. 1 R is resistance of the transmission line, L denotes transmission line inductance, Lf is inductance of filter connected to inductor. Rnl_load denotes nonlinear loads. R1, R2, R3, L1, L2, L3, C1, C2, C3 represents resistance, inductance and capacitance of unbalanced load in each phase.

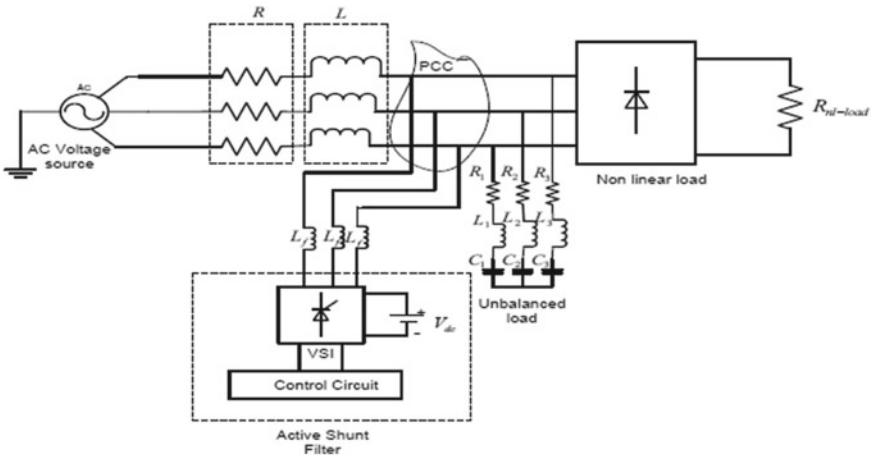

Fig. 1 Nonlinear and Unbalanced load with active shunt filter

2.1 Calculation of Reference Current by P-Q Theory

From Clarke's transformation matrix equation we get two axis component of three-phase system. Three-phase voltage and current can be transformed into voltage and current of d-axis and q-axis component [6, 7].

For voltage transformation in three-phase three wire system from Clark's transformation matrix equation [5, 10] we get (1)–(4)

$$v_\alpha = \sqrt{\frac{2}{3}}\left(v_a - \frac{v_b}{2} - \frac{v_c}{2}\right) \tag{1}$$

$$v_\beta = \sqrt{\frac{2}{3}}\left(\frac{\sqrt{3}v_b}{2} - \frac{\sqrt{3}v_c}{2}\right) \tag{2}$$

For current transformation we get from [5, 10]

$$i_\alpha = \sqrt{\frac{2}{3}}\left(i_a - \frac{i_b}{2} - \frac{i_c}{2}\right) \tag{3}$$

$$i_\beta = \sqrt{\frac{2}{3}}\left(\frac{\sqrt{3}i_b}{2} - \frac{\sqrt{3}i_c}{2}\right) \tag{4}$$

The active and reactive power can be obtained from Eqs. (5) and (6)

$$p = v_\alpha i_\alpha + v_\beta i_\beta \tag{5}$$

$$q = v_\alpha i_\beta - v_\beta i_\alpha \tag{6}$$

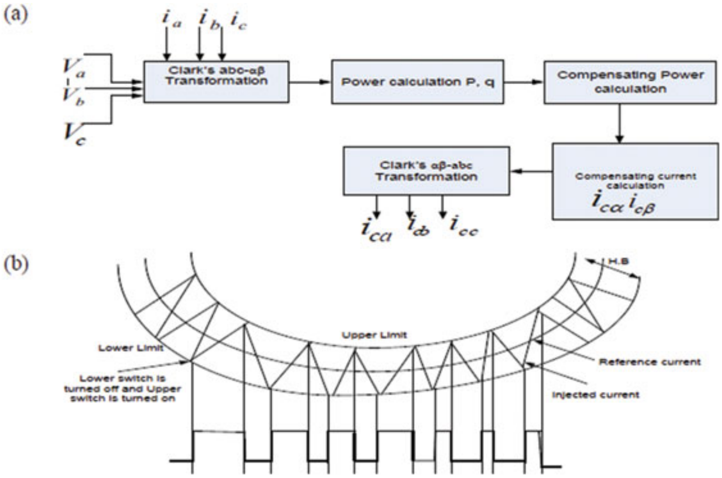

Fig. 2 **a** Block diagram of reference current calculation. **b** Hysteresis current controller

Now from these equations obtained from Clarke's abc-αβ transformation the reference current can be calculated [6, 7]. The generation of reference current is delineated in Fig. 2a. At first supply voltage and current are transformed into two axis components by Clark's transformation. The active and reactive powers are calculated from Eqs. (5) and (6). The calculated active power contains fundamental power called average power and higher order harmonics power called oscillating power. The oscillating power is separated from the average power by using a high pass filter. Now we can derive reference current $i_{c\alpha}$ and $i_{c\beta}$ from calculated oscillating power, reactive power, and two-axis component of supply voltage. Clarke's inverse matrix transformation is taken into consideration to calculate the reference current [8].

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{-1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\alpha & v_\beta \end{bmatrix} \begin{bmatrix} p_{oscillating} \\ q \end{bmatrix}$$

These two axis reference currents are further converted to three-phase current [8].

$$\begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix}$$

Here i_{ca}, i_{cb} and i_{cc} are three-phase reference current.

2.2 Hysteresis Current Controller

Figure 2b shows hysteresis controller. For the purpose of controlling the compensating current hysteresis current controller method is a novel one. It has advantages of quick dynamic response as well as simplicity [1]. Besides these it provides smooth switching frequency for fixed switching frequency [2, 5]. A current control VSI is connected in parallel with the load in order to generate reference compensating current. When the injecting filter current through the coupling inductor crosses the reference current out of either upper or lower band limit the upper and lower switches of inverter are tripped according to hysteresis controller logic [1, 2, 5, 10]. The switching control strategy follows [1] and is shown in Fig. 2b.

S (Switching State) = 0: if $\boldsymbol{i}_f(\boldsymbol{t}) > \boldsymbol{i}_f^*(\boldsymbol{t}) + \frac{\boldsymbol{H \cdot B}}{2}$

The upper switch is off and lower switch is on, S $= -v_{dc}$

S = 1: if $\boldsymbol{i}_f(\boldsymbol{t}) < \boldsymbol{i}_f^*(\boldsymbol{t}) - \frac{\boldsymbol{H \cdot B}}{2}$

The upper switch is on and lower switch is off, S $= +v_{dc}$.

Thus it happens to maintain injected current to be in hysteresis band limit.

3 MATLAB Simulink Model

The MATLAB Simulink model in Fig. 3 shows that a nonlinear rectifier load and an unbalanced three-phase load are connected to a three-phase voltage source through circuit breaker and three phase V-I measurement unit. In parallel to nonlinear and unbalanced load an active shunt filter is connected. Active shunt filter comprises of an IGBT-based voltage source inverter which is connected to PCC (Point of common coupling) through coupling inductor. At the input of the VSI two capacitors are connected in series. A PI controller is connected to the input dc voltage of VSI with a reference voltage. From p-q theory [6, 7] all equations are formed using mathematical functional blocks in MATLAB software. After the reference current calculation is done the Boolean NOT gate and relational operator have been used for implementation of hysteresis current controller to generate gate pulses. The generated gate pulses have been given to the gate input of VSI. In hysteresis current controller circuit model the reference current has been compared with the measured supply current and according to the error the filter current ramps up and down through inductor and provides compensating current to the supply side in phase opposition to the harmonics components eliminating harmonics introduced by nonlinear and unbalanced load.

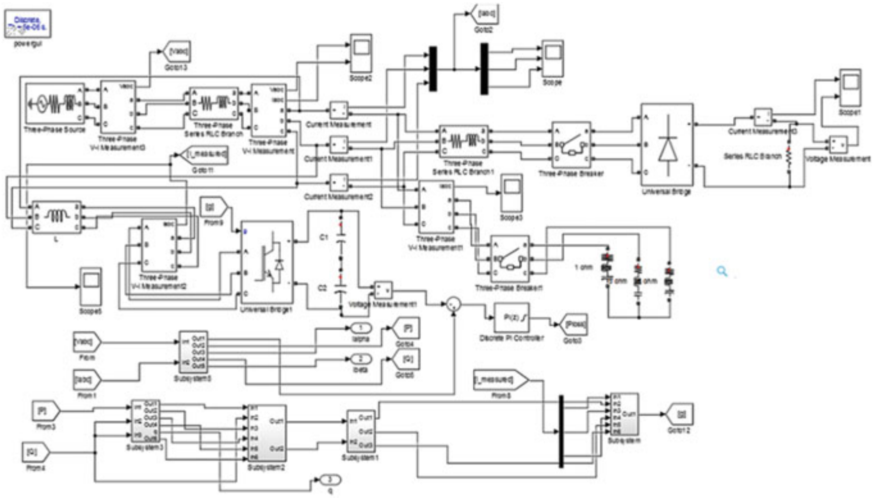

Fig. 3 MATLAB Simulink model

4 Result and Discussion

Before connecting the shunt active power filter supply voltage and current, total harmonics distortion (THD) of supply current, DC load voltage and current and unbalanced load current are observed. As the two circuit breakers (one each connected to nonlinear load and unbalanced load) are switched after 0.2 s the THD is measured after starting time 0.2 s for 100 cycles. The two loads draw current which shows 30.26% THD and the supply current is highly distorted. After the active filter is connected parallel to the load the THD goes down and comes to 5.32%. Before connecting active filter the fundamental current component was 64.03 A and after connecting the filter the fundamental current is 65.78 A. Besides this the supply current shows sinusoidal waveform. The compensating filter current is observed and along with all the measured quantities is shown in Figs. 4 and 5. Figure 4a shows supply voltage and current without filter. The supply current is not pure sinusoidal. Figure 4b shows that the supply current contains 30.26% THD. The fundamental component has frequency of 50 Hz and the fundamental component contains the magnitude of 64.03 A. Figure 4c shows the three-phase unbalanced current which contains higher notches. Figure 4d shows voltage and current waveform after the shunt filter is connected. This shows pure sinusoidal current waveform which was a distorted one in Fig. 4a. Figure 4e shows the THD in supply current with active shunt filter. Without active shunt filter Fig. 4b shows that the THD level is 30.26% where as Fig. 4e shows that the THD is only 5.32%. This shows that the THD level has been reduced significantly to a lower margin. Figure 5a represents the waveform of compensating current flowing through coupling filter which ramps filter current up and down to remain within the hysteresis band and trace the reference current.

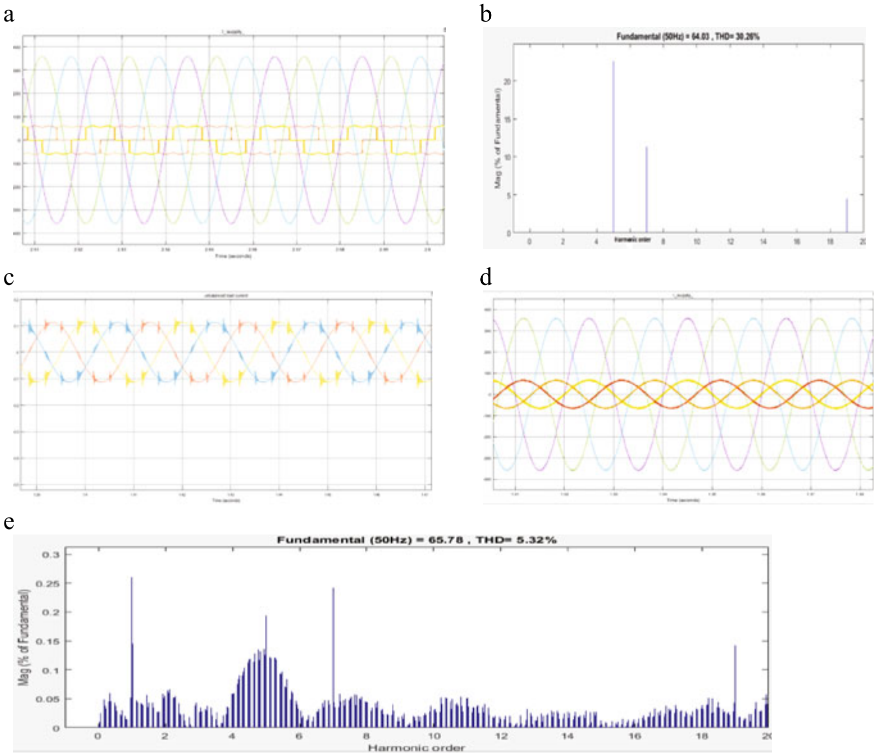

Fig. 4 **a** Supply voltage and current without filter, **b** THD of supply current without filter, **c** unbalanced load current without filter, **d** supply voltage and current with filter, **e** THD of supply current with filter

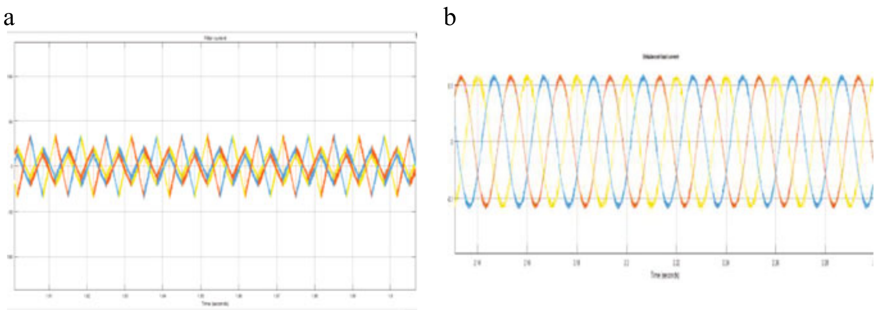

Fig. 5 **a** Compensating current through coupling inductor, **b** unbalanced load current with SAF

Figure 5b shows the unbalanced load current with active power filter and this contains fewer notches whereas Fig. 4c shows higher notches.

Table 1 Value of various parameters which were used in the system modeling

Name	Value
Ph–Ph voltage of three phase voltage source	440 V
Circuit breaker switching time	0.2 s
Nonlinear Dc load	10 Ω
Unbalanced RLC load	Phase A: R = 1 Ω, L = 1 mH, C = 1 μF; Phase B: R = 10 Ω, L = 1 mH, C = 1 μF; Phase C: R = 17 Ω, L = 1 mH, C = 1 μF
Filter inductance	0.39 mH
Capacitor used in VSI	50 μf

5 Conclusion

From the above result it is concluded that we have achieved our goal in reducing Total Harmonic Distortion of supply current and improving the power quality. By using hysteresis current controller based shunt active filter we have improved the shape of supply current waveform. This shows the transfer of a better quality of power. However more advanced methodologies of controlling method have been introduced such as adaptive fuzzy hysteresis band—current controller, space phasor based hysteresis current controller [3] etc. In future our focus is to improve power quality issues with the help of more advanced controlling methodology.

Appendix

See Table 1.

References

1. Kale M, Ozdemir E (2005) An adaptive hysteresis band current controller for shunt active power filter. Electr Power Syst Res 73(2):113–119
2. Suresh Y, Panda AK, Suresh M (2012) Real time implementation of adaptive fuzzy hysteresis-band current control technique for shunt active power filter. IET Power Electron 5(7):1188–1195
3. Chauhan SK, Shah MC, Tiwari RR, Tekwani PN (2013) Analysis, design and digital implementation of a shunt active power filter with different schemes of reference current generation. IET Power Electron 7(3):627–639
4. Hareesh M, Kumar GS, Sreenivasarao D (2015) Power quality improvement by shunt active filter for low cost applications. In: 2015 international conference on computation of power, energy information and communication (ICCCPEIC), 22 Apr 2015, pp 0153–0158. IEEE
5. Panda AK, Patel R (2015) Adaptive hysteresis and fuzzy logic controller-based shunt active power filter resistant to shoot-through phenomenon. IET Power Electron 8(10):1963–1977

6. Akagi H, Kanazawa Y, Fujita K, Nabae A (1983) Generalized theory of the instantaneous reactive power and its application. Trans Inst Electr Eng Jpn B 103(7):483–490
7. Akagi H, Kanazawa Y, Nabae A (1984) Instantaneous reactive power compensators comprising switching devices without energy storage components. IEEE Trans Ind Appl 625–630
8. Shah A, Vaghela N (2014) Shunt active power filter for power quality improvement in distribution system. Int J Eng Dev Res 1(2):23–27
9. Poonia A, Dey A (2016) Space phasor based improved hysteresis current controller for shunt active power filter using 3–level inverter. In: 2016 18th European conference on power electronics and applications (EPE'16 ECCE Europe), 5 Sep 2016, pp 1–10. IEEE
10. Ahuja RK, Chauhan A, Sharma S (2012) Hysteresis control for current harmonics suppression using shunt active filter. Int J Adv Res Technol 1(6):17–24