An Adaptive Hysteresis Current Control Technique based Shunt Active Power Filter for Power Quality Improvement

Poongothai.K[1], Avila Priya.F[2], Arunkumar.R[3], SenthilKumar.A[4], Vijayakumar.K[5]
[123]PG student, [4]Research Scholar, [5]Assistant Professor
[123]Sri Manakula Vinayagar Engineering College, Puducherry, India
[4]Pondicherry Engineering College, Puducherry, India
[5]Sri Manakula Vinayagar Engineering College, Puducherry, India

***Abstract*— This paper presents a novel adaptive pulse generation technique to enhance the quality of power using shunt active power filter. The main objective of this paper is to identify a suitable pulse generation technique for obtaining a better compensation capability of shunt active power filter. The compensation capability of the device is mainly depends on the regulation of DC link capacitor voltage. Conventionally fixed hysteresis current control technique has been used. To raise the performance of shunt active power filter, an adaptive hysteresis current control technique has been proposed here. The comparison between the conventional and proposed technique has been made here for different operating conditions. The platform used for this purpose is MATLAB/SIMULINK model.**

Keywords—* *Power quality (PQ), Shunt active power filter, Unit vector template generation (UVTG), Adaptive hysteresis current control technique, Total harmonic distortion (THD).

I. INTRODUCTION

The present power system scenario mainly focused on the issue of power quality problems. The major research topic in the power distribution system is to improve the quality of power [1]-[3]. The primary cause for poor power quality is the arrival of power electronics based devices and non-linear loads in industries as well as commercial applications. The ideal power system has balanced, pure sinusoidal phase supply, the loads operating with unity power factor and zero harmonics. But practically this is not possible because the system comprises of linear and non-linear loads. Due to these complex loads there will be a change in the system parameters such as voltage, current and frequency together they are termed as 'Power quality issues'. The poor power quality results malfunction of devices and equipment, voltage and current harmonics and unbalances, low power factor and reactive power consumption. Among these harmonics is the primary index for poor power quality. Due to the development in the field of power electronics and the digitalized control technology the entry of custom power devices is encouraged. A most widely used custom power device is called active power filters (APF). There are generally three types of APF series APF, shunt APF and UPQC (Unified Power Quality Conditioner). Series APF is gives compensation for voltage related problems like voltage sag, swell, flicker and unbalances. Shunt APF is a device which is used to compensate the current related problems like harmonics, inter harmonics and reactive power consumption. UPQC is the combination of series and shunt APF. So that it will provide both voltage and current related compensation [10], [12].

This paper deals with the application of shunt APF to the distribution system to mitigate the current related issues and provide a satisfaction to the customer by delivering good electrical power. The operation of shunt APF can be identified by using the control technique [2]. There are different control strategies provided by different authors. In this paper Unit Vector Template Generation is described. Among the different pulse generation techniques, here Adaptive hysteresis current control technique is chosen because of its simplicity and easy to implementation.

In section 2, the concept of shunt APF was discussed and the section 3 comprises of control technique for shunt APF, section 4 includes adaptive HCC technique, mathematical formulation was described in section 5. The section 6 holds the results obtained from MATLAB/SIMULINK model and its discussions. The final section incorporates conclusion part.

II. SHUNT ACTIVE POWER FILTER

The shunt active power filter is a device which is connected in parallel at the Point of Common Coupling (PCC). The center point where the source and the load are meeting is called as PCC. Generally the active power filter consists of inverter topology in it which may be voltage source inverter (VSI) or current source inverter (CSI). Most of them prefer VSI based shunt active power filter because CSI holds some of the drawbacks [5] - [6]. At the output terminal of the VSI a dc link capacitor is connected which acts as an energy storage element and is used to maintain a constant DC voltage with small ripple in steady state. The dc link voltage of the capacitor has to be maintained as constant in order to achieve a better compensation. This is achieved with the help of closed loop operation that is PI controller. The shunt active power filter provides compensation for current related problems like harmonics, low power factor and reactive power consumption. This is accomplished by applying a suitable control technique for VSI [2], [8]. The next section holds the control technique for shunt APF.

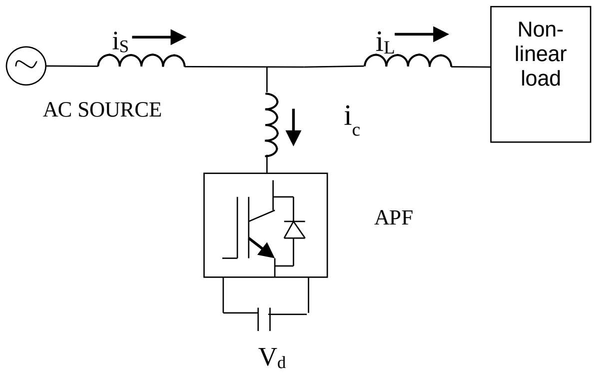

Fig.1. Shunt Active Power Filter

III. CONTROL TECHNIQUE USED FOR SHUNT ACTIVE POWER FILTER

The control strategy decides the behavior and desired operation of filter topology of a power system. The estimation of compensation current is an important task in the control of APF. There is different time domain and frequency domain based control techniques are stated by many authors. Among them Unit Vector Template Generation (UVTG) is preferred here. It is very simple and easy to implement because it does not needs any complex mathematical model or algorithm to implement [4], [9]. The closed loop operation of shunt APF can be accomplished by PI controller which is used to maintain the dc link voltage as constant. The required reference source current (Is_{ref}) can be produced by multiplies the three phase unit sine vector (120^0 phase shift with each other) with the output of PI controller [7]. The essential compensation current can be obtained by comparing the actual source current with the resultant reference source current. The final stage of the active filter circuit is gate signal production unit. The diagram for control technique used in shunt APF is shown in figure 2. In the next section pulse generation technique for shunt active power filter has been discussed.

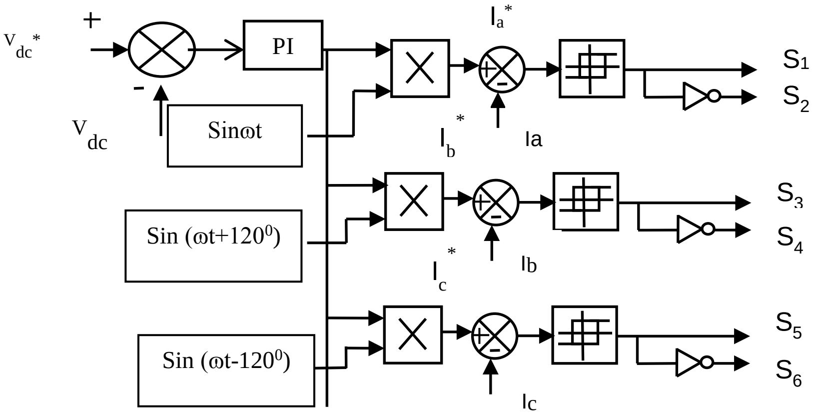

Fig.2. Control technique used for shunt Active Power Filter

IV ADAPTIVE HYSTERESIS CURRENT CONTROL TECHNIQUE

The hysteresis current control technique has been preferred for most of the active power filter applications because of its undesirable characteristics such as fast response, good accuracy unconditioned stability and simple design. Conventionally Fixed Hysteresis Current Control (HCC) technique has been used. The fixed-HCC is simple in design, unconditioned in stability and easy to implement. However, this control scheme exhibits several unsatisfactory features such as the uneven switching frequency where the switching frequency varies within a particular band limit. The slope of current waveform may vary widely and the peak amplitude of current waveform may exceed the hysteresis-band. Consequently, inverter switches will be operated at high switching frequency in order to track reference current. Moreover, the variable switching frequency makes it difficult for the design of interface inductor and the selection of dc-link capacitor voltage value. Due to this the efficiency of active power filter and its reliability gets affected. The demerits of conventional fixed HCC have been overcome by the proposed adaptive HCC technique [11]. The conventional fixed HCC switching pattern is shown in figure3.

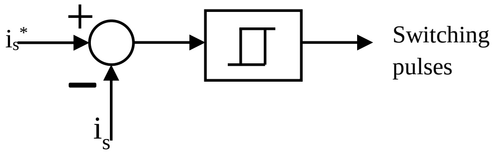

Fig.3. Conventional Fixed HCC technique switching pattern

The adaptive HCC is proposed by Bose for machine drive system and here it is adapted for 3phase 3 wire active filter system. As similar to conventional HCC technique the actual and reference source currents are subtracted and the resultant error signal is applied to the relay circuit to produce gate pulses. In adaptive HCC, the additional hysteresis bandwidth (HB) is given to the relay circuit. The switching pattern for this adaptive HCC is shown in fig. when e(t) exceeds the upper limit of HB, then the lower switches are turned ON. Similarly if the e(t) exceeds the lower limit of HB then the upper switches are turned ON [13]. The switching pattern for proposed adaptive HCC is shown in fig4 and block diagram for calculating the HB in MATLAB is shown in fig. 5. Proposed adaptive HCC is shown in fig4 and block diagram of calculating the HB in MATLAB is shown in figure5.

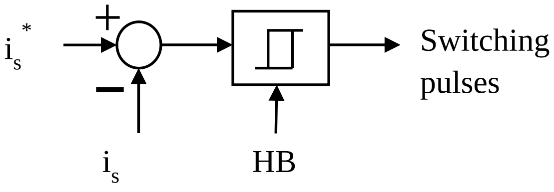

Fig.4. Switching pattern for Proposed Adaptive HCC technique

The following equation is used to calculate the value of adaptive HB,

$$HB = \frac{0.125V_{dc}}{fcL}\left[1-\frac{4L^2}{V_{dc}^{\,2}}\left(\frac{V_s}{L}+m\right)^2\right] \quad \text{------(1)}$$

$$i_L(t) = \sum_{n-1}^{\infty} I_n \sin(\omega t+\phi_n)$$

$$= I_1\sin(n\omega t+\phi_1)+\sum_{n-2}^{\infty}\sin(\omega t+\phi_n)$$

The instantaneous load power can be given as,

$$P_L(t) = V_s(t) * il(t)$$

$$= P_f(t)+P_r(t)+P_h(t) \quad \text{------(4)}$$

The fundamental real power drawn by the load is,

$$P_f(t) = V_s(t) * i_s(t)$$

$$\text{where, } i_s(t) = I_m \sin\omega t$$

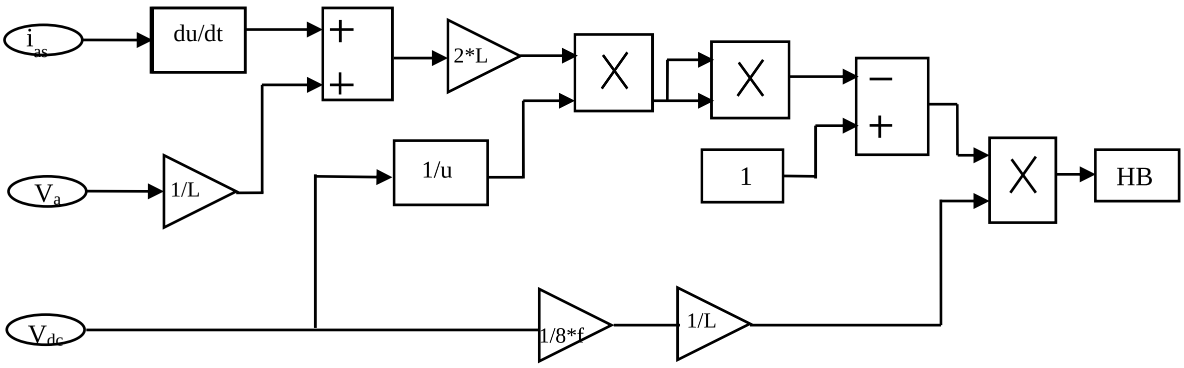

Fig.5. Block diagram of Adaptive hysteresis current controller

Where, V_s is the supply voltage, V_{dc} is the DC link capacitor voltage, L is the coupling inductor and $m=di_a^*/dt$ is the slope of reference current. From the equation it is clear that the switching frequency of inductor depends upon the value of V_{dc} and L. In conventional fixed HCC the HB is constant and the switching frequency has been varied according to the load connected. But here the HB is made variable and hence the switching frequency is maintained as constant. Hence the compensation current get from the output of control technique part is used to produce the required gate signal for VSI operation. This compensation current has been fed at the PCC. It is noticed that the compensation current obtained is 180^0 opposite to that of harmonics current produced by the load. Hence both currents will get cancel each other, so the load current becomes sinusoidal. Finally the source current waveform is sinusoidal and in phase with the source voltage. Therefore the enhancement of power quality is achieved [11]-[15].

V. MATHEMATICAL FORMULATION

The instantaneous current can be written as,

$$i_s(t) = i_L(t) - i_c(t) \quad \text{------(2)}$$

The source voltage is given by,

$$V_s(t) = v_m \sin wt \quad \text{------(3)}$$

If a non-linear load is applied, then the load current will have a fundamental and harmonic components which can be represented as,

Source current supplied by the load after compensation is,

$$i_s(t) = P_f(t)/V_s(t) = I_1\cos\phi_1 \sin\omega t = I_m \sin\omega t \quad \text{----(5)}$$

$$\text{Where } I_{sm} = I_1\cos\phi_1$$

There are also some switching losses in the PWM 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 peak current supplied by the source is,

$$I_{sp} = I_{sm} + I_{sl} \quad \text{------(6)}$$

If the active power filter provides the total reactive power and harmonic power, then i_s (t) will be in phase with the source voltage and becomes sinusoidal. At this time the compensation current of the active power filter is,

$$i_c(t) = i_L(t) - i_s(t) \quad \text{------(7)}$$

Hence it is necessary to estimate the reference source current. It is estimated by controlling the DC side capacitor voltage.
For a better compensation it is necessary that the main current to be sinusoidal and in phase with the source current irrespective of the load current. The desired source current after compensation is,

$$i_{sa}^* = I_{sp}\sin\omega t$$

$$i_{sb}^* = I_{sp}\sin(\omega t-120) \quad \text{-----(8)}$$

$$i_{sc}^* = I_{sp}\sin(\omega t+120)$$

VI. SIMULATION RESULTS AND DISCUSSION

A. *System data and operating conditions:*

1. Supply Voltage = 440Vrms
2. Supply Frequency = 50 Hz
3. Source Impedance = 1 Ohms and 0.1mH
4. Filter impedance = 1 Ohms and 15mH
5. Load impedance = 1 Ohms and 10mH
6. DC link voltage=700 V

Operating condition:

I. Normal Load Condition – Rectifier RL load 15KW and 5KVA–here no change in Load

II Load Change Condition – 0.3 to 0.5sec – another load R=15KW and Q=5KVA is added on DC side

B. *Discussion:*

The performance of Shunt active power filter using fixed HCC technique and adaptive HCC technique is analyzed for rectifier RL non -linear load with respect to two different operating conditions in MATLAB/Simulink environment. The analysis has been carried out for current %THD and power factor for with and without filter as below.

I) *Analysis of THD% for current*: The dynamic waveform of current for conventional and proposed approach is highlighted in Fig. 7 and Fig. 15. For without filter the THD% for current is seen to be 30.92% in operating condition I and 42.71% in operating condition II. Whereas with conventional approach, the THD% is observed to be 4.38% in operating condition I. By using the proposed Adaptive hysteresis current control technique for shunt active power filter THD is minimized as 2.9% in operating condition I. In operating condition II, another load is connected from 0.2 to 0.4 sec in conventional technique and 0.3 to 0.5 sec in proposed technique. During this time conventional technique fails to operate because of fixed hysteresis bandwidth. By using proposed approach the better compensation ability of the filter is achieved in sudden load change condition. The DC link voltage for operating condition IIs for without and with filter for both HCC and adaptive HCC techniques are represented in the figures and 16 & 17. From the analysis, THD% for current is found to be for operating condition II of conventional HCC technique it is 18.28% and for proposed technique it is reduced to 3.69% very highly poisonous to dead the load and components in its network. This demonstrates the performance of shunt active power filter on minimize of current total harmonic distortion. The THD% of current comparison for both techniques is tabulated in table 1.

II) *Analysis of power factor for without and with filter*: The simulation results for power factor analysis of Load I and Load II with filter are shown in Fig. 11 and Fig. 18. From the obtained results during operating condition II it is observed that the voltage and current waveform are not in phase by which the power factor is found to be 0.7483 whereas with proposed approach the voltage and current are found to be in phase with each other and the power factor is improved to 0.999. This approach ensures the performance of the shunt active power filter by improving the power factor. The simulation results for supply voltage and the load voltage is shown in figure 6 & 8. The compensation current for both condition is shown in fig 10 & 13. By noticing the DC link capacitor voltage the compensation capability of filter is improved by proposed work. DC link voltage for Load I is shown in fig 12 & for operating condition II of conventional technique is shown in fig 16 and for proposed work is in fig 17. Hence from the result it is proven that by proposed approach the performance of filter is improved. Finally the value of %THD is maintained within the limits as per IEEE standards.

C. *Simulation results for rectifier RL load:*

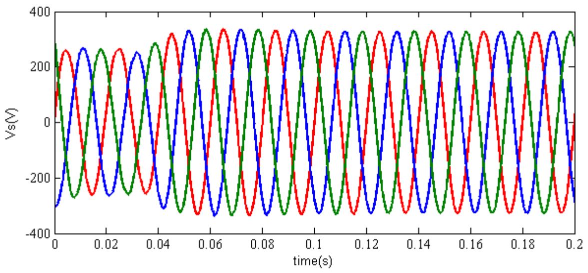

Fig.6. Source voltage with filter for Load I

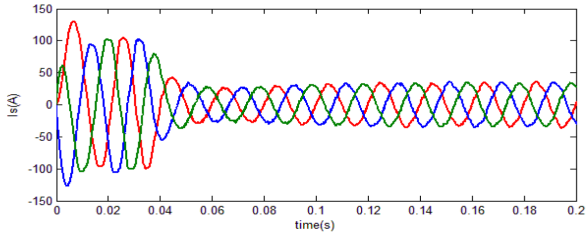

Fig.7. Source current with filter for Load I

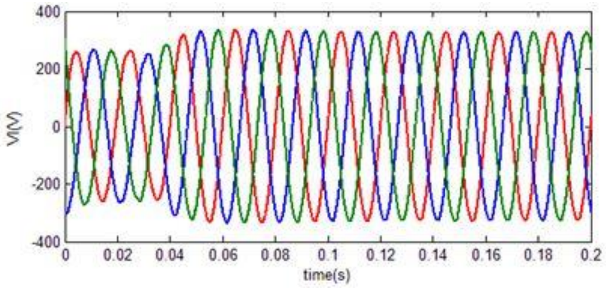

Fig.8. Load voltage with filter for Load I

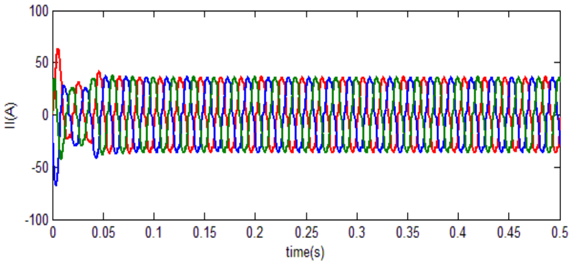

Fig.9. Load current with filter for Load I

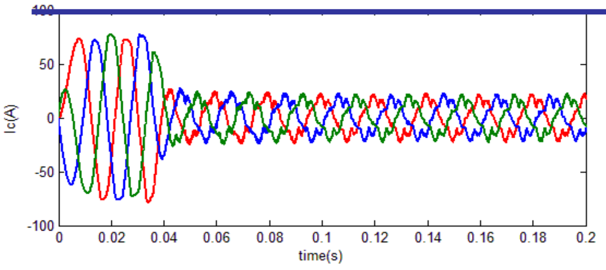

Fig.10. Compensation current with filter for Load I

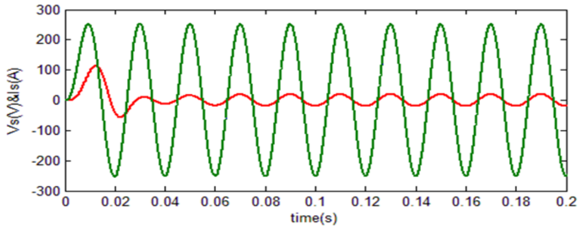

Fig.11. Power factor with filter for Load I

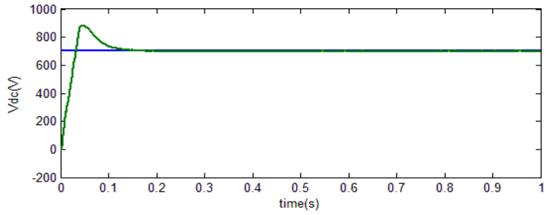

Fig.12. DC link capacitor voltage with filter for Load I

D. Simulation results for two load operating condition (Fixed HCC and Adaptive HCC technique):

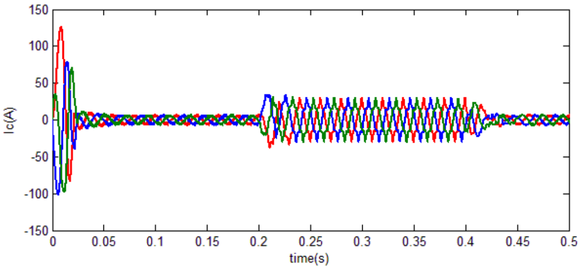

Fig.13. Compensation current with filter for Load II

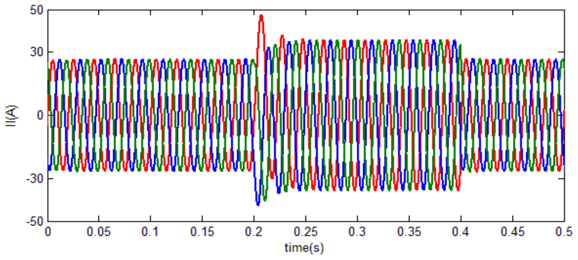

Fig.14. Load current with filter during 2 load operating condition

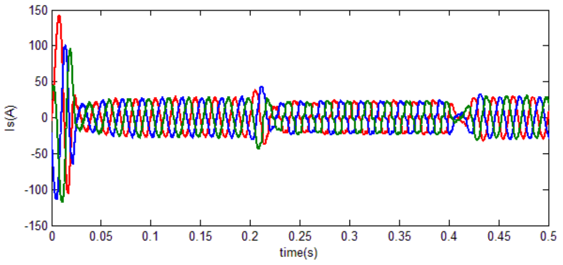

Fig.15. Source current with filter for Load II

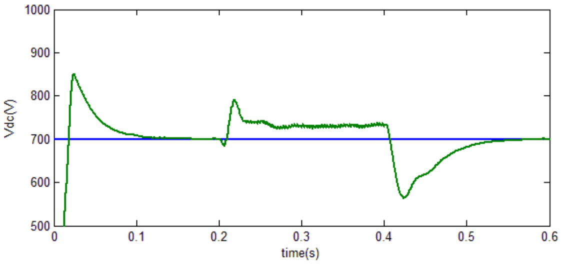

Fig.16. DC link capacitor voltage during operating condition II using fixed HCC technique

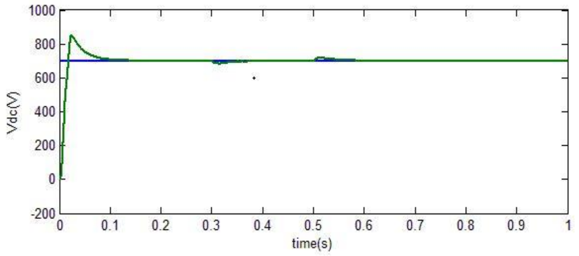

Fig.17. DC link capacitor voltage during operating condition II using adaptive HCC technique

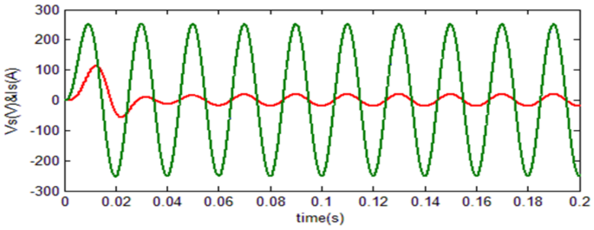

Fig.18. Power factor during operating condition II using adaptive HCC technique

THD% for Current by HCC technique					
Operating Condition I			**Operating Condition II**		
With out Filter	**With Filter (HCC)**	**With Filter (AHCC)**	**With out Filter**	**With Filter (HCC)**	**With Filter(A HCC)**
30.92	4.38	2.9	42.71	18.28	3.69

Table1. Comparison of %THD for without and with filter of conventional and proposed technique

VII. CONCLUSION

This paper investigates the validity of proposed adaptive HCC technique for Shunt APF. From the result of simulation study of both conventional and proposed Pulse generation technique, it is found that the proposed technique gives quite satisfactory performance during sudden load increasing condition. This is proven by noticing the DC link capacitor voltage regulation waveform and also the utility supply current becomes sinusoidal with supply voltage. Hence the shunt APF presented in this paper for current compensation of non-linear load was effective. The compensation capability of filter was improved by using proposed pulse generation technique. Thus the filter is found as operative to meet IEEE standard recommendation of harmonic limits. The future work has been carried for implementing this technique in FPGA platform.

REFERENCES

[1] Abdelmadjid Chaoui, Jean Paul Gaubert, Fateh Krim, Gerard Champenois ,“PI Controlled Three-phase Shunt Active Power Filter for Power Quality Improvement”, Electric Power Components and Systems, 35, pp.1331–1344, 2007.

[2] Karuppanan P and Kamala kanta Mahapatra, “PID with PLL Synchronization controlled Shunt APLC under Non-sinusoidal and Unbalanced conditions” , National Power Electronics Conference (NPEC) Proceedings, IIT-Roorkee, June-2010.

[3] W.M.Grady, M.J.Samotyj, A.H.Noyola, “Survey of Active Power Line Conditioning Methodologies”, IEEE Trans on Power Delivery, Vol.5, No.3, pp.1536-1542, 1990.

[4] E.E. EL-Kholy, A. EL-Sabbe, A. El-Hefnawy, Hamdy M. Mharous, “Three-phase active power filter based on current controlled voltage source inverter”, Elsevier , vol. 28, no. 8, pp. 537-547.2006.

[5] Bhim Singh, Kamal Al-Haddad and Ambrish Chandrs, “A Review of Active Filters for Power Quality Improvements”, IEEE Trans on Industrial Electronics, Vol.46, No.5, pp. 960-970, Oct-1999.

[6] Bhim Singh, Kamal Al-Haddad & Ambrish Chandra, “A New Control Approach to 3-phase Active Filter for Harmonics and Reactive Power Compensation”, IEEE Trans. on Power Systems, Vol. 46, No. 5, pp. 133 – 138, Oct-1999.

[7] L. Gyugyi, E. C. Strycula, “Active AC Power Filters”- in Process of IEEE/IAS Annual Meeting, 1997.

[8] Karuppanan P and Mahapatra, Kamala Kanta, “Shunt Active Power Line Conditioners for compensating harmonics and reactive power”, IEEE conference on Environment and Electrical Engineering, pp. 277 – 280, May 2010.

[9] B. Singh, K. Al-Haddad, and A. Chandra, “A review of active power filters for power quality improvement,” IEEE Transaction on Electronics, vol. 45, no. 5, pp. 960–971, Oct. 1999.

[10] Gayadhar Panda,Pravat kumar, “Novel schemes for estimation of power system harmonics and their elimination in a three phase distribution [illegible] energy system , 10.1016/j.ijepes.2013.05.037,2013.

[11] V. Khadkikar, A. Chandra, A.O. Barry and T.D. Nguyen, “Power quality enhancement utilising single-phase unified power quality conditioner: digital signal processor-based experimental validation,” in Process of IET Power Electronics, 2011, Vol. 4, Iss. 3, pp. 323–331.

[12] Ravit Gautam, Dipen A. Mistry , Manmohan Singh Meena, Bhupelly Dheeraj , Suresh Mi kkili, “Adaptive Hysteresis Based SHAF Using PI and FLC Controller for Current Harmonics Mitigation”, International Journal of Electrical, Robotics, Electronics and Communications Engineering Vol:8 No:5, 2014.

[13] Mohamed R. Amer, Osama A. Mahgoub, Sherif A. Zaid, “ New Hysteresis Control Method for Three Phase Shunt Active Power Filter”, International multiconference of engineers and computer scientists 2011, vol 2.

[14] Manish Kumar Soni, Nisheet Soni, “A Novel Current Controller Technique for Three Phase Shunt Active Power Filter”,International journal of Innovative Research & Development, September, 2014 Vol 3 Issue 9.

[15] Murat Kale*, Engin Ozdemir, “An Adaptive Hysteresis Band Current Controller for Shunt Active Power Filter”, Electric Power System Research 73(2005) vol.113-119, 2005.