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AN ANALYTICAL STUDY OF TOTAL HARMONICS REDUCTION IN APF USING ADAPTIVE ZERO CROSSING DETECTION TECHNIQUES

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ABSTRACT

The excessive waveform distortions in the present power distribution systems are produced mainly by the large number of non-linear loads. Such distributed sources of harmonics cannot be easily treated by the traditional mitigation methods. Furthermore, classical control theory suffers from some limitations due to the nature of the controlled system. These problems can be overcome by using adaptive zero crossing detection (AZCD). A comparison between the conventional PI controller and AZCD for three-phase, six-switch VSI-based APF using synchronous reference frame (SRF) theory is realized in this paper to improve the step transient response of DC link voltage of APF at sudden change of the load. Shunt active power filters operate as a controllable current source and are implemented preferable with voltage source PWM inverters, with a dc capacitor. The time domain simulation is performed using MATLAB/ Simulink environment to compensate the non-active power in different conditions. Results showed that the source current THD% can be reduced to less than 5% the harmonic limit imposed by the IEEE-519 standard and the DC voltage are settled to their steady state values within a few cycles. It is clear from the results that DC link with AZCD has better dynamic behavior than conventional PI control strategy.

KEYWORDS: shunt active filter, zero crossing detection, PWM, PI Controller, THD.

INTRODUCTION

An Electrical energy is the most efficient and popular form of energy because it can be use easily at high efficiency and reasonable cost. The first electric network in the USA was established in 1882 and after that every corner of earth connected through these lines [1]. Both electric utilities and end users of electrical power are becoming increasingly concerned about the quality of electric power. The term power quality has become one of the most prolific buzzword in the power industry since the late 1980s [2]. Power quality is a set of parameters related to properties of power supply. In a broader perspective, power quality includes considerations regarding different aspects of reliability of electrical power supply such as distortion, phase unbalance, line interruptions, amplitude variations, frequency changes, flicker, and transients, etc. But while narrowing down, the focus of power quality revolves around distortion in waveforms of voltage and current. One of the most serious problems is that of the harmonic, which is generated from the nonlinear loads. Harmonics in the electrical power system are unwanted effect due to various reasons. They produce undesirable effects in the power system. Power electronic devices based converters have found numerous applications. The increasing use of power electronic system has led voltage harmonic distortion level to an unacceptable level at point of common coupling (PCC). If the level of harmonics is above the limit, they must be mitigated to operate the power system satisfactorily.

Conventionally, passive filters have been used to eliminate harmonics but due to their inherent drawbacks, they have been replaced by active power filter, as active filters have superior filtering characteristics and dynamic response compared to passive filters. There has been a significant increase in interest of active power filters and its control methods. Till now in the field of active power filter main focus of research has been on development of novel techniques for reference compensating current generation in order to improve the compensation characteristic and to extend the application of active power filter from harmonic compensation to harmonic damping, harmonic isolation, voltage regulation, etc. Active power filter plays a measure role in power quality improvement. The quality of the active power filter (APF) depends on three considerations: The modulation and control method used to implement the compensation scheme, power circuit configuration, and the method used to extract the harmonic content [3].

In various conventional PI controller tuning methodologies such as Ziegler-Nichols method, the recommended settings are empirical in nature and are obtained from extensive experimentation [4]. The conventional controllers are used to reduce the errors [5]. However, these controllers may present a poor steady-state error for harmonic reference signal. These controllers, perform unsatisfactorily during variation in parameters under nonlinear load conditions and require precise linear mathematical models which are hard to derive [6]. With adaptive zero crossing detection, the tracking is significantly better. A good control technique should be able to shape the regulated signal to follow its reference without generating distortion [91]. The proposed control was introduced as a goal for DC-Link voltage control so the aim of this work is to propose an adaptive current control techniques namely adaptive zero crossing detection for shunt active power filter for regulating DC-Link voltage instead of PI controller. The basic compensating principle of SAPF was shown in figure 1. The Proposed controller is simple and fast in architecture and it can be successfully applied for harmonic filtering under different conditions.

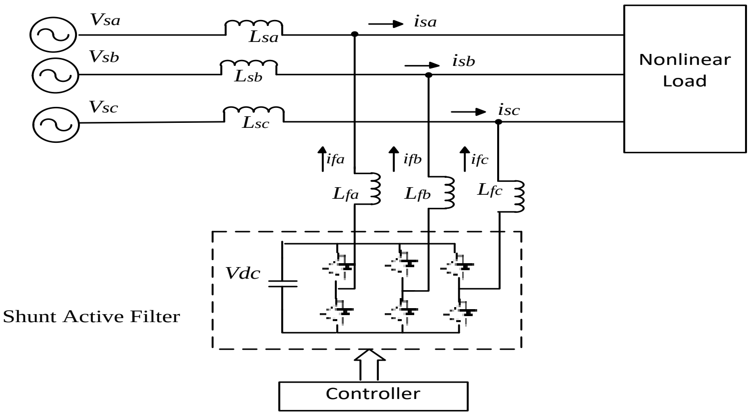


Figure 1: Schematic diagram of shunt APF.

HARMONIC CURRENTS EXTRACTION METHOD

The inaccuracy and inefficiency of the harmonic extraction method would inevitably deteriorate the overall compensation performance. Harmonic extraction is the process in which, reference current is generated by using the distorted waveform. The APF control has two main blocks: the first and most important is to generate the control reference signals quickly and accurately; i.e. harmonics detection, and the second one is to carry out the control method effectively. So, harmonics detection is one of the important steps to compensate harmonics distortion in electrical system [7]. The performance of SAPF strictly depends on the features of the improved algorithms and controllers. However, usually one algorithm is only more appropriate to some situation but not to all situation [8].

A variety of methods are used for instantaneous current harmonics detection in active power filter such as FFT (fast Fourier technique) technique, instantaneous p-q theory [9], synchronous d-q reference frame theory or by using suitable analog or digital electronic filters separating successive harmonic component [10], but in practice, FFT and synchronous rotation (dq-frarne) methods are developed more extensive [11]. Out of these theories, more than 60% research works consider using p-q theory and d-q theory due to their accuracy, robustness and easy calculation [12]. It has been shown in [13] and [14] that synchronous frame based compensators achieve better overall performance than compensators based on reactive power theory [15]. It is, therefore, this last method of harmonic current derivation that will be adopted in this work. To compensate harmonic currents, synchronous reference frame detection method is used for extraction of the reference current. SRF theory in time domain based on reference current generation techniques have been developed.

CONTROL METHODS OF VOLTAGE SOURCE INVERTER

The reference signals generated by these APF controllers are processed by the pulse width modulation (PWM) controllers. These controllers use a number of control techniques like linear control method and hysteresis control methods to generate the gate on / off signals for the insulated gate bipolar transistor (IGBT) switches. The hysteresis current controller (HBCC) is widely used among all current control techniques because of the fast response current loop and its simplicity of implementation. To keep the current provided within the hysteresis band, the HBCC derives the switching signals of the inverter based on the comparison of the reference current [16].

In hysteresis current control, there are two upper bands and lower bands in order to change the slop of inverter output current based on their level voltages. Figure 2 shows a conventional single phase hysteresis band and the condition of switching devices are tabulated in Table 1. When the load current exceeds the upper band output voltage is changed to reduce the load current between the bands, while the comparator output is activated when the load current is smaller than the lower limit. The switching frequency varies in relation to the distance between the upper and lower bands. Also the other parameters such as inverter-network inductance and DC link voltage has a significant influence on the switching frequency. The highest switching frequency is determined as follows:

$f_{sw(max)}=V_{dc}/9HBL$ (1)

where, L and HB are load inductance and hysteresis band, respectively.

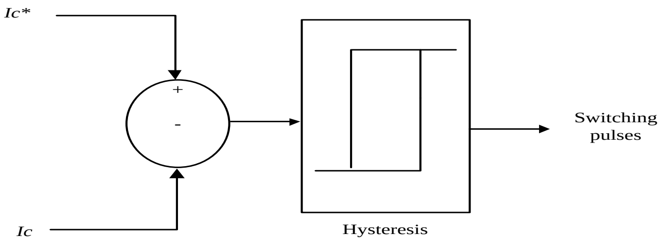


Figure 2: Conventional hysteresis band current controller.

Table 1. The conditions of switching devices.

Switch	Hysteresis Band (HB)
Lower switch on	$i_{ref} - i_{act} < -HB$
Upper switch on	$i_{ref} - i_{act} > HB$

DC BUS CONTROLLER

The DC link voltage controller is designed for balancing the power flow in the system. The dc voltage magnitude can be fixed or adjustable depending upon the power electronic switches that are used for switching. Therefore, a critical issue in this active filter is the DC-bus voltage control. During operation, the active filter may absorb an amount of active power into, or release it from, the DC capacitor. Excessive active power absorption will increase the DC-bus voltage, and may damage the active filter. The DC-link capacitor will be charged or discharged by the difference of the active load current and source current, forcing the PI controller to change its output correspondingly, until both active currents are equal.

The DC side capacitor serves two main purposes:

1. It maintains a DC voltage with small ripple in steady state, and
2. It serves as an energy storage element to supply the real power difference between load and source during the transient period.

The required filtering to DC bus voltage is dependent on the value of capacitor, which in turn is sized according to the voltage ripples. The sensed DC link voltage (V_{dc}) of the APF is compared with its reference counterpart (V^*_{dc}). The relationship between V_{dc} and the amplitude of the source phase voltage V_s is [17]

$V_{dc} = K.V_s$ (2)

$$\begin{cases} v_a = R_s i_a \\ v_b = R_s i_b \\ v_c = R_s i_c \end{cases} \qquad (3)$$

Where K is the amplification coefficient.

$$V_S = RI_S \qquad (4)$$

Substituting eqn. (4) into eqn. (2), we get:

$$V_{dc} = K.\ R\ I_S \qquad (5)$$

The filtering performances can be improved by a correct choice of the DC-bus voltage and capacitor values [18]. The design of DC side capacitor is based on the principle of instantaneous power flow. The selection of C_{dc} is governed by reducing the voltage ripple. As per the specification of peak-to-peak voltage ripple ($V_{dcr,\,p-p}$) is:

$$V_{dcr,p-p} = \pi I_{c,rated}/\sqrt{3}\,\omega C_{dc} \qquad (6)$$

The dc side capacitor C_{dc} can be found as:

$$C_{dc} = \pi I_{c,rated}/\sqrt{3}\,\omega V_{dcr,p-p} \qquad (7)$$

The DC voltage V_{dc} feeding the inverter of the SAPF system can be dimensioned according to the RMS value of the fundamental component contained in the voltage. Knowing that inverter output the maximum value of the output voltage is $+V_{dc}/2$, then the RMS value of the fundamental voltage is $+V_{dc}/(2\sqrt{2})$ [19, 20]. Thus, V_{dc} will be as:

$$V_{dc} = 2\sqrt{2}.V_{sRMS} \qquad (8)$$

PROPOSED METHOD

Theoretically, adaptive zero crossing detection (AZCD) will be able to deliver a regulated signal exactly as the reference without any distortion. DC-link voltage of the filter should be controlled in order to supply the power losses of filter on the source, providing that more effective filtering and reactive power compensation are obtained. So to obtain constant performance DC- link voltage should be constant. The error signal of DC link voltage and reference voltage is given to the PI controller. The proposed control (adaptive zero crossing detection) in this work acts as a controller which may be varied by changing the duty cycle of the semiconductor switches. The inverter turned on and off employing a digital output from the control system via a solid-state relay. In order to implement the control system, we can simply employ logic that turns the inverter on when the measured voltage (V_{dc}) is lower than desired (V_{ref}) and turns the inverter off when the voltage is higher than desired. In other words, the inverter is turned off when the measured rises above desired, and it turns on when the falls below desired. In mathematics, the sign function shown in figure 3 is an odd mathematical function that extracts the sign of a real number. The signal is controlled by the error with the desired levels getting reduced as the error signal becomes smaller. This causes the output signal to settle on its final value instead of continuing to ramp. This is why the recent work has been focused to replace the PI with circuits that can simulate the required value with much less power consumption.

$$\operatorname{sgn}(x) := \begin{cases} -1 & if\ x < 0, \\ 0 & if\ x = 0, \\ 1 & if\ x > 0, \end{cases} \qquad (9)$$

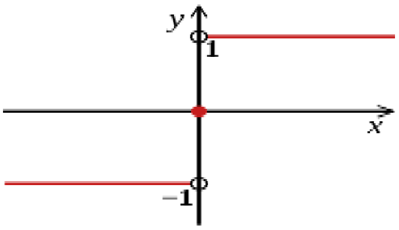


Figure 3: The sign function.

SIMULATION RESULTS

In the elaboration of the research, a harmonic analysis of source current distortion has been carried out. It has featured a nonlinear full-bridge diode rectifier with DC load as a harmonic currents source. The three phases SAPF under study are shown in figure 1. The time domain simulation is performed using MATLAB/Simulink simulation package. Basically the implementation of the control strategy will be done in three steps. In the first step, the required load current and source voltage signals are measured to know the exact information about the system studied. In the second step, by using synchronous reference frame theory (SRF), the reference compensating currents are obtained. In the third step, by using hysteresis-based current control technique the required gating signals for the solid-state devices are generated. The performance of the shunt active filter for mitigation of current harmonics in the source current was analyzed with the hysteresis based current control techniques and AZCD controller techniques for closed loop control of DC link capacitor voltage to get the reference current templates as shown in figure 4 and the specification of the test system is given in table 2.

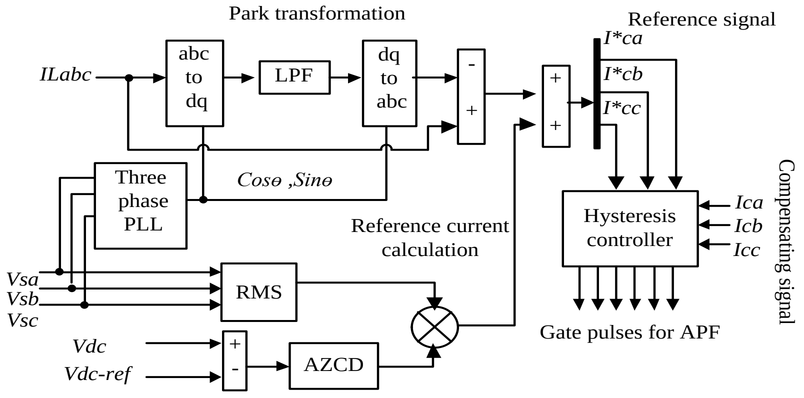
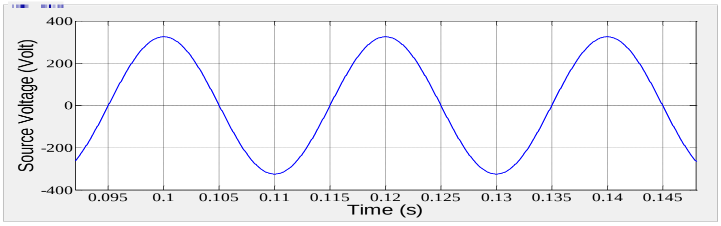


Figure 4: A three phase power system with the active power filter topology using SRF and AZCD.

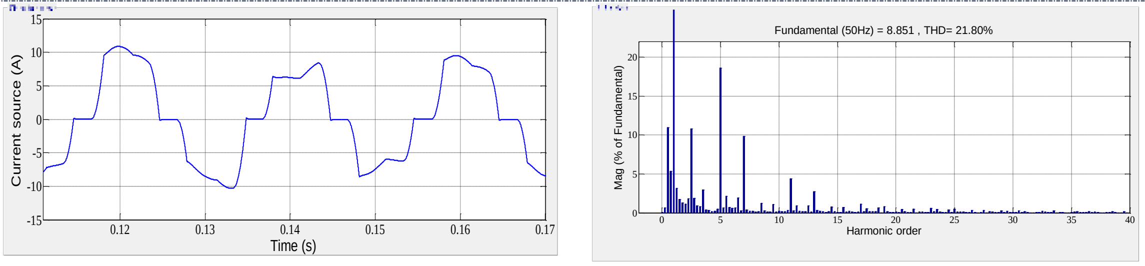
Table 2. Parameters of the system.

Quantity	Symbol	Value
Supply phase voltage(Peak)	V_S	311V
Supply frequency	f_S	50 Hz
Line inductor	L_L	0.01 H
Filter inductor	L_f	0.006 H
DC link capacitor	C_{dc}	2000 µF
DC link capacitor Voltage	V_{DC}	750V
Sample time	T_S	5 µs
Hysteresis Band Limit	*HBL*	0.5 A
DC Load Brush Motor driving a fuel pump Resistive load	DC machine R_L	R_a=0.35Ω, L_a=0.12 H 5KW

Figure 5 shows: (a) the voltage source waveform, (b) the current source waveform and (c) the total harmonic distortion (THD) spectrum of the current source waveform in the test system without filter, THD is 21.80%. The total harmonic distortion should be equal or less than 5% depend on IEEE 519 standard.



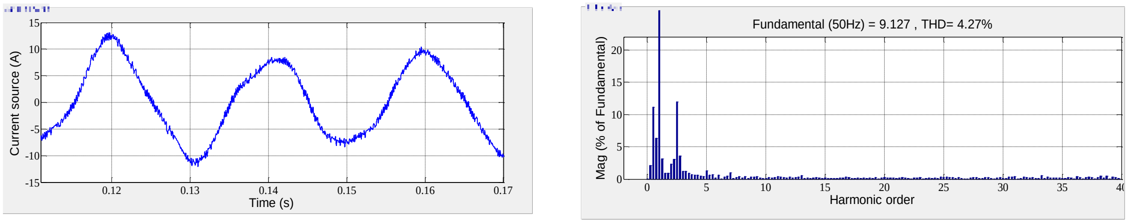
(a): Supply voltage waveform.



(b): Source current, I_{sa} without APF. ***(c): I_{sa} harmonic spectrum without APF.***

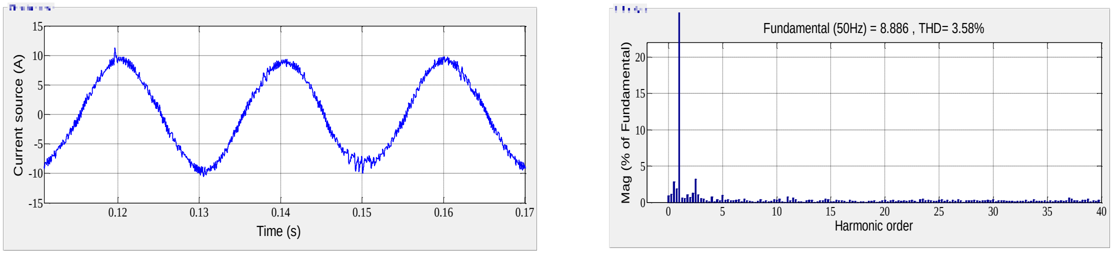
Figure 5: The simulation results of the source current without APF.

PI control scheme involves the regulation of DC link voltage to set the current amplitude reference for harmonic and reactive power compensation. After connection APF, the source current THD is 4.27 % with conventional method PI as shown in figure 6. The simulation results with APF using the proposed technique are shown in Figure 7.



(a): Source current, I_{sa} with APF& PI ***(b): I_{sa} harmonic spectrum with APF & PI.***

Figure 6: The simulation results with APF using PI.



(a): Source current, I_{sa} with APF& AZCD. ***(b): Harmonic spectrum of source current using AZCD***

Figure 7: The simulation results with APF using AZCD method.

From analysis, it has been found that AZCD technique proves to be effective in reducing the THD of the source current and compensating the reactive power. DC voltage of SAPF shown in the figure 8 proves the efficiency of the proposed controller in the control of the capacitor voltage compare with PI controller. It is clear that the capacitor voltage follows its defined reference ($V_{dc\text{-}ref}$=750 V).

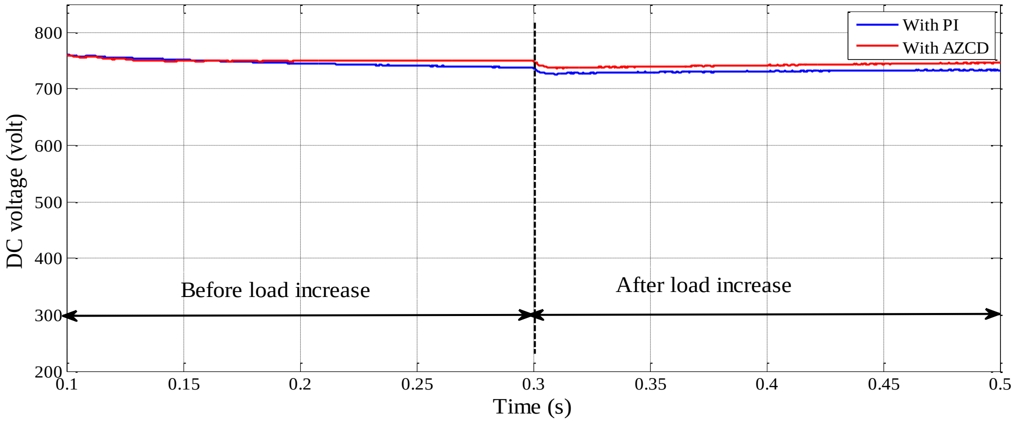


Figure 8: DC link voltage regulation.

The fundamental current harmonic spectrums; in state of without the APF; IEEE 519 Limit & APF with AZCD are shown in figure 9.

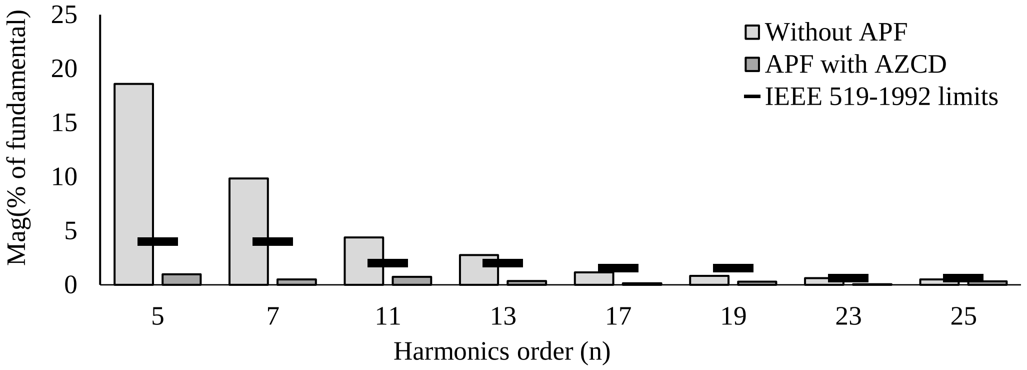


Figure 9: The fundamental current harmonic spectrums; in state of without the APF; IEEE 519 Limit & APF with AZCD.

In order to demonstrate that the proposed control system has strong robustness in the transient state, the load resistance at the instant of 0.3 second is increased by 5kW. The active and the reactive power reference has been varied in two steps, in steady-state case and transient case of the current as shown in figure 10.

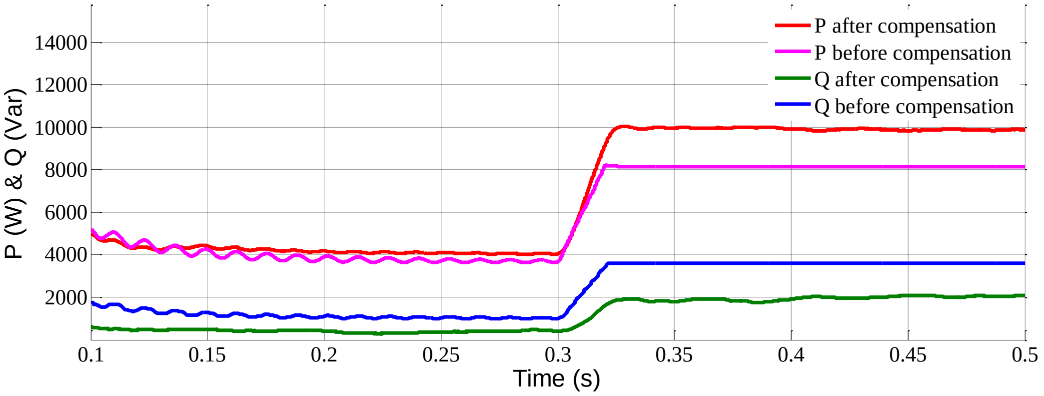


Figure 10: Real and Reactive power before filtering and after filtering using SRF with AZCD.

Table 3 shows the results of applying the two controller methods to regulate the DC-Link voltage in steady-state case and transient case by using SRF method. Results show that the traditional and the proposed controller are capable of recovering from the sudden power increase and the THD values of these currents after compensation were all less than 5% but the AZCD is the best as it achieves satisfactory performances compared with the PI controller.

Table 3. Result of the system using SRF.

		At steady-stat (S.S) case		After load increase at 0.3 sec		*P*,*Q* at source side		*PF*
		I_{sa} (A)	THD %	I_{sa} (A)	THD %	P_s (kW)	Q_s (kVar)	
Before compensation		8.85	21.80	18.26	19.05	8.158	3.606	0.866
DC voltage control technique after compensation	PI	9.12	4.27	20.57	2.59	9.833	1.959	0.995
	AZCD	8.88	3.58	20.57	2.01	9.883	2.091	0.996

CONCLUSIONS

Active power filters are an optimal solution for harmonic mitigation and reactive power compensation. DC-voltage of the filter is regulated in different control methods. A comparison between the proposed and conventional PI controller for three-phase, six-switch VSI-based APF using SRF theory is realized in this work. The DC controller was developed to improve the step transient response of DC link voltage of APF at sudden change of the load by using AZCD for the DC-link voltage to set the amplitude of the active current of the APF inverter to regulate the DC-link voltage. Results show that AZCD and traditional controller are capable of recovering from the sudden power increase and the THD values of these currents after compensation were both less than 5% the harmonic limit imposed by the IEEE-519 standard. The proposed controller is the best controller as it achieves satisfactory performances and it is found to satisfactorily reduce the THD and thus improves the source current compared with classical PI.

REFERENCES

[1] R. Biswas, "Active power filter based on interleaved buck converter," National Institute of Technology Rourkela, 2013.

[2] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, "Electrical power systems quality," New York, NY: McGraw-Hill,| c1996, vol. 1, 1996.

[3] W. M. El-Mamlouk, H. E. Mostafa, and M. A. El-Sharkawy, "Active power filter controller for harmonic suppression in industrial distribution system," Ain Shams Engineering Journal, vol. 2, pp. 161-172, 9// 2011.

[4] S. H. Zak, Systems and control: Oxford University Press New York, 2003.

[5] S. Bangia, P. Sharma, and M. Garg, "Design of optimal pi controller using particle swarm optimization for power quality," in Proceeding of the National Conference "Science in Media 2012" Organized by YMCA University of Science and Technology, December 3rd -4th 2012 Faridabad, Haryana (India), 2012, pp. 112-117.

[6] J. Jayachandran and R. Murali Sachithanandam, "ANN based controller for three phase four leg shunt active filter for power quality improvement," Ain Shams Engineering Journal, vol. In press, 2015.

[7] H. Liu, G. Liu, and Y. Shen, "A novel harmonics detection method based on wavelet algorithm for active power filter," in Intelligent Control and Automation, 2006. WCICA 2006. The Sixth World Congress on, 2006, pp. 7617-7621.

[8] P. Balasubramaniam and G. Gurusamy, "Evaluation and Implementation of a Shunt Active Power Filter under balanced Source Voltages," Journal of Engineering Science and Technology Review, vol. 5, pp. 35-41, 2012.

[9] E. Ozdemir, M. Ucar, M. Kesler, and M. Kale, "The design and implementation of a shunt active power filter based on source current measurement," in Electric Machines & Drives Conference, 2007. IEMDC'07. IEEE International, 2007, pp. 608-613.

[10] M. Kale and E. Ozdemir, "An adaptive hysteresis band current controller for shunt active power filter," Electric Power Systems Research, vol. 73, pp. 113-119, 2005.

[11] W. Zhao and G. Chen, "Approaches to shunt Active Power Filter for application with capacitive nonlinear load," in Industrial Electronics, 2009. ISIE 2009. IEEE International Symposium on, 2009, pp. 1835-1840.

[12] K. Chaturvedi, A. Mahor, and A. D. Dwivedi, "Active Power Filter Techniques for Harmonics Suppression in Non Linear Loads," International Journal of Scientific Engineering and Technology, vol. 1, pp. 123-127, 2012.
[13] S. Bhattacharya, D. Divan, and B. Banerjee, "Synchronous frame harmonic isolator using active series filter," in European conference on power electronics and applications, 1992, pp. 030-030.
[14] S. Bhattacharya and D. Divan, "Design and implementation of a hybrid series active filter system," in Power Electronics Specialists Conference, 1995. PESC'95 Record., 26th Annual IEEE, 1995, pp. 189-195.
[15] N. Zaveri and A. Chudasama, "Evaluation of control strategies for parallel active filter under different supply voltage conditions," in Innovative Smart Grid Technologies-India (ISGT India), 2011 IEEE PES, 2011, pp. 316-321.
[16] L. Xia, D. Taihang, and T. Shengxue, "A fuzzy logic variable hysteresis band current control technique for three phase shunt active power filter," in Control, Automation and Systems Engineering (CASE), 2011 International Conference on, 2011, pp. 1-4.
[17] F. Krim, "Parameters estimation of Shunt Active Filter for Power quality improvement," in Power Engineering and Optimization Conference (PEOCO), 2011 5th International, 2011, pp. 306-311.
[18] A. Bitoleanu, M. Popescu, M. Dobriceanu, and F. Nastasoiu, "DC-bus voltage optimum control of three-phase shunt active filter system," in Optimization of Electrical and Electronic Equipment (OPTIM), 2010 12th International Conference on, 2010, pp. 538-543.
[19] L. Moran, J. W. Dixon, and R. R. Wallace, "A three-phase active power filter operating with fixed switching frequency for reactive power and current harmonic compensation," Industrial Electronics, IEEE Transactions on, vol. 42, pp. 402-408, 1995.
[20] N. Elhaj, T. Jarou, M. B. Sedra, H. Djeghloud, and Y. Terriche, "Contribution of a shunt active power filter control using double fuzzy PI controller," in Power Electronics and Motion Control Conference and Exposition (PEMC), 2014 16th International, 2014, pp. 1177-1182.