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A Technical Survey on Control Strategies of Active Filter for Harmonic Suppression

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Abstract

In modern era, the tradition of non-linear loads in Electrical power system has sparked the research in power quality (PQ) concern like voltage flicker, voltage sag and swell, harmonics, etc., Among all the other concerns, one of the the majority significant of PQ problem is Harmonics .Active Power Filter (APF) is one of most challenging filter for the mitigation of harmonics. The heart of the Active power Filter is the controller part. In this study, a wide-ranging review of various controllers have been projected ,Which mitigate harmonics, reactive power and unbalanced load currents originating from load side, and also the advantages and disadvantages of presented techniques are presented. The study also helps the researchers to select the optimum control strategies and power circuit configuration for APF applications.

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1. Introduction

To reduce the harmonics conventionally passive L–C filters were used and also capacitors were employed to improve the power factor of the ac loads .But the passive filters have several drawbacks like fixed compensation, large size and resonance problem. To mitigate the harmonics problem [6][7], many research work development are developed on the active power (APF) filters or active power line conditioners [1]-[5] .Active filters appear to be a viable solution for power quality conditioning [7]-[9].

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With the emergence of fast computing devices, control strategies [8] for active filters are continually changing aiming at near perfect compensation. This paper presents a review of the state-of-the-art control techniques in active filters and reactive power

2. Control techniques for active power filters

Advancement in Microelectronics has motivated new directions for APF design starting from the use of analog and digital components to microprocessors, microcontrollers, digital signal processors (DSP's)[27] and FPGA[34] implementation. From fig 1 it shows that control part plays important role in filtering. Further, these developments have made it possible to use different control algorithm, the controller of active power filter mainly divided into two parts i.e. reference current generation and PWM current controller. The PWM current controller is principally used for providing gating pulse to the active power filter. In reference current generation scheme, reference current is generated by using the distorted wave form. Many control schemes are there for reference current generation, such as p-q theory[9][10], Dead Beat controller[19], Adaptive control[18][23], Neuro[22-26], Fuzzy[27][28], wavelet control[29-33], sliding mode control [29]-[33], delta-sigma modulation[14][15] vector control[13], SFX control[18], repetitive control[17], etc. for improving the steady state and dynamic performance of APFs. By implementing this performance, response as well as the cost is efficient compare to the analog one.

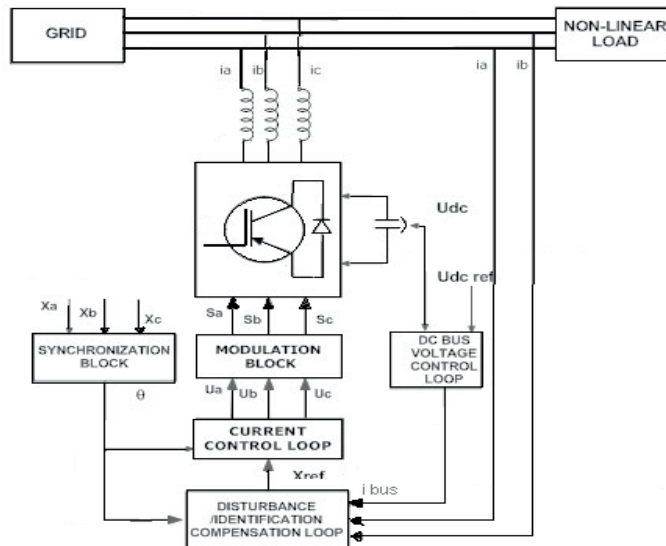


Fig 1: General Block Diagram For shunt a Active filter

2.1. Fixed Frequency Control

The fixed frequency control [6] has been shown in figure 2 in which the error between the reference and actual current is fed through a PI controller which integrates the error between the feedback and reference current to generate a variable voltage value then, this value is fed into a triangle pulse-width modulator to produce gate signal. The output V control of the amplifier is compared with a fixed frequency (switching frequency f_s) triangular waveform v_{tri} . A positive error ($i_A^* - i_A$) and hence a positive

Control result in a larger inverter output voltage, thus bringing i_A (phase A current) to its reference value(i_A^*). Similar action takes place in other two phases.

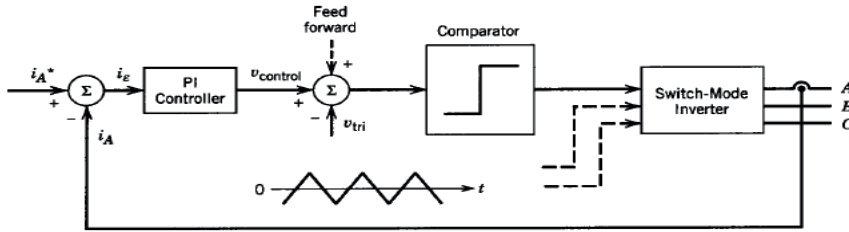


Fig:2 Fixed Frequency Control

2.2. SFX Algorithm Based Adaptive Control

This method proposes a new current control method for active power filters (AF's). It requires only detecting the source current. It requires neither detecting AF output current nor extracting a harmonic component from the source current. Thus, the current control system can be greatly simplified compared to conventional load current detection AF's. It introduces an adaptive digital filter (ADF) with a synchronized filtered-x (SFX) algorithm [18]. An SFX-ADF based current controller exhibits a high gain only at fundamental and harmonic frequencies that the load current contains. A proportional regulator is also used to improve the dynamic performance of the current control system. The proposed method is suitable for filtering harmonic currents from one or more specified harmonic-producing loads. This method requires the following conditions.

- The harmonic-producing load has current-source
- Both harmonics and reactive power compensation is done by AF

The Source currents is given by the difference of load and controller current $I_s = I_L - I_C$. Consider a finite impulse digital filter with a desired response and error signal shown in Fig. 3. The input x and output y of ADF has the following relation

$$y(n) = \sum_{k=0}^{N-1} w_k(n)x(n - k) \tag{1}$$

$$\varepsilon(n) = d(n) - y(n) \tag{2}$$

The ADF operates so as to minimize the mean-square error by renewing the filter weights at every sampling. If the LMS (least-mean-square) algorithm is used, the filter weights are renewed as follows:

$$w_k(n + 1) = w_k(n) + 2\mu\varepsilon(n)x(n - k) \tag{3}$$

Where $k=0, 1, \dots, N-1$

A serious problem of this ADF is that the adaptive algorithm involves a lot of calculations that should be executed within a short sampling time period. Therefore, the order of ADF 'N' must be limited and as a result the upper frequency of the output is limited. To solve this problem this paper introduces a synchronized filtered-x (SFX) algorithm. The SFX algorithm [18] is suitable for controlling periodic signals, and has been used for controlling noises and Vibrations. Its advantage is that the amount of calculation of the adaptive algorithm can be greatly reduced; the proportional regulator with gain K_p is also used to improve the dynamic performance of the current control system. The SFX-ADF based controller automatically adjusts its transfer function to minimize the mean-square error ε^2

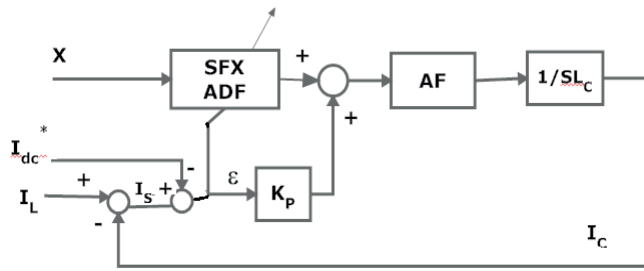


Fig:3 Current Control Scheme For SFX-ADP

2.3. Delta Modulation (DM)

The Delta Modulation method [14][15] is a variation of the traditional hysteresis current regulator . This method consists in applying a constant voltage in all the switching period. The aim of the control is to obtain the switching signals from the comparison between the a fixed tolerance band and current error (normally this band is close to 0).If the mismatch between the actual and reference current is positive, the inverter output voltage must be positive and if there is mismatch then, the inverter voltage output must be negative. During a regular interval T_{sw} synchronized with the switching frequency, the voltage is held constant. If the Delta Modulation [15] is used, the current generated at the $(k+1)^{th}$ sampling time instant.

2.4. Dead-Beat Current Control

In the conventional digital dead-beat control schemes, the regulator calculates the phase voltage to make the phase current reach its reference by the end of the following modulation period. In this Control, a modified Method Based on Dead-Beat controller is used (MBDB)[19][20] . The purpose of this method is to compute directly the time period when a switching device is turned on in order to make the phase current reaches its reference by the end of the following modulation period. Figure 4 shows the basic principle of this control strategy for a single-phase equivalent.

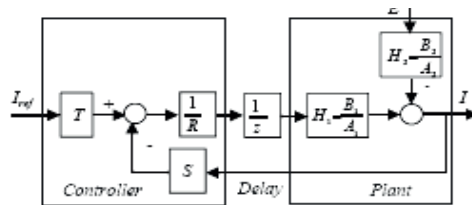


Fig 4: Dead Beat Controller

2.5. Soft computing Techniques:

Soft computing Technique is a technology to extract information from the process signal by using expert knowledge [21][36]. It either seeks to replace a human to perform a control task or it borrows ideas from how biological systems solve problems and applies it to control processes. The main areas in soft computing notably are fuzzy logic [27][28], neural network[22] -[26],Wavelet control[29]-[33], genetic algorithm (GA), rough sets, etc.[36]

2.5.1. Neuro Controller

The different described neural networks have been trained and simulated in many different ways with the goal of getting the parameter values that produce the optimal performance for each of the topologies [23]. Two different performance indices were chosen to evaluate the effectiveness of each studied network by both of the operation strategies the reached accuracy level (in terms of the error rate) and the required training time [26]. With respect to the accuracy level, at the measuring of the harmonic coefficients an error rate of 1% were estimated as minimum desired accuracy. With respect to the training time, network topologies and parameters were desired, that could be trained in so short times as possible. For this purpose it were compared the needed times to achieve similar accuracy levels [22]-[25]. The software tool employed has been the Neural Networks Toolbox of MATLAB. All types of available training algorithms were used and tested, and the most efficient was found to be the Levenberg-Marquardt modified Back propagation

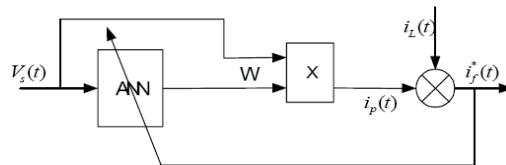


Fig: 5: Structure of Nero Controller

2.5.2. Fuzzy Controller

Fuzzy control [27] involves four stages: fuzzification, knowledge base, inference mechanisms, and defuzzification. The knowledge bases are designed to provide a good dynamic response under uncertainty in process parameters and external disturbances. In recent years, fuzzy logic controllers [28] have generated a great deal of interest in certain applications. The advantages of fuzzy logic controllers are: robustness, no need to accurate mathematical model, can work with imprecise inputs, and can handle non-linearity. The compensation process is based on sensing line currents only, an approach different from Conventional methods, which require harmonics or reactive volt-ampere requirement of the load

Fuzzy logic serves to represent uncertain and imprecise knowledge of the system, whereas fuzzy control enables taking a decision even if we can't estimate inputs/outputs only from uncertain predicates. The synoptic scheme of Fig. 6 shows a fuzzy controller [27], which possesses two inputs and one output. The inputs are namely the error (e), which is the difference between the reference current (harmonic current) and the active filter current (injected current) ($e = i_{ref} - i_f$) and its derivative (d_e) while the output is the command (c_{de}). [56]

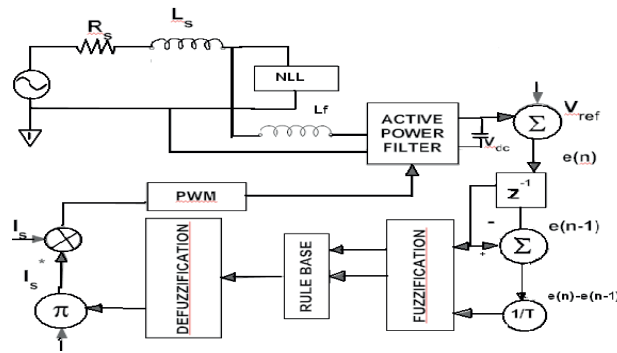


Fig: 6: Structure of Fuzzy Controller for APF

2.5.3. Wavelet Controller

A Wavelet Transform (WT) based Technique to extract fundamental frequency component from a Non sinusoidal and unbalanced load current in a three phase System. The fundamental frequency component is extracted using Multiresolution analysis (MRA) [29]. The remaining harmonics can be used by the active filter for compensation .The constructed controller based on multi resolution analysis has the advantage of better frequency bandwidth selection. The tuning parameters of the controllers are the gains to be applied to the time-frequency signals at different resolutions. This has the advantage of aiding the process of a proper choice of coefficients of tuning parameters. The extraction by FFT leads to inaccurate results if the signal is contaminated by noise. The main problem of the Fourier transform is the number of points in the observation window, which should be a multiple of the numbers of samples per period. When the fundamental's frequency varies around the 50Hz value, this corresponds to a Modification in the number of samples per period [32]. Thus, the number of points in the observation window is not a multiple of the number of sample per period. As a result, the accuracy of the extraction is reduced.

The Wavelet Transform based technique can eliminate the above mentioned drawbacks up to certain extent. Wavelet analysis is a new development in the area of applied mathematics [31]. Fourier analysis is ideal for studying stationary data (data whose statistical properties are invariant over time) but is not well suited for studying data with transient events that cannot - be statistically predicted from the data's past. In many filtering applications we need filters with symmetrical coefficients to achieve linear phase. None of the orthogonal wavelet systems except Haar are having symmetrical coefficients. But Haar is too inadequate for many practical applications. Biorthogonal wavelet system can be designed to have this property.

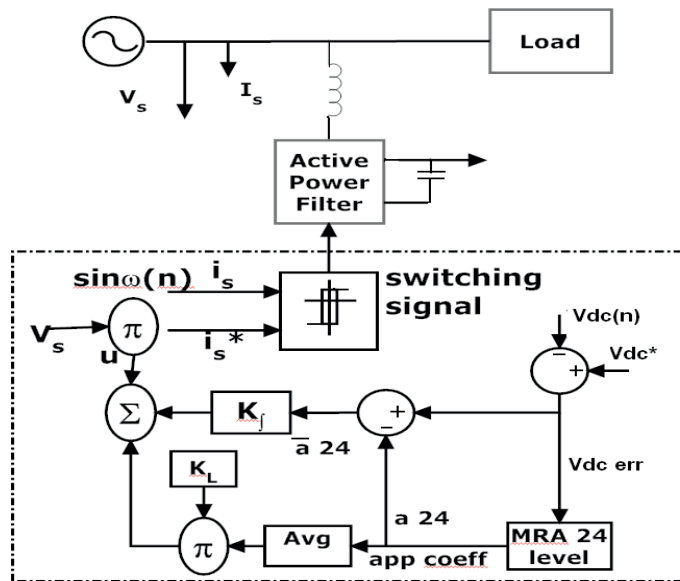


Fig: 7: Structure of wavelet Controller for APF

3. Conclusion

Active power filters are the emerging devices, which can perform the job of harmonic elimination properly. Most of the proposed control strategies for power quality improvements have been reviewed with regard to performance and implementation. This work reveals that there has been a significant increase in interest of active power filters and its control methods. This could be attributed to the availability of suitable power-switching devices at affordable price as well as new generation of fast computing devices (microcontroller and DSP and FPGA) at low cost. It is hoped that this survey on control techniques for active power filters will be a useful reference to the users and manufacturers.

References

- [1] Bhim Singh, Kamal Al-Haddad, , and Ambrish Chandra, "A Review of Active Filters for Power Quality Improvement", *IEEE Transactions On Industrial Electronics*, VOL. 46, NO. 5, October 1999
- [2] Zainal Salam, Tan And Awang "Harmonics Mitigation Using Active Power Filter: A Technological Review " *Faculty of Electrical Engineering Universiti Teknologi Malaysia ELEKTRIKA* Vol. 8, No. 2, 2006, pg 17-26
- [3] Quin, C., Mohan, N., "Active Filtering of Harmonic Currents in Three-phase Four-Wire Systems with Three-Phase and Single-Phase Non-Linear Loads", *APEC*, 1992, p. 829-836.
- [4] F.-Z. Peng, G. W. Ott, and D. J. Adams, "Harmonic and reactive power compensation based on the generalized instantaneous reactive power theory for three-phase four-wire systems," *IEEE Trans. Power Electron.*, vol. 13, no. 6, Nov. 1998, p. 1174–1181.
- [5] Adrian GLIGOR "Design and Simulation of a Shunt Active Filter in Application for Control of Harmonic Levels" *Acta Universitatis Sapientiae Electrical and Mechanical Engineering*, 1 (2009) 53-63
- [6] Mauricio Aredes and Luis F. C. Monteiro "A Control Strategy for Shunt Active Filter" 0-7803-7671~/02/5178.2W0 02 *IEEE*
- [7] Afonso, Couto, and Martins, "Active filters with control based on the p-q theory," *IEEE Ind. Electron. Soc. Newslett.*, Sep. 2000, pp. 5–11
- [8] Moleykutty and Kartik , "Three-Phase Shunt Active Power Filter" *American Journal of Applied Sciences* © 2008 Science Publications
- [9] E.A. Alradadi, A. Draou (Senior MIEEE) , "A New Modified PQ Theory Used For Reactive Power And Current Harmonic Compensation", *Speedam 2006 International Symposium On Power Electronics ,Electrical Drives, Automation And Motion*.
- [10] Akagi, S. Ogasawara, and H. Kim, "The theory of instantaneous power in three-phase four-wire systems: a comprehensive approach," in *Proc. IEEE IAS Annu. Meeting*, 1999, pp. 431–439.
- [11] Abdelmajid Chaoui, "On the Design of Shunt Active Filter for improving Power Quality", *2008 IEEE*
- [12] Hirofumi Akagi, "Active Harmonic Filters," *Proceedings of the IEEE*, Vol. 93, No.12, Dec. 2005, pp.2128- 2141.
- [13] Alfredo Nava-Segura, "Vector Active Filter without Current Hysteresis Controllers" *2000 IEEE*
- [14] R. Kazemzadeh "Sigma-Delta Modulation Applied to a 3-Phase Shunt Active Power Filter Using Compensation with Instantaneous Power Theory", ©2010 *IEEE*
- [15] E. Wiebe-Quintana , "Delta-Sigma Integral Sliding-Mode Control Strategy of a Three-Phase Active Power Filter using d-q Frame Theory", *Proceedings of the Electronics, Robotics and Automotive Mechanics Conference (CERMA'06)IEEE computer society 2006*
- [16] Majid Nayeripour and Taher Niknam, "Nonlinear Sliding Mode Control Design for Shunt Active Power Filter with the Minimization of Load Current", *World Applied Sciences Journal ,IDOSI Publications, 2008*
- [17] Xie, Zhengxian, Liang, "Energy Shaping Repetitive Control (ESRC) for Three-phase three-wire Shunt Active Power Filter " *2009 IEEE*
- [18] Shoji Fukuda, Takeshi, "SFX Algorithm Based Adaptive Control Of Active Filters Without Detecting Current Harmonics " *IEE 2004*
- [19] F. Kamran, and T. G. Habetler, "Combined deadbeat control of a series parallel converter combination used as a universal power filter," in *Proceedings of the 1995 IEEE/PELS Power Electronics Specialist Conference*, 1995, pp. 196-201.
- [20] Nishida, K., Y. Konishi, And M. Nakaoka, "Current Control Implementation With Deadbeat Algorithm For Three-Phase Current-Source Active Power Filter." *Electric Power Applications, IEE Proceedings* -,2002. 149(4): P. 275-282.
- [21] Parmod Kumar, and Alka Mahajan , "Soft Computing Techniques for the Control of an Active Power Filter" *IEEE Transactions On Power Delivery*, Vol. 24, No. 1, January 2009

- [22] Vazquez, J.R. and P. Salmeron, "Active power filter control using neural network technologies. Electric Power Applications", *IEE Proceedings* -,2003. 150(2): p. 139-145.
- [23] Tey, L.H., , and Y.C. Chu, "Adaptive neural network control of active filters". *Electric Power Systems Research*, 2005. 74(1): p 37-56.
- [24] Rachid.Dehini, Abdesselam.Bassou, "Artificial Neural Networks Application to Improve Shunt Active Power Filter" *International Journal of Computer and Information Engineering* 3:4 2009
- [25] J.L. Flores Garrido, "Harmonic detection by using different artificial neural network topologies" *Department of Electrical Engineering E. P. S., Huelva University*
- [26] Rachid Dehini1, "The harmonics detection method based on neural network applied to harmonics compensation", *International Journal of Engineering, Science and Technology* Vol. 2, No. 5, 2010, pp. 258-267.
- [27] Yu Dongmei,"A Novel DSP Based Current Controller with Fuzzy Variable-Band hysteresis for Active Power Filters", 2005 *IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific*
- [28] S.K. Jain, P. Agrawal and H.O. Gupta , "Fuzzy logic controlled shunt active power filter for power quality improvement" *IEE proc-Electr.Power Appl*,Vol.149,No.5,September 2002
- [29] K. G. Firouzjah, A. Sheikholeslami, M. R. Karami-Mollaei , "A New Harmonic Detection Method for Shunt Active Filter Based on Wavelet Transform," *Journal of Applied Sciences Research*, 4(11): 1561-1568, 2008 © 2008, *insinet Publication*
- [30] Malabika Basu, "A wavelet controller for shunt active power filter", *Dublin Institute of Technology, 3rd IET International Conference on Power Electronics, Machines and Drives, Dublin, Ireland, 2006*, pp.76-79
- [31] karunesh K Gupta, Rajneesh Kumar , "Active Power Filter Control Algorithm using Wavelets" ©2006 *IEEE*
- [32] M. Marinelli, L. Salvatore, " wavelet-based algorithms Applied to harmonic detection for active shunt filters," *11thInternational Conference on Harmonics and Quality of Power* 2004,Sept. 12-15, 2004, pp.721 -727.
- [33] Hui Liu, Guohai Liu and Yue Shen, "A Novel Harmonics Detection Method Based on Wavelet Algorithm for Active Power Filter", *Proceedings of the 6th World Congress on Intelligent Control And Automation*, June 21 - 23, 2006, Dalian, China
- [34] Saswat Kumar Ram, "FPGA Implementation of Digital Controller for Active Power Line Conditioner using SRF Theory" ©2011 *IEEE*
- [35] Angelo Baggini , "A Handbook of Power Quality" *University of Bergamo, Italy*
- [36] Devendra K. Chaturvedi ,A book on "Soft Computing Techniques and its Applications in Electrical Engineering", *Springer*