Online ISSN 1848-3380, Print ISSN 0005-1144
ATKAFF 56(1), 42–54(2015)

Papan Dey, Saad Mekhilef

Current Controllers of Active Power Filter for Power Quality Improvement: A Technical Analysis

DOI 10.7305/automatika.2015.04.572
UDK 621.372.852.018.7.072.8-533.7; 519.254

Original scientific paper

Non-linear load deteriorates the quality of current waveforms at the point of common coupling of various consumers. Active power filter (APFs) is used to mitigate the most concern harmonic pollution in an electrical network. The controller part is the nucleus of an active power filter configuration. Active power filter performance is affected significantly by the selection of current control techniques. The active filter and its current control must have the capability to track sudden slope variations in the current reference to compensate the distorted current drawn by the voltage source inverter. Therefore, the choice and implementation of the current regulator is more important for the achievement of a satisfactory performance level. In this survey, technical reviews of various types of controllers covering a wide range have been presented. This work also reveals the advantages and disadvantages of the practiced control strategies. The effectiveness of the study will help the researchers to choose the proper control methods for various applications of active power filter.

Key words: Active power filters, Control algorithms, Current controllers, Comparison, Harmonic currents Power quality, Total harmonic distortion, Root mean square (RMS) error

Regulatori struje aktivnih filtara snage za poboljšanje kvalitete snage: Tehnička analiza. Nelinearni tereti pogoršavaju kvalitetu strujnih valova u točki u kojoj se spaja više potrošača. Aktivni filtar snage se koristi za ublažavanje najvažnijeg harmoničkog onečišćenja strujne mreže. Jezgra aktivnog filtra snage je regulator. Na performanse aktivnog filtra snage značajno utječe odabir upravljačke tehnike. Aktivni filtar i njegova tehnika upravljanja strujom moraju imati mogućnost pratiti nagle skokove u referentnoj vrijednosti struje kako bi mogli kompenzirati izobličenja struje koju vuče inverter naponskog izvora. Zato su izbor i implementacija regulatora struje iznimno važni za postizanje zadovoljavajuće razine performansi. U ovom pregledu su predstavljene tehničke recenzije koje pokrivaju širok raspon regulatora. Ovaj rad također otkriva prednosti i mane korištenih strategija upravljanja. Efektivnost ovog pregleda pomoći će istraživačima da izaberu ispravnu metodu upravljanja za različite aplikacije aktivnog filtra snage.

Ključne riječi: Aktivni filtar snage, Upravljački algoritam, Regulator struje, Usporedba, Kvaliteta snage harmoničke struje, Ukupno harmoničko izobličenje, Korijen srednje kvadratne pogreške

1 INTRODUCTION

APFs are widely used to control harmonic distortion in power systems. They use power electronics converters in order to inject harmonic components to the electrical network that cancel out the harmonics in the source currents caused by non-linear loads. Passive L–C filters were used conventionally to reduce the harmonics and for power factor improvement of the ac loads, capacitors were also employed. But several drawbacks like fixed compensation, large size and resonance problem are occurred in the passive filters. Now many research works are done on the active power (APF) filters for the mitigation of harmonics problem. But the control strategy of active power filter plays a vital role in the overall performance. Rapid detection of disturbance signal with high accuracy, fast processing of the reference signal and high dynamic response of the controller are the prime requirements for desired compensation. This paper presents a review on the state-of the- art of several control techniques of active filters for harmonic current mitigation and reactive power compensation in terms of their advantages, disadvantages and some limitations [1-8]. Though, to follow the generated reference current quickly without any error is a basic function of those controllers it is challenging because of the high rates of change and wide bandwidth of that reference. With following the reference better, it would compromise the attenuation of the switching frequency components. Also the processing delay of those current controllers can create significant miscalculation of distortion terms. These crucial factors are also considered here as the performance criteria. After a short description of the principles of the fifteen control techniques the results of the comparison are shown and discussed based on their performance and implementation process. This paper is followed as three parts. Section 2 describes the current control techniques of active power filter; section 3 provides the analysis and comparison details of those controllers. Finally concluding remarks with further research directions are presented in Section 4.

2 COMPENSATION STRATEGY

The reference signal, processed by the controller is the key component that ensures the correct operation of APF. The reference signal estimation is initiated through the detection of essential voltage/current signals to gather accurate system variables information. The voltage variables to be sensed are the AC source voltage, DC-bus voltage of the APF and the voltage across interfacing transformer [9]. Typical current variables are load current, AC source current, compensation current and DC-link current of the APF. Based on these system variables feedbacks, reference signals estimation in terms of voltage/current levels are estimated in frequency-domain or time-domain. We measure load harmonic current to be compensated and using this as a reference command. Then, with the achieved information, the controller is imposed to compensate the existing distortion [10-14]. Finally, the appropriate gating signals for the solid-state devices of the APF are generated using sinusoidal PWM, hysteresis-band current control PWM, space-vector PWM or more recently artificial intelligence network technique. It can be easily seen that if there are some errors when estimating proper switching signals, the overall performance of the active filter could be seriously degraded. This control is realized using discrete analog and digital devices or advanced programmable devices such as single-chip microcomputers, DSPs or FPGA implementation [15-19]. From Fig. 1 it shows that control part plays an important role in filtering process.

2.1 Hysteresis-band Current Control

In this method, the actual current continually tracks the command current within a hysteresis-band. Figure 2 shows HCC for a single phase VSI. Assume the VSI terminal voltage u connects to a sinusoidal voltage source e through an equivalent inductance L and resistance R. To control the APF output current I_f, a certain reference current, I_r, should be tracked. Pre-set upper and lower tolerance limits are compared to the extracted error signal. As long as the error is within the tolerance band, no switching action is taken. Switching occurs whenever the error exceeds the tolerance band [20].The hysteresis current control is the fastest method with minimum hardware and software. With the simple, extreme robustness, good stability, fast dynamic and automatic current limited characteristic hysteresis controller keeps the primary status in current control technologies. Its drawback is uneven switching frequency resulting in widely spread switching harmonics, which are difficult to filter out and possibly stimulate the resonance between the active filter and mains [21-23]. The irregular switching also affects the converter efficiency and reliability, involving overrating of the switches [24].

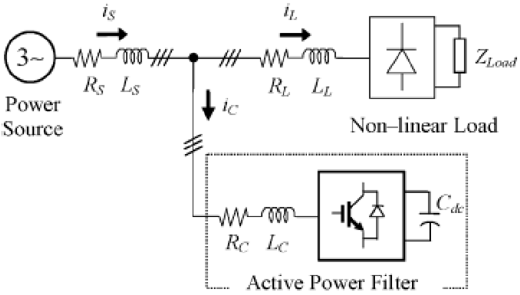

Fig. 1. Block Diagram of an Active power filter

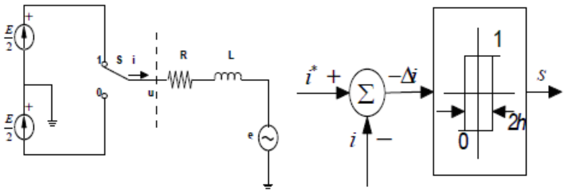

Fig. 2. Block diagram of hysteresis controller

2.2 Sliding Mode Control

In sliding mode control algorithm the compensating current supplied by the APF is controlled in such a way as to tract along a 'reference' prescribed by unity power factor condition at the PCC. The deviation of the actual trajectory from the reference trajectory is detected by the controller and correspondingly changes the switching strategy to restore the tracking [25]. It is a kind of adaptive control which gives robust performance with parameter variation. Furthermore, its implementation is easy [26]. The SMC with variable structure is determined as follow:
$x = f(x, u, t),\ x \in R_n,\ u \in R_m,\ \in R$
where x is a non-linear switched system;
x is system variable, $x \in R_n$;
u is control variable, $u \in R_m$;
t is the moving time, $t \in R$;
m is equal to dimensions of control variable.

For sliding mode control 3 basic design steps are proposed such as:

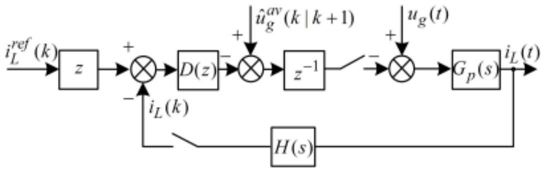

Fig. 3. Dead Beat Controller

1) Proposal of a sliding surface,
2) Testing for the sliding mode surface existence and
3) Stability analysis inside the surface.

The MATLAB simulation proved its main advantages, including fast dynamic response and strong robustness [27]. But like hysteresis current control, it also suffers from uneven switching frequency [28].

2.3 Negative Sequence Current Component Control

In this technique, the negative sequence components of the load currents are measured in magnitude and phase, and the PWM-controlled active power filter is controlled to inject currents opposite to these quantities, thereby achieving the load balancing function [29].This technique mainly balances the unbalanced loads. For power factor correction and harmonic compensation, it requires separate mode of operation [30-31].

2.4 Deadbeat Control

For Deadbeat control structure two state variables (e.g., load voltage and capacitor current) are measured at each sampling interval. Then using these data, the pulse width is computed in real time so as to force the output voltage equal to the reference at each sampling instant [32]. It confirms the best possible dynamic performance among the fully digital solutions. Figure 3 shows the basic block diagram of a dead beat controller where feedback signal is delayed by a sampling interval and some forward gain blocks are used for switching signal [33]. The drawbacks with tilt control high sensitivity to parameter and modeling errors. Recently adaptive line enhancer (ALE) is introduced to bring the robustness of parameter uncertainties to deadbeat controller [34].

2.5 Predictive Control

Reference current estimation through conventional time domain or frequency domain techniques where high pass or low pass filters delay computational and response time. Even in deadbeat controller, there is a minimum delay of two sampling times 2Ts. It causes phase and magnitude error in the derived signal. It may work satisfactorily only in steady state condition. So a popular approach for the prediction of error signal comes into APF applications. In predictive control algorithm statistical time series modeling method and the use of neural nets are two popular approaches to predict or forecast problems. Reference signal estimation at next sampling value (say $v,"+')$ is obtained by rotating the present sampling value $(v,")$ through an angle in a space plane using rotation matrix [35]. The first approach is complicated and the amount of computation is large. On contrary, ANN offers fast computation because of its parallel nature, adaptability to changing parameters or even plant structure and high noise immunity. But it requires prior trainings of the network. In spite of the superior performance, the predictive controllers have two main drawbacks: First, they require considerable calculations; second, a good knowledge of system parameters is critical for their implementation [36-38]. In order to reduce computational burden, very often Artificial Neural network predictor is used [39].

2.6 Space Vector Modulators

In three-phase voltage-source and current-source converter based active filters, Space vector modulation (SVM) has become the preferred PWM method for digital implementation [40]. The switching states are defined in sectors and back to back converters are operated in chronological orders shown in Fig. 4. Thus exploiting the benefits like better voltage utilization, lesser current harmonics, and fixed frequency operation. It has the following advantages over other control schemes:

1. Use factor of DC link voltage is high.
2. It can be conveniently used as current control or flux tracking control in applications such as motor drives. Although implementation of SVM in digital system is simple, the required calculations and corresponding execution time limit is the maximum sampling time. And it results maximum switching frequency and maximum bandwidth [41]; however, along with reduction of hardware and software complexity ANN based vector classification techniques reduces the computation time.

2.7 Delta Modulation Control (DMC)

The delta modulation current control (DMC) is also based on a nonlinear control as shown in Fig. 5. From this figure, the limit comparators and D-type flip-flops are applied to generate the switching signals of six IGBTs. The concept of the delta modulation current control technique is simple and easy for implementation [42]. In Fig. 5 for phase a, if I_{ca} is over than $I*ca$ then the comparator output (y1) is 0. In contrast, if I_{ca} is less than $I*ca$ then y1 is 1. This output is transferred to D-type flip flop for generating the switching pulses. The output of D-type flip-flop (Q or S1) is determined by the clock signal as shown in Fig. 5. When the clock signal changes from 0 to 1, S1 is set equal

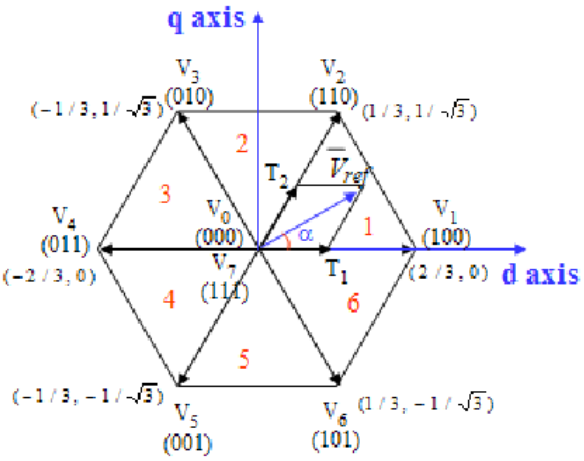

Fig. 4. *Switching table of SVM technique*

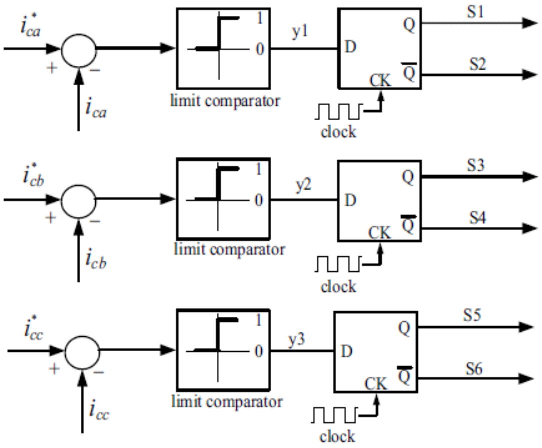

Fig. 5. *DMC controller block diagram*

to the output of comparator (y1). The signal S2 or Q is the opposite state of the switching pulse S1.

The switching frequency of delta modulation controller is not constant and the performance of the controller, based on %THD is not as good as HCC or TCPWM.

2.8 Triangle-comparison PWM Controls (TCPWM)

This current control technique is also called linear current control. The modulation signal achieved by a current regulator from the current error signal is intersected with the triangle wave and the pulse signals obtained are the principles of the conventional triangle comparison PWM control. The technique has fast response and simple implementation. But the current loop gain crossover frequency must be kept below the modulation frequency [43-47]. To overcome this limitation, this paper presents an effective scheme in Fig. 6 where filter currents are subtracted from reference currents and go through PI controller. Comparator selects definite level for the signal. Choosing proper K_P and K_i values are very important for good operation.

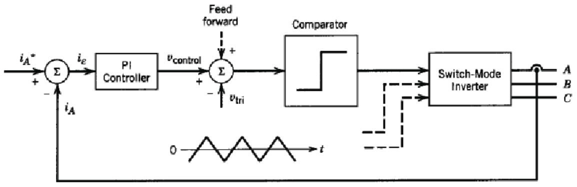

Fig. 6. *Block diagram of PWM controller*

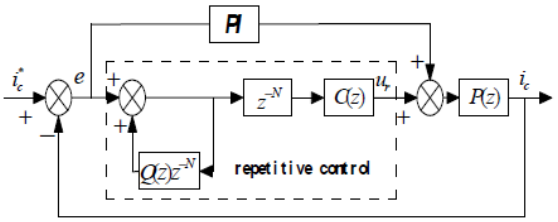

Fig. 7. *Block diagram of repetitive controller*

2.9 Repetitive Control

The repetitive control method based on internal model principle is very effective to deal with the periodical tracking errors, but the fatal weakness of this method is the control effect on the tracking errors lags about one fundamental wave period. Consequently, in the dynamic process of nonlinear load catastrophe, a fundamental wave period of the output compensating current is out of control [48-52]. In order to resolve the problem, PI and repetitive controller in parallel can be put into use, shown in Fig. 7.The scheme will hold the advantages both of the repetitive controller with excellent steady state characteristics and the PI controller with well dynamic performance.

2.10 One-cycle Control

One-cycle control (OCC) technique has shown great promise featuring with excellent harmonic suppression, simple circuitry, robust performance, and low cost for the control of three-phase APFs. The validity of OCC controlled APFs working with balanced line voltages and balanced nonlinear loads have demonstrated in theory and experiments in previous papers [53-54]. In Fig. 8, a basic control core is shown. A clock generates a periodic pulse train that sets the flop/flop at the beginning of the each switching cycle. When both signals at the two inputs of the comparator approach one another, the comparator changes its state, which in turn resets the flip/flop and the integrator to zero [55-57].OCC takes advantages

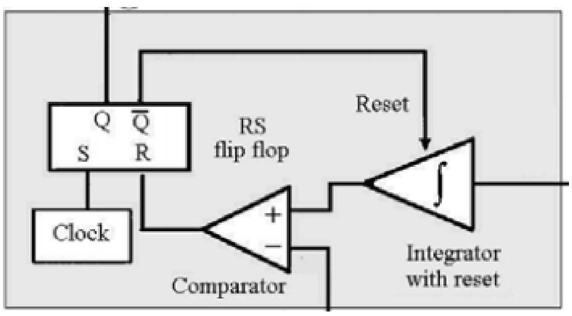

Fig. 8. Block diagram of one cycle control technique

of the pulsed and nonlinear nature of switching converters to achieve instantaneous dynamic control of the average value of a switched variable. In one switching cycle, OCC restrains power source perturbations, and the controller eliminations switching errors, and thus the average value of the switched variable follows the dynamic reference.

2.11 Soft Computing Algorithms

By using expert knowledge to extract information from the process signal is the basic principle of soft computation process [58]. Some ideas are borrowed from problems solved by biological systems and apply it to control processes. It also replaces a human to perform a control task .The main areas in soft computing notably are fuzzy logic, neural network, Wavelet control, genetic algorithm (GA), particle swarm optimization etc. [59-61].

2.11.1 Fuzzy Control

Four stages are involved in fuzzy logic: fuzzification, knowledge base, inference mechanisms, and defuzzification [60-62] which are presented in Fig. 9. To provide a good dynamic response under uncertainty in process parameters and external disturbances, the knowledge bases are designed. Fuzzy logic controllers have generated a great deal of interest in recent years in certain applications. It has some advantages such as robustness, can work with imprecise inputs and can handle non-linearity. Moreover it needs no accurate mathematical model [62-63]. The inputs are namely the error e signal , 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 (de) while the output is the command(cde).

The fuzzy controller is the most sensitive of all the controllers. However, it also has some drawbacks like iteration and redundancy problems. Therefore, the membership function must be chosen on the basis on system complexity.

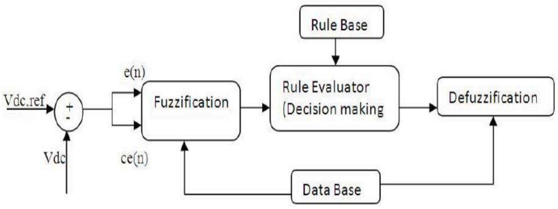

Fig. 9. Block diagram of Fuzzy logic control

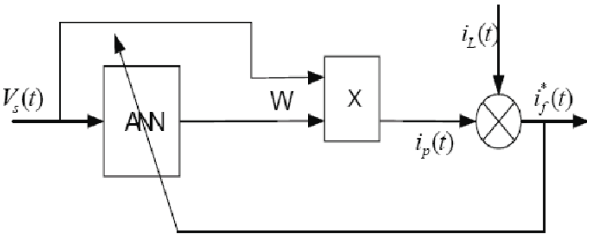

Fig. 10. Block diagram of neural network control technique

2.11.2 Artificial Neural Network

In the recent years the theory of artificial neural network (ANN) has been greatly developed. Due to its strong nonlinear mapping and learning abilities, applications of ANN to control systems have been successful [64]. Nowadays this technique is considered as a new tool for designing APF control circuits. It is not necessary to establish specific input-output relationships, but they are formulated through a learning process or through an adaptive algorithm [65]. Moreover, parallel computing architecture increases the system speed and reliability the target is to obtain reliable control algorithms and fast response procedures to get the switch control signals [65]. The software tool employed here is 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 is shown in Fig. 10.

2.11.3 Genetic Algorithm

A genetic algorithm (or GA for short) is a programming technique that contains biological evolution as a problem-solving strategy. Given a specific problem to solve, the input to the GA is a set of potential solutions of that problem which is encoded in some fashion. And a metric called a fitness function that allows each candidate to be quantitatively evaluated [66-67]. These candidates may have solutions already known to work, with the aim of the GA being

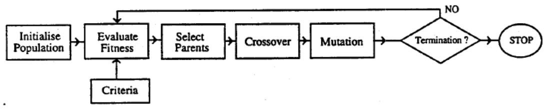

Fig. 11. Block diagram of genetic algorithm

to improve them, but more often they are generated at random. Before a genetic algorithm can be put to work on any problem, a method is needed to encode potential solutions to that problem in a form that a computer can process [67-68]. One common approach is to encode solutions as binary strings: sequences of 1's and 0's, where the digit at each position represents the value of some aspect of the solution which is shown as Fig. 11.

In active power filters applications. A good dynamic response is required and conventional control design techniques are not adequate due to the approximation of the real system model they use. The advantages of this design technique are that it evaluates the performance of control parameters performing a parallel search over the solution space in order to select the most appropriate final values. Moreover it can use several weighted criteria to create an appropriate fitness function for the evaluation of controller performance and consider all the system nonlinearities in the design procedure, reaching a more efficient solution. The GAs has proven to be very efficient in obtaining an optimum solution in a short time.

2.11.4 Particle Swarm Optimization

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Beernaert and Dr. Kennedy in 1995, inspired by social behaviour of bird flocking or fish schooling's shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA)[69-72]. The system is initialized with a population of random solutions and searches for optima by updating generations. Figure 12 shows the flow charts of PSO where it can easily test the result with fitness function and select the desire output. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. There are several papers reported using PSO to replace the back-propagation learning algorithm in ANN in the past several years. It showed PSO is a promising method to train ANN. It is faster and gets better results in most cases. It also avoids some of the problems GA met [72]. But it has some disadvantages. Lacking somewhat of a solid mathematical foundation for analysis, some limitations in real-time ED applications, such as in the 5-minute dispatch with network constraints and due to relatively longer computation time it should compromise with other controllers.

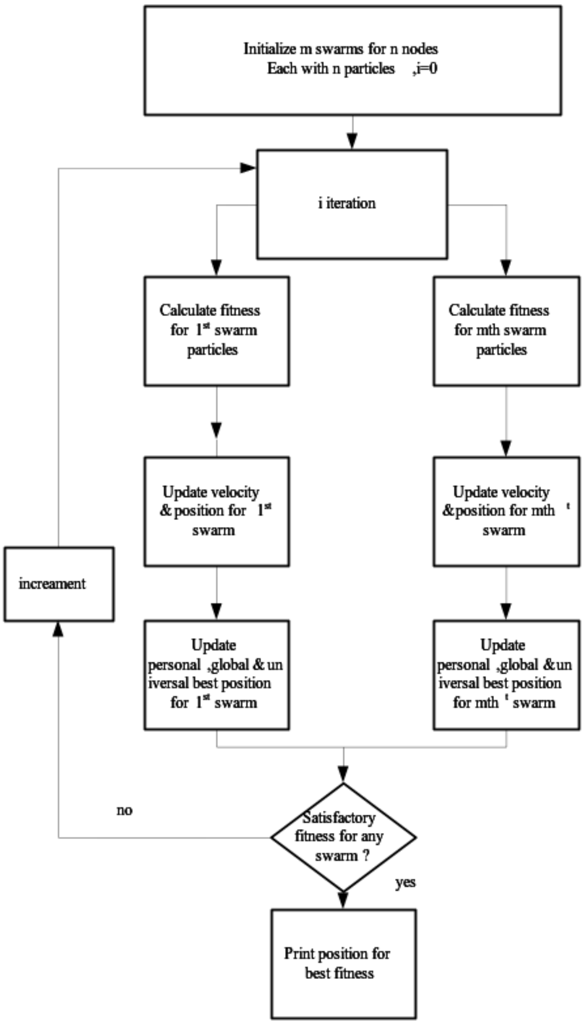

Fig. 12. Flow chart diagram of PSO technique

2.11.5 Wavelet Theory

Wavelet transform is a high performance signal processing technique since it can provide information on transients localized in time domain, and the capacity of multi resolution analysis in the domain of time-frequency without the any assumption of initial values is necessary. Moreover, the wavelet analysis can often de-noise a signal at the same time of decomposing without appreciable degradation [73-75]. Wavelet transform can be used as a derivative method and it was proved that wavelet transform has the advantages over simple derivatives. Wavelet theory is an advanced mathematical tool that uses multi resolution

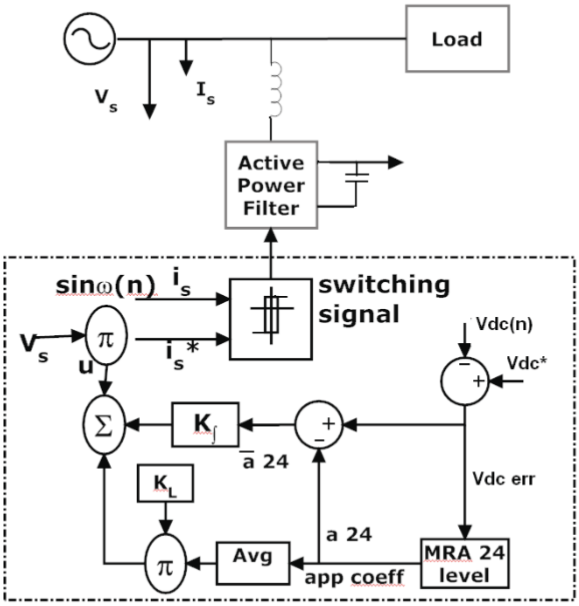

Fig. 13. Block diagram of wavelet theory

techniques to analyze waveforms and images. Wavelet analysis is capable of revealing aspects of data that other analysis tools would miss, including trends, breakdown points, discontinuities, and self-similarity [76-79]. Feature extraction is a vital step that completes the link between intelligent analysis tools and actual PQ waveforms and data. Wavelet analysis has proven very strong and efficient in feature extraction from PQ disturbance data. Application of wavelet theory to PQ analysis has been well researched.

The error signal (Vdcerr (n)) has been decomposed up to 24 levels. The reconstructed signal (a24 = c24) using the approximate coefficients at this level correspond to frequency lower than 0.0015 Hz, which carries the DC information of the error voltage. This is used to design a part of the controller such that the constant DC link voltage is achieved. In addition, another part of the controller is based on a signal which is the complementary part of the signal a24 and is denoted by a24, The two signals a24 and a24 constitute the total error signal e(n) which are shown in Fig. 13.

3 SELECTION OF CURRENT CONTROL TECHNIQUE

Most of the practiced control strategies for power quality conditioners have been reviewed with regard to their performance and implementation. Their high processing speed and flexibility in operation facilitates incorporation of complex control algorithms. Each technique has its advantages and disadvantages. Selection of any technique depends on load characteristics; accuracy required and eases of implementation [80-83]. The specifications of this paper are listed in Table 1.

Moreover, those current controllers' performances are analyzed with the consideration of instantaneous error and root mean square (RMS) error for following the extracted reference current. Three criteria are defined for the capability of measurement of tracking the current reference and for the evaluation of which the studied methods has a better performance [84].The quasi-instantaneous mean error between the current active filter and the reference current is shown in Equation (1). An idea of the average error is found from the resulting criterion for a switching period, Tsw. Being the period of the main wave much longer than this lapse of time, the error can be considered instantaneous. Notice that the difference is not done in absolute value and the sign in every sample is conserved in the integral.

The root mean square error in a period of the fundamental frequency evaluates the ripple in the waveform created by the active power filter. The units of this criterion are in amperes. However, the value is not instantaneous but averaged in a long period of time. The effect of peaks in the reference current that would give a large instantaneous error is diminished through this. The equation is exposed in (2).

Finally, to evaluate the quality of source current, the compensated signal, used criteria is the total harmonic distortion as defined in:

The harmonic content of a signal is measured as THD referred to the first harmonic. The waveform is better as the value of THD is lowest. So the criteria defined in equation (1) and (2) evaluate the ability of the algorithm to follow the reference and the units are amperes [85]; whereas the overall quality of the signal is measured by equation 3.

With the knowledge of those terms using a sinusoidal waveform reference the evaluation of every studied method is shown in Table 2.

From Table 1 and Table 2 it reveals that for PI based TCPWM of error control which is a very simple technique to implement but the main disadvantages of this technique are very high switching losses and high frequency distortion. And fast switching rates result high losses.

As a very quick response times in hysteresis band control also, it suffers fewer switching losses than triangular wave based method. Rather than to control the switching rate using a high frequency carrier wave, switching occurs only when the error leaves the specified band [86].

Sliding mode control provides good results but it is difficult to implement due to complex logic.

For only steady state condition repetitive controllers are implemented as harmonic compensator and current controller to track the fundamental reference current. But for

Table 1. Control techniques comparison based on implementation process

Compensation strategy	**Complexity**	**Speed of response**	**Switching frequency**	**Delay time**	**Injected current harmonics**
Hysteresis-control	simple	Fast	Variable	no	Can be employed for harmonic elimination in a frequency range of interest
Sliding mode control	simple	Medium	variable	no	
Negative sequence current control	simple	Medium	constant	no	
Deadbeat control	complex	Medium	constant	medium	
Predictive-control	middle	Medium	constant	long	
Space Vector modulation	complicate	slow	constant	long	
DMC	simple	fast	variable	no	
TCPWM	middle	fast	constant	no	
Repetitive-control	simple	Medium	constant	medium	
One cycle Control technique	simple	fast	constant	no	
Wavelet theory	complex	fast	constant	no	
Fuzzy logic	Medium	fast	constant	small	Not suitable for selective harmonic elimination
Neural network	Medium	Fast	constant	small	
Genetic algorithm	complex	fast	constant	no	
Particle swarm optimization	complex	fast	constant	small	

Table 2. Control techniques comparison based on error using a sinusoidal waveform reference

Control methods	**Switching frequency**	$\Delta \mathbf{i}(\mathbf{t})$	$\delta \mathbf{i}(\mathbf{t})$
DMC	20 kHz	1.610	0.692
Deadbeat control	10 kHz	0.206	0.129
TCPWM	10 kHz	1.959	0.644
Hysteresis-control	12 kHz	1.35	0.432
Sliding mode control	12.5 kHz	1.23	0.543
Negative sequence current	15 kHz	1.89	0.542
Predictive-control	10 kHz	1.01	0.356
Space Vector modulation	10 kHz	1.12	0.412
Repetitive-control	12 kHz	1.24	0.463
One cycle Control	20 kHz	0.879	0.765
Fuzzy logic	12 kHz	0.293	0.324
Neural network	10 kHz	0.231	0.241
Genetic algorithm	4 kHz	0.219	0.181
Particle swarm optimization	15 kHz	0.207	0.145
Wavelet theory	19 kHz	0.91	0.672

transient response, predictive control provides a considerable error according to its algorithm used the previous data to predict signals [87]. To improve this poor transient behavior, techniques can be applied. consideration of this design, performance of resonant based control is determined by the parameters of controller and these parameters are relatively complicated to obtain when higher order harmonic compensation is required particularly. Instead, the predictive based control is less complicated regarding the design procedure and can control many harmonics, not only the selected harmonics.

SVPWM control is more superior in improving wave quality compared with traditional SPWM control, with reducing switching frequency and enhancing the utilization of DC voltage [88].

From Table 2 it is shown that amplitude of the error signal is low for the deadbeat controller and satisfactory performance can be obtained. But due to its adaptive filtering the implementation process becomes quiet complex [89].

Though DMC, negative sequence current control and one cycle controller show acceptable performance in normal balance and unbalance condition but in highly unbalanced and distorted position they fail to track the desired reference current [90-91].

Now artificial neural network technique provides better result than the discussed conventional APF current controller included fuzzy logic for the reduction of harmonic distortions. The main advantage of this technique is its ability to adapt to varying loads in real time [92]. The compensation structure is modular and composed of different blocks of homogeneous neural networks. So it can be used as basis for more general architectures especially for hardware implementation [93].

Wavelet theory is not sensitive to voltage distortion. Even with serious harmonic distortion in the voltage sinusoidal currents are obtained. This makes it different from those methods that try to mimic a linear resistance that generates currents proportional to the voltage [94]. But in order to have a better transient response, load-related information has to be taken into account that initiates some advanced control method such as genetic algorithm, particle swarm optimization etc.

Compared to genetic algorithm, particle swarm optimization is easy to implement and there are few parameters to adjust. It has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control, and other areas where GA can be applied [95].

Although the control strategies of APFs have advanced greatly, still more work is need to be done to maintain better power quality and more sensitive as complex loads are coming into electric power networks. As every controller consists of some advantages or limitations, combinations of them provide a complete solution for the upcoming power distribution network disturbances.

4 CONCLUSION

Active power filters are used in industrial and commercial sectors to perform the job of harmonic elimination properly. Most of the proposed control strategies for power quality improvements have been reviewed regarding their 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, DSP, FPGA and RTDS) at low cost.

As more and more commercial products are based on multilevel inverter structure and development of worldwide research artificial intelligence based control algorithms are popular due to its ability to handle complex problem at difficult situations. Ant colony (ACO) algorithm, bee colony (BCO) algorithm and bacterial foraging optimization (BFO) which are intended now a days for optimal harmonic compensation by minimizing the undesirable losses occurring inside the APF itself. So, the consumer can select the control methods with the required features.

It is hoped that this survey on control techniques for active power filters will be a useful reference to the users and manufacturers. With this study, the findings about APF studies in the literature and the application notes of APF in service are presented and thus the trends of APF through the years are clearly observed. As soft computing algorithms show better compensation performance, more research should be focused on this.

ACKNOWLEDGMENT

The authors would like to thank University of Malaya for providing financial support ERGS project ER023/2011A.

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P. Dey was born in Chittagong, Bangladesh in 1987. He received the B.Sc. degree in electrical engineering from Chittagong University of Engineering and Technology (CUET) in 2009. Since 2010, he joined several academic institutes in Bangladesh as a lecturer. In 2012 he joined the department of electrical engineering at University of Malaya to continue his Study towards masters. His research interests are in the areas of Power electronics and power quality.

S. Mekhilef received the B. Eng. degree in Electrical Engineering from University of Setif, Algeria in 1995, and Master of Engineering science and PhD from University of Malaya in 1998 and 2003 respectively. He is currently professor at Department of Electrical Engineering; University of Malaya. Prof. Saad is the author and coauthor of more than 150 publications in international journals and proceedings. He is actively involved in industrial consultancy, for major corporations in the power electronics projects. His research interest includes power conversion techniques, control of power converters, renewable energy and energy efficiency.

AUTHORS’ ADDRESSES

Papan Dey
Saad Mekhilef, Ph.D.
Power Electronics & Renewable Energy Research Laboratory (PEARL),
Department of Electrical Engineering,
University of Malaya,
Kuala Lumpur 50603, Malaysia
email: papan@siswa.um.edu.my, saad@um.edu.my

Received: 2013-05-07
Accepted: 2013-11-08