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Current Control Strategies for Active Filter for Harmonic Mitigation

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ABSTRACT: An effective way for harmonic suppression is the harmonic compensation by using active power filter. This paper presents a comprehensive survey of active power filter (APF) control strategies put forward recently. The control strategies applied to active power filters play a very important role on the improvement of the performance and stability of APF. In this paper, the control strategies applied to active power filters are reviewed and analyzed. The characteristics and applicability obtained from the analysis can become the reference to the design of the APF. This paper presents the possible trends of the control strategies based on Artificial Intelligence applied to active filters.

KEYWORDS: Active power filter, hysteresis current controller, *Predicative Current Control*, fuzzy logic, reference current generator.

1 INTRODUCTION

The Energy crisis, globalization and competitiveness have forced the industries to produce the quality product using minimum energy at minimal cost. For the desired quality product and minimum utilization of electric energy need is to operate the process plant, machines and equipments at desired operative point. These devices and microcontrollers form a nonlinear system and overall nonlinear loads, thereby generate harmonics, noise, spikes, voltage sag and poor power factor of overall system and also enter other end-users system. These non linear loads draw non-sinusoidal currents due to the current harmonics generated by them. Non Linear loads which include adjustable-speed motor drives, electronic power supplies, DC motor drives, battery chargers, electronic ballasts are responsible for the rise in PQ related problems [1],[2]. These nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system. Harmonic currents produced by nonlinear loads are injected back into power distribution systems through the point of common coupling (PCC). As the harmonic currents pass through the line impedance of the system, harmonic voltages appear, causing distortion at the PCC. These harmonic currents can also cause interferences with telecommunication lines and errors in metering devices [3]-[4]. Because of the adverse effects that harmonics have on PQ, Standard has been developed to define a reasonable framework for harmonic control conventionally passive L–C filters were used and also capacitors were employed to improve the power factor of the ac loads Limitations of Passive Filters like fixed compensation or harmonic mitigation, large size and possible resonance with supply system impedance at fundamental and/or other harmonic frequencies lead to other alternative i.e. Active power filters. The Active power filters rely on active power conditioning to compensate for undesirable harmonic currents[5]. They actually replace the portion of the sine wave that is missing in the non linear load current and use power electronic switching devices to inject harmonic current with complimentary magnitudes, frequencies and face shifts into the power system. They are particularly useful for large non linear loads such as arc furnace, paper mill and rolling mills.

The main advantage of shunt active filter over passive filters is their fine response to the changing loads and harmonic variations. This paper presents a review of the state-of-the-art control techniques in active filters and reactive power.

2 STATE-OF-THE-ART CONTROL TECHNIQUES

The main component in the Active Power Filter is the control unit. Controlling of APF is implemented in *three stages:* First stage can be called as the *signal conditioning stage*. The essential voltage and current signals could be sensed using power transformers, Hall Effect sensors and isolation amplifiers to gather accurate system information. The instantaneous voltage and current signals are useful to monitor, measure and record various performance indexes such as Total Harmonic Distortion(THD), Power factor, active and reactive power, crest factor, etc,.

Second stage is the *derivation of compensation signals* stage. In this stage compensating commands in terms of current or voltage levels are derived based on control methods and APF configurations. The third stage is the *generation of gating signals* to the device of Active filters. The main component of APF is the solid state devices. Earlier BJTs and MOSFETs were used. Now-a-days IGBTs are used for medium ratings and GTOs are used for high ratings. The gating pulses are generated by current control technique like sinusoidal pulse width modulation (SPWM), triangular PWM, hysteresis current control technique , Space Vector current controller.

The models of APF have been developed by various methods, and the behavior of reference signal tracking has been improved with help of advanced control approaches. .Compensation in frequency domain is based on Fourier analysis of distorted signal. In time domain a number of control strategies such as instantaneous reactive power theory (*p-q* theory)initially developed by Akagi et al[5]. , synchronous frame d–q theory , synchronous detection method , notch filter and fuzzy logic controller method , sliding mode controller,etc..are used in the development of three-phase AFs .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 Different control methods and harmonic suppression approaches for APF have been investigated.

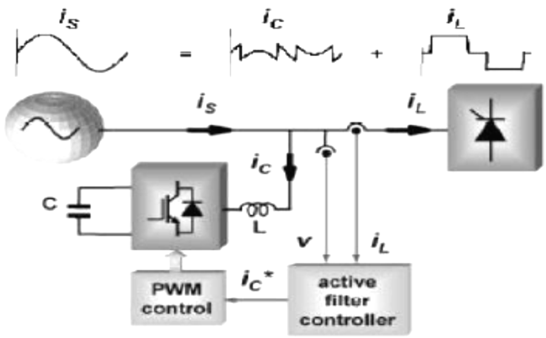

Fig 1: General Block Diagram For shunt a Active filter

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, Hysteresis Current Control [5] , *Fixed Frequency Control,* Adaptive control[6] ,sliding mode control[6],[7],[8],modulation vector control , SFX control, repetitive control,[12][13],[14] Dead Beat controller [15] Neural Network, Fuzzy logic,[17] wavelet control [18].[19]etc. for improving the steady state and dynamic performance of APFs.

The choice and implementation of the current regulator is one of the more critical issues for the achievement of a satisfactory performance level.This paper presents a comprehensive review of Active Power filter configurations, control strategies and the Total Harmonic Distortion(THD) for different control strategies both in traditional and current environments.

2.1 FIXED FREQUENCY CONTROL

The fixed frequency control [6] has been shown in figure 2 in this scheme the error between the reference and actual current is fed through a conventional 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 fs) triangular waveform. 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.

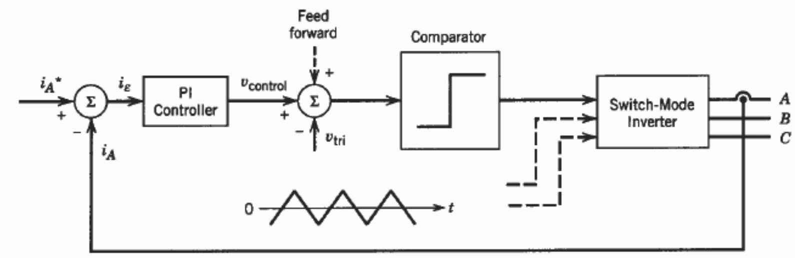

Fig:2 Fixed Frequency Control

2.2 HYSTERESIS CURRENT CONTROL [HCC]

There are various current control methods proposed for active power filter configurations; but the hysteresis current control method is proven to be the best among other current control methods, because of fast current controllability, easy implementation and unconditioned stability. This method controls the switches of the voltage source inverter asynchronously to ramp the current through the inductor up and down, so that it follows the reference current. Hysteresis current control is the easiest control method to implement in the real time. The hysteresis band current control is robust, provides excellent dynamics and fastest control with minimum hardware.

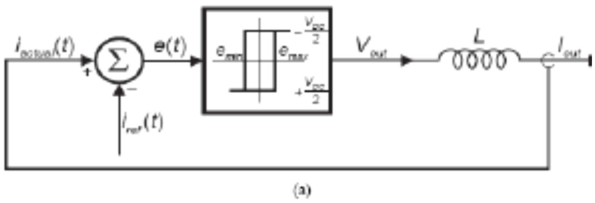

Fig 3. Hysteresis Current Control [HCC]

2.3 SLIDING MODE CONTROL

The sliding mode control has been widely applied to power converters due to its operation characteristics such as fastness, robustness and stability for large load variations. The references for the sliding mode control system are obtained by using the instantaneous reactive power theory. In sliding-mode controllers, either dc-bus voltage (in a VSI) or dc-bus current (in a CSI) is maintained to the desired value and reference values for the magnitudes of the supply currents are obtained. Subtracting load currents from reference supply currents, compensating commands are derived. From the total harmonic distortion in the line currents is less than 2% satisfying limitations required by international standards. For the generation of gating pulses the commonly used techniques are PWM and Hysteresis Current Control (HCC).

2.4 SFX ALGORITHM BASED ADAPTIVE CONTROL

This method discusses a new current control method for active power filters (APF'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 APЄF's. It introduces an adaptive digital filter (ADF) with a synchronized filtered-x (SFX) algorithm . 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. Both harmonics and reactive power compensation is done by active power filters. 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

$$y(t) = K_P \cdot e(t) + K_I \int e(t) \cdot dt \qquad (1)$$

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:

$$w(n+1) = wk(n) + 2\epsilon\mu(n)x(n-k) \qquad (2)$$

Where k= 0,1------------N-1

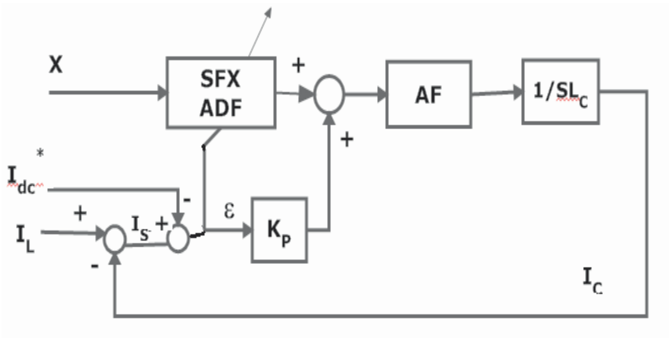

Fig:4 Current Control Scheme For SFX-ADP

The problem with this ADF is that the adaptive algorithm involves a large number 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 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

2.5 DELTA MODULATION (DM)

The Delta Modulation method is a variation of the traditional hysteresis current regulator. This method consists in applying a constant voltage in all the switching period. The purpose of this control is to obtain the switching signals from the comparison between 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 is used, the current generated at the $(k+1)^{th}$ sampling time instant.

2.6 PREDICATIVE CURRENT CONTROL

In the *Predicative* control schemes, the regulator measures 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 *Predicative* controller is used. 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.

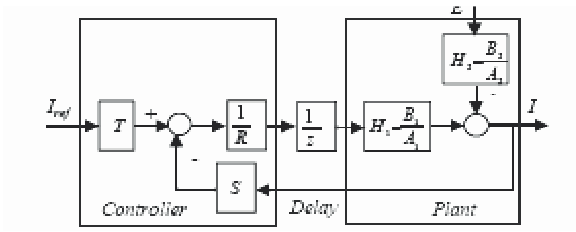

Fig 4: Predicative Controller

3 ARTIFICIAL INTELLIGENCE TECHNIQUES

Artificial Intelligence has experienced an extensive growth in the last decade partially due to uncertainties and vagueness in the process signal and occurrence of random events, and partially due to nonlinearity and complexity of the processes. The system can be complex with nonlinearity and parameter variation problems. An intelligent or self-organizing control system can identify the model, if necessary, and give the predicted performance even with a wide range of parameter variation. *Artificial Intelligence* is an alternative solution to meet the process and user's requirements simultaneously. *Artificial Intelligence* Technique is a technology to extract information from the process signal by using expert knowledge. 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 , neural network, Wavelet control, genetic algorithm (GA), rough sets, etc.

3.1 FUZZY CONTROLLER

Fuzzy control system processes the imprecise and vague measurements information using expert knowledge In this theory fuzzy logic and control system features are integrated by using IF-THEN rules. A set of such rules can be used to create a functional controller. The advantages of Fuzzy logic Controller (FLC) over traditional controllers are high robustness, high tracking accuracy, and quick response . Two types of fuzzy controllers are used frequently for the control of APF-Mamdani type and Takagi-Sugeno-Kang (TS) type. Mamdani has developed the application of FL in control system. It was investigated earlier that Mamdani type fuzzy logic controller require large number of fuzzy sets and rules . So, TS method was implemented for the control of APF and it found various advantages over Mamdani type. Using TS type controller the system is found to be robust and it found that it uses less number of fuzzy sets and rules whether it has been used in Harmonic Detection techniques or in Current Control Technique . Many controllers have been developed to improve power quality for single-phase, and three-phase four-wire system using Fuzzy Logic and compared with PI type controller. Results shows that PI controller fails to respond quickly and whether it is harmonics detection technique or current control technique.

To develop the fuzzy-logic control algorithm for APF, two inputs: 1) the voltage error (reference voltage minus actual capacitive voltage, e), 2) the change of capacitive voltage (previous error minus current error; ce) were considered over one sample period. The two inputs were represented by sets of seven membership functions and expressed in linguistic values as negative big (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM), and positive big (PB). The range for the "error" input was set as[-30,30] and that for "change of error" was set as[-10,10] . A limiting block was introduced before the fuzzy block in order to truncate values beyond these ranges before supplying them to the fuzzy-logic controller. The shape of these membership functions was varied and the effect on the system was studied. The input to the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single non fuzzy number, obtained by the center-of-gravity (COG) method of defuzzification. The output (magnitude of reference supply current,) is represented by a set of nine membership functions (MFs) (NVB to PVB) whose shape was taken to be similar to the shape of the input MFs. The range for the output was set as [-30, 30]. The output of the fuzzy-logic controller was multiplied by a unit sine wave in order to bring it in phase with the supply current before comparison. The AND method used during interpretation of the IF-THEN rules was "min" and the OR method used was "max." Also, "min" was used as the implication method whereas the "max" method was used for aggregation. The 49 fuzzy IF-THEN weighted rule base was designed to maintain the capacitor voltage constant by providing the required reference current amplitude. Rule generation and weighting were decided based on the pendulum analogy.

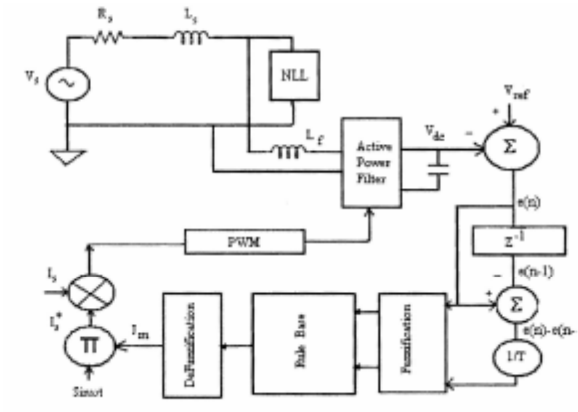

Fig: 5 Structure of Fuzzy Controller for APF

3.2 NEURO CONTROLLER

The described neural networks have been trained and simulated in various ways with the goal of getting the parameter values that produce the optimal performance for each of the topologies . 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. 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.*

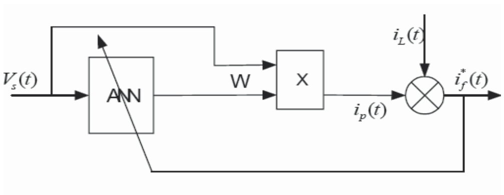

Fig6 Structure of NN Controller for APF

3.3 WAVELET CONTROLLER

A Wavelet Transform (WT) based Technique is used 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 Multi resolution analysis (MRA) . 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 . 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 **.** 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.

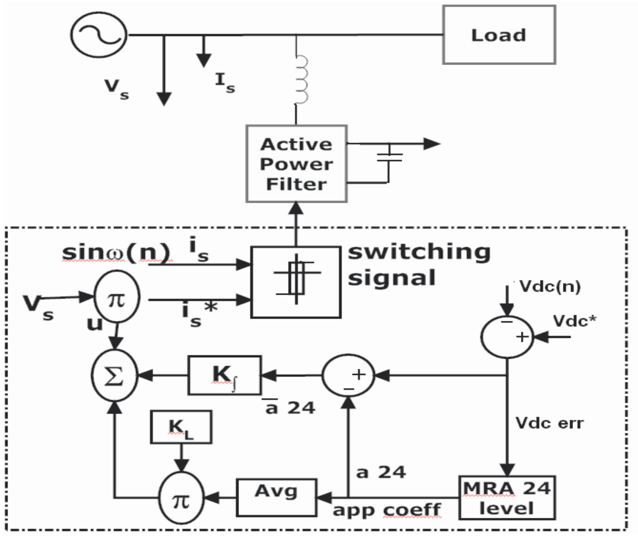

Fig: 7: Structure of wavelet Controller for APF

4 Conclusion

Active power filters are the developing 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.

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