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Research paper

A Review on Shunt Active Power Filter Control Strategies

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Abstract

Shunt active power filter (SAPF) has now become a well-known sophisticated technology to overcome current harmonics and reactive power compensation issues. In this paper a technical review of various control strategies for operation of SAPF has been presented. Control strategies such as reference current generation by time domain, frequency domain and soft computing approaches; voltage control for dc link voltage regulation and current control for generating switching patterns for voltage source inverter has been discussed. This paper aims to provide a broad understanding on SAPFs for various research and engineering applications.

Keywords: *active power filter; artificial neural network; reference current generation; voltage control, controller*

1. Introduction

With the introduction of solid state power electronics switching elements, the demand of power converters based on semiconductor switches have been increased to feed the loads such as personal computers, mobiles, induction heating, arc furnaces, elevator and motor drives. Due to the non-linear behavior of these loads; extraction of excessive harmonic current, reactive power demand from the main supply and also current unbalance come into picture [1-3]. When these harmonic currents flows to entire electrical power grid, which result in voltage harmonics and disturbances. Moreover, these harmonic currents adversely affect the operation of circuit breakers, relays, protecting equipments and other sensitive devices. These abnormal conditions results in excessive power losses, reduction in overall efficiency of the power system operation [4-6]. Hence it imposes extra burden on the power utility and connected application.

The wide consumption of reactive power by the industrial loads also leads to bad effect on power quality. The consumption of reactive power by the inductive loads causes increased transmission and distribution losses because of higher the value of RMS current. To compensate the reactive power demand various Static Var Compensators have been proposed. But due to the limited application for higher current harmonics they seem to be inefficient [7-8]. To deal with the rapid evolution of harmonics, load side management strategies were devolved such as special structure single/three phase rectifier and pulse width modulation rectifiers.

Traditionally, Passive RLC filters were employed to eliminate the voltage and current harmonics but due to resonance, voltage oscillations, fixed compensation, ageing effect and bulky size of energy storing elements (i.e. inductor and capacitor) made them rarely useable.

Active power filter is a modern solution for mitigation of power quality derivatives. Because of the superior filtering performance, small physical size and flexibility of control, they are considered to be best suitable technique for voltage and current harmonic elimination issues [9]. Different configurations of APF have been designed such as SAPF, series active power filter and unified shunt and series active power filter to sort out current harmonics, voltage harmonics and simultaneous current and voltage harmonics respectively. Hybrid Active power filters combines the function of both active and passive filters.

2. Shunt Active Power Filter

SAPF is a most eminent filter among other types of power conditioning filters, which is used to cancel out current harmonics. In order to make, load current to be sinusoidal, SAPF generate the compensating current of 180 degree out of phase with same magnitude of the harmonic currents.

In SAPF, reference current signal is generated by using SAPF control strategy. Then reference signal is utilized to generate gate signals with the help of pulse width modulation technique/Hysteresis loop control. Later on these gate signals are used to generate the output current signal of SAPF with mean of voltage source inverter. The basic configuration of SAPF is shown in Fig. 1.

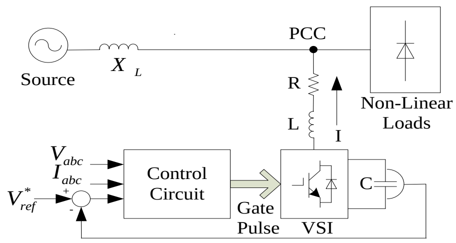

Figure 1: Shunt active power filter

2.1 Basic Components of SAPF:

Control circuitry:

It is the main functions of control circuitry are voltage control, current control and current reference generation. Voltage control can be achieved with the help of PI and sliding mode control techniques [10]. Current control is maintained with the help of artificial neural network, fuzzy logic and sliding mode controllers [11-

13]. Current reference is generated with the mean of PQ theory [14], synchronous reference frame method [15], Fourier Transform [16] and by applying various soft computing approaches [17-18].

Firing angle generator: the function of firing angle generator is to produce gate pulses for the operation of voltage source inverter. The most likely used approaches for triggering of VSI switches are hysteresis controller [19], fuzzy logic controller [20] and Pulse width modulation [21].

Voltage source Inverter: Two levels PMW VSI is a most commonly used in SAPFs. Multilevel VSI is used in high power applications. THD in voltage and current waveforms of three levels VSI is quite lesser as contrast with two levels VSI. The performance of VSI depends upon the dimensions of energy storing elements, dc bus voltage, current control strategies and current reference generation techniques adopted.

3. Reference Current Generation

For shunt active power filers, Reference current generation methodologies are divided into two groups, one is traditional reference current generation techniques and other is modern techniques. Traditional techniques are based on the time domain and frequency domain approaches and modern techniques are based on soft computing techniques as shown in figure 2.

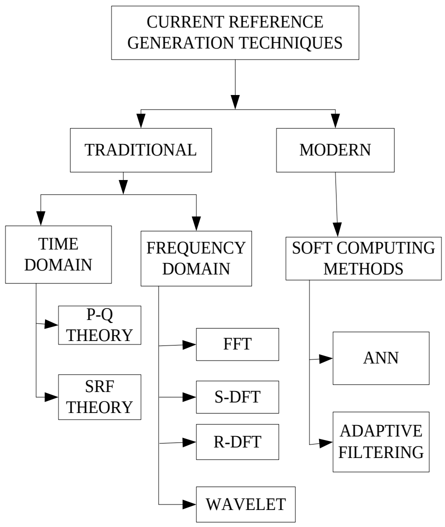

Figure 2: Classification of reference current generation techniques.

3.1. Traditional Reference Current Generation Techniques

These reference current generation techniques are based on time and frequency domain approaches.

3.1.1. Time Domain Approaches

There are two widely used reference current generation techniques such as P-Q theory and SRF theory.

Instantaneous active and reactive power theory (P-Q Theory): *T*he instantaneous *P-Q theory* was proposed by Akagi et al. [22]. Figure 3 shows basic principle of P-Q theory Due to lesser number of mathematical calculations, this approach can be implemented easily and has excellent performance. But the drawbacks of this approach are: delay in output responses, sensitive to imbalance of grid voltages, large numbers of transducers are needed and poor performance in case of negative and zero current compensation [23].

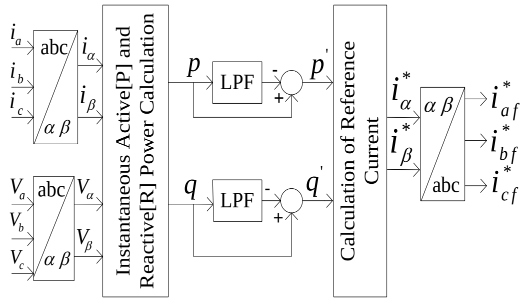

Figure 3: Basic principle of P-Q theory for Reference current generation.

***Synchronous reference frame method (SRF Method)*: In this method the three phase load current I_{abc} is transformed into *d-q* synchronous reference current using park transformation Then this *d* and *q* components of current are fed to low pass filter to eliminate harmonic components from fundamental current. Later inverse park transformation is used to convert instantaneous *d* and *q* component of current into three phase components [24]. Figure 4 shows the basic principle of SRF method. Drawbacks of SAF theory are: required large number of transducer and delay in output responses.

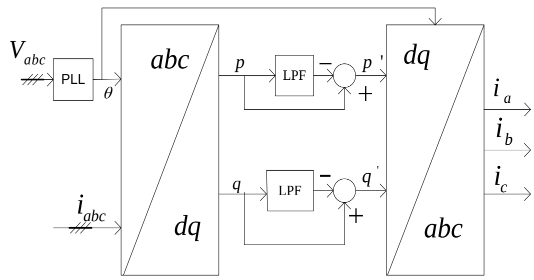

Figure 4: Basic principle of SRF method for reference current generation.

In [25], recursive park transformation is used improve the performance of synchronous reference frame controller. It allows the accurate designing of SRF controller by discarding filtering mechanism and this approach is independent of Point of common coupling conditions.

3.1.2. Frequency Domain Approaches

The common frequency domain approaches are:

Fast Fourier Transform: This technique is based on Fourier analysis and has ability to eliminate harmonics from different patterns of harmonic currents. Fast Fourier transform is a Speedy trial of DFT. Figure 5 explains the basic scheme where *i(0)……i(n)* are the discrete current samples, and *I(0)……I(n)* are their corresponding output currents and *Φ(0)……… Φ (n)* are their respective phases [26-27]. Short time Fourier Transform can also be applied for fast harmonic compensation. This approach can be implemented easily and there is not any requirement of voltage and current transducers. Disadvantages of Short time Fourier transform are: it requires at least one cycle of fundament frequency of reference current estimation and estimation is prone to noisy current samples.

***Recursive discrete time transform (RDFT approach)*: It is applied to extract fundamental components of current instead of using filters [28]. It provides reference signal having identical steady state performance with improved computational efficiency and fast transient responses as compared to traditional filtering methods.

In [29], RDFT technique is used to extract the real and imaginary components of fundamental current. The drawback of this approach is: it does not provide correct output during unbalance of line currents. Figure 6 shows the RDFT based reference signal generator.

In [30], to obtain active and reactive current components under both balanced and unbalanced load conditions, positive sequence components are extracted using fortescue decomposition. Figure 7 shows the fortescue decomposition combined RDFT based reference signal generator.

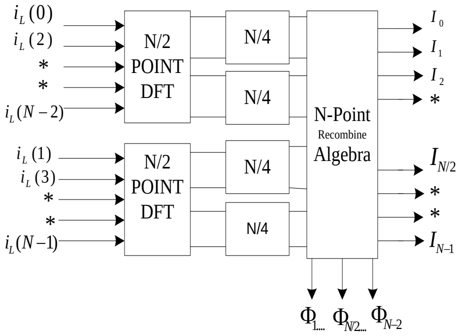

Figure 5: FFT based reference current calculation criteria.

Wavelet transform (WT): The basic functions of wavelet transform are waves localized in time and frequency. Wavelet is a rapidly decaying signal with waveform of limited duration and having zero average value [31]. The disadvantages of wavelet transform based reference current generation is: performance depends upon the design of mother wavelet.

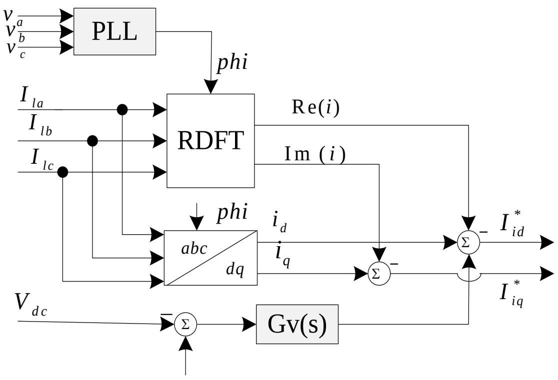

Figure 6: The RDFT based reference signal calculation.

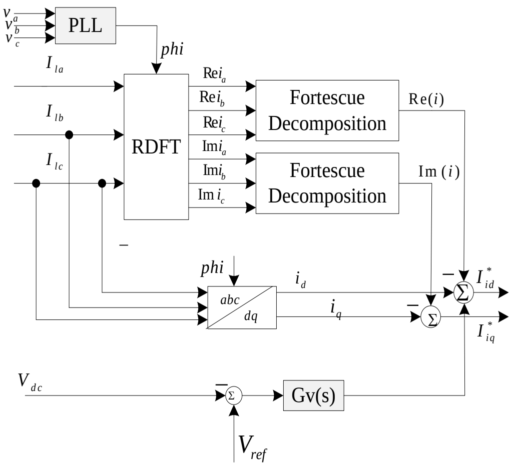

Figure 7: Fortescue decomposition combined RDFT based reference signal generator.

4. Modern Current Generation Techniques

Soft computing based approaches are among the most commonly used modern computing techniques.

Artificial neural network based techniques: ANN based Active filter control approaches are very popular parallel computing techniques due to their ability to learn and model linear and complex relationships [32]. The most commonly used structures of ANN are ADALINE and MADALINE. Least mean square and back propagation algorithms are used for training of ADALINE and MADALINE structures respectively [33-35]. Figure 8 (a) and 8 (b) shows the basic structure of ADALINE and MADALINE respectively.

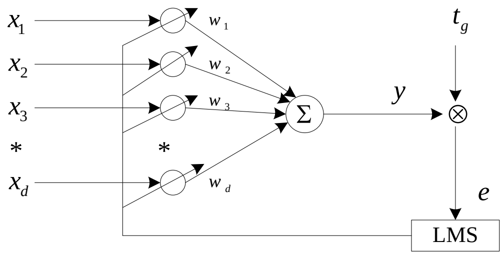

Figure 8 (A): Structure of ADALINE.

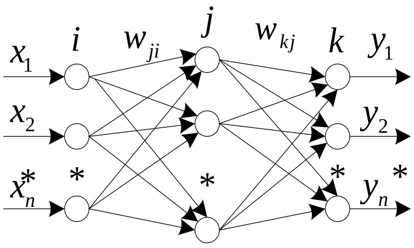

Figure 8 (B): Structure of MADALINE.

The disadvantages of ANN based current reference generation techniques are: low convergence rate and local minima can occur during error minimization.

In [36], implementation of control algorithms for ADALINE and Feed forward MNN has been proposed to extract fundamental harmonic components from load current. Moreover, performance is studied using MATLAB/Simulink environment.

Adaptive filtering method: This technique is very efficient for current reference generation in SAPF [37]. Reference current is extracted by making sine and cosine functions from load current. Adaptive filtering provides the adequate results for distortion in source voltages but sensitive to frequency fluctuations. Local minima can occur during convergence. Figure 9 shows the adapting filtering technique for reference current generation.

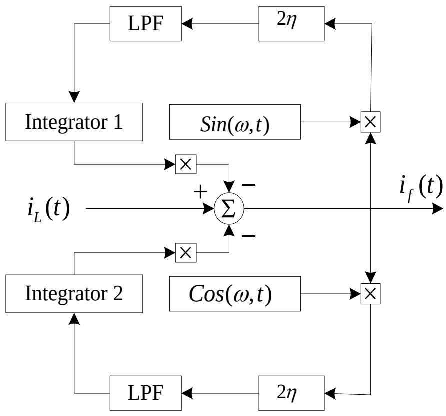

Figure 9: Adapting filtering technique for reference current generation.

5. Voltage and Current/VSI Control

In SAPFs, the purpose of current and voltage control is follow predefined reference currents and voltages by comparison of reference valves with actual one. The most commonly used voltage and current control approaches are discussed in following sub sections.

PI Controller: In Proportional integral control scheme, to regulate dc link voltage and source current estimation, initially an error signal is generated; by comparing reference voltage V_{ref} with dc link voltage V_{dc} and later on this steady state error is processed using PI controller. The drawbacks of PI controller are: linear mathematical modelling is very difficult and complex, sensitive to unbalance and parameter variations.

Fuzzy Controller: Fuzzy controller consists of Fuzzification, interface mechanism and Defuzzification units. The basic representation of structure of fuzzy controller is figure 10. The generated voltage error signal is input to fuzzy controller, Fuzzification unit maps the input error signal into fuzzy sets, Interface mechanism applies fuzzy control action to process the fuzzy sets, Defuzzification unit convert the fuzzy output from interface mechanism to required control signals [38].

In [39], the performance investigation of SAPFs said that TS fuzzy controller produce better response at less computational time and required less number of fuzzy sets and rules as compared to mamdani and PI controllers.

ANN controller: Adaptive controllers can also be used for current control. In [40], a three layer structure of ANN has been proposed for current control mechanism and Levenberg- Marquardt algorithm is used for error minimization by adjusting adaptive weights of network. Technically it is discussed that ANN based current controller produce better results in terms of Percentage THD as comparison with predictive and Hysteresis controllers.

In [32], to enhance the performance of SAPF during transient conditions, dc link voltage is controlled using ANN control and ANN is trained using PI data.

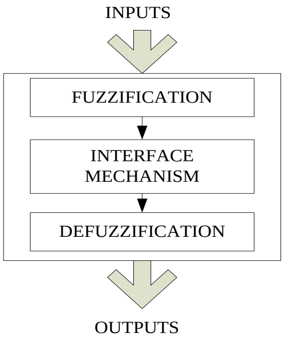

Figure 10: Fuzzy controller.

6. Conclusion

In this paper, a comprehensive study on SAPF control strategies has been presented, which covers a deep understanding on various current reference generation, voltage and current control approaches required for maintaining effective operation of SAPFs. In present scenario current harmonics and reactive power are the major problems related to power quality. Shunt active power filer is a best solution to deals with following power quality problems. It provides a robust operation with reliable performance

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