Implementation of a Novel Control Strategy for Shunt Active Filter

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ABSTRACT

Use of nonlinear loads, such as thyristor controlled inductors for FACTs devices, converters for HVDC transmission and large adjustable speed motor drives, is expected to grow rapidly. All of these loads inject harmonic currents and reactive power into the power system.

This paper presents a new control scheme for a 3 phase parallel active filter. The presented control system is able to compensating current harmonics, reactive power and current unbalance of non linear loads. The conventional controllers based on pq theory need more calculations, since they need the use of Clark transformation (abc to αβ transformation). The proposed control system is very simple and therefore practical implementation of active filters is available. The presented simulation and experimental results show the validity of control strategy. In this paper the PSCAD/EMTDC program and LAB VIEW software are used for simulation and hardware implementation, respectively.

Keywords: Shunt Active Filter, Harmonic Compensation, Power Factor Correction, Lab View software.

1. INTRODUCTION

In power systems, thyristor controlled inductors for static VAR compensators, converters for high voltage DC transmission line, large adjustable speed motor drivers and a variety of nonlinear loads are used widely in industrial plants. These devices are major sources of current harmonics and low power factor in power system. Conventionally, passive filters were the choice for the elimination of harmonics and to improve power factor. These passive filters have the disadvantages such as large size, resonance and fixed compensation. Active filters avoid the disadvantages of passive filters by utilizing a switch mode power electronic converter to supply harmonic currents equal to those in the load currents [1-3]. Almost, all controllers developed by other authors, for active filters use the pq theory [4, 5]. The major disadvantages of active filter controllers based on pq theory are:

1. These need to low pass filters to separate the average and oscillating parts of instantaneous powers. This factor introduces time delays and therefore, the dynamic performance of active filter is not guaranteed.

2. These demand more calculation, since they need the use of Clark transformation, and are not suitable for hardware implementation. This paper presents a simple control scheme for shunt active filter. In active filter the main object is to maintain sinusoidal and unity power factor supply currents. The simulation and experimental results, carried out by PSCAD/EMTDC simulation program [6] and LAB VIEW [7] software respectively, show effective and validity of presented control system. The steady state and transient performance of the proposed control scheme is found quite satisfactory to eliminate the harmonics, unbalances and reactive power components from source currents.

2. BASIC CONFIGURATION OF ACTIVE FILTER

The basic configuration of shunt active filter is shown in Fig.1. The AF is composed of a standard 3-phase voltage source inverter bridge with a DC link capacitor to provide a effective current control. The shunt active filter generates the compensating currents ica, icb, icc to compensate the load currents ia, ib, ic in order to guarantee sinusoidal, balanced, compensated currents isa, isb, isc drawn from the AC system. For the 3- phase ungrounded system only two current sensors could be used, since ic=−ia−ib. The non linear load is combination of RL load supplied by 3-phase controlled rectifier and a 3-phase unbalanced RL load.

3. PROPOSED CONTROL SYSTEM

The presented control system of shunt active filter is concise and requires less computational efforts than many others found in the literature. It is formed by a DC voltage regulator and reference current calculation box. Also, closed loop PWM is used for generating switching signals of AF to force the desired cur-
rents into the AF phases. The compensating currents of AF are calculated by sensing the load currents, DC bus voltage, peak voltage of AC source (Vs_m) and zero crossing point of source voltage. The last two parameters is used for calculation of instantaneous voltages of AC source as below:

\[ v_{sa}(t) = Vs_m \sin(\omega t) \]
\[ v_{sb}(t) = Vs_m \sin(\omega t - 2\pi/3) \]  
\[ v_{sc}(t) = Vs_m \sin(\omega t - 4\pi/3) \]  

In order to compensating the current harmonics and reactive power of load the average active power of AC source must be equal with \( P_{Lav} \). With considering the unity power factor for AC source side currents the average active power of AC source can be calculated as bellow:

\[ P_s = 3/2Vs_mI_{smp}^* = P_{Lav} \]  

From this equation, the first component of AC side current can be obtained and named \( I_{smp}^* \).

\[ I_{smp}^* = 2/3P_{Lav}/Vs_m \]  

The second component of AC source current \( I_{smd}^* \) is obtained from DC capacitor voltage regulator as Fig.2.

\[ i_{ua} = v_{sa}/Vs_m \]
\[ i_{ub} = v_{sb}/Vs_m \]
\[ i_{uc} = v_{sc}/Vs_m \]
\[ i_{ua}^* = I_{smp}^*i_{ua} \]
\[ i_{ub}^* = I_{smp}^*i_{ub} \]
\[ i_{uc}^* = I_{smd}^*i_{uc} \]

Finally, the reference currents of AF can be obtained as equation 10.

\[ i_{ca} = I_{ca}^* - i_{La} \]
\[ i_{cb} = I_{cb}^* - i_{Lb} \]
\[ i_{cc} = I_{cc}^* - i_{Lc} \]

With noticing to above equations the control block diagram of shunt active filter can be redraw as Fig. 3.
4. SWITCHING STRATEGY OF CONVERTER

There are two basic control strategies that can be used to control the switching of semiconductor switches in the converters.

1. Pulse Width Modulation (PWM) method.
2. Phase Control Strategy.

GTO switches operate adequately at the low switching frequencies required in phase control, but present losses at the high switching frequencies needed for PWM control. However, recent advances in high voltage semiconductor technology have led to the development of the Integrated Gate Commutated Thyristor (IGCT) and Insulated Gate Bipolar Transistor (IGBT), which is basically an optimum combination of thyristor and GTO technology at low cost, low complexity and high efficiency.

It can handle higher switching frequencies with relatively low losses, allowing for the practical implementation of PWM control methodologies.

In the phase control approach in order to generating the output voltage waveforms with low harmonics, must be used multi connected phase shifted converters with a common DC link and coupled through appropriate magnetic circuits.

The PWM technique is based on fast switching of semiconductor switches to produce an output voltage waveform with low harmonic, which depends on the number of notches per cycle. The advantage of this technique is that it allows independent and easy control of active and reactive power components, provided that the DC voltage is kept constant and sufficiently high.

In this paper we use a closed loop carrier based PWM technique for tracking the computed currents by AF. Presented PWM technique scheme is shown in Fig.4. In this technique the difference of reference and measured currents is applied to a PI controller and its output signal is given to conventional carrier based PWM. In this paper the carrier signal is considered as triangle wave form with 1650 Hz frequency.

5. HARDWARE IMPLEMENTAION

The presented AF is contains a 3-phase voltage source IGBT based inverter and DC bus with a capacitor.

Since the IGBT is very sensitive device to variations of current and voltage, therefore it must be protected in face these parameters. For this propose we use a protection and Opto isolated driver device [8]. This device not only protects IGBT from over current and voltage but also isolates the base signals of IGBT from control system. Fig. 5 shows the protection and isolation circuit. In this paper for sensing the voltages and currents the Hall Effect sensors is used. The advantages of these sensors are:

1. Linearity.
2. They can be used in the AC and DC signals. For transmitting measured signals to the computer and gate pulses to inverter a Data Acquisition card (Axiom 5095P [9]) is used.

Fig. 6 shows the block diagram of designed hardware system.

The presented control system is implemented by LAB VIEW software.

6. SIMULATION AND EXPERIMENTAL RESULTS

A power system corresponding to Fig.7 was simulated. Table 1 shows the test system and active filter parameters. The nonlinear load configuration is described in figure 7.

Fig.8 shows the simulation results carried out by PSCAD/EMTDC simulation program. This figure shows AC source voltage, load current, source side current in the steady and transient states. These
Fig. 5: IGBT protection and isolation circuit.

Fig. 6: Block diagram of designed hardware system.

Table 1: Parameters of test system and active filter.

<table>
<thead>
<tr>
<th>System Voltage (v)</th>
<th>Rs + jLsw</th>
<th>CµF</th>
<th>Rp (Ω)</th>
<th>Lp (mH)</th>
<th>Cp (µF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>1 + j.63</td>
<td>200</td>
<td>5</td>
<td>10</td>
<td>16</td>
</tr>
</tbody>
</table>

Results show that source currents always remain sinusoidal and lower than the load currents. In this simulation nonlinear load is considered a 3-phase full controlled rectifier with fire angle 30 degree. Fig. 9 presents the reference current of active filter for phase a. Fig. 10 shows the DC link capacitor voltage. It can be seen that the presented control system can properly regulate the DC link capacitor voltage. Fig. 11 shows the experimental results of designed AF by LAB VIEW software. A suddenly changing in the fire angle of rectifier (from 30 o to 90 o) is applied and the experimental results show fast response of AF with presented control system. Figures 11a, 11b, 11c and 11d show load currents, source currents carried out from control system, experimental source currents and injected current by active filter, respectively. From these figures are seen that presented control system and its hardware implementation have fast dynamic response. Figures 12a and 12b reveal the harmonic spectra of load currents before and after changing in the fire angle of rectifier (it is used in nonlinear load). Figures 13a and 13b describe the harmonic spectra of source currents before and after changing in the fire angle of rectifier. It can be observed from the harmonic spectra of currents that, presented algorithm is effective to meet IEEE519 standard recommendations on harmonic level. Fig. 14 shows the experimental DC capacitor voltage. It can be seen that the presented control system is capable to regulating DC link voltage. The presented experimental results show the validity and effectiveness of presented control system and simulation results.
Fig. 7: Test power system configuration

Fig. 8: AC source side currents, load current, voltage and current of source.

Fig. 9: Reference current of active filter for phase a.

Fig. 10: DC link capacitor voltage.

Fig. 11: (a) Load currents.
(b) Source currents carried out from control system.
(c) Experimental source currents.
(d) Injected currents by active filter for phase a.
7. CONCLUSION

In this paper a simple control system of AF is presented. In the presented control system the number of equations is reduced, since it does not use any transformation, such as park transformation. Therefore the presented control system is very suitable for the hardware implementation.

In this paper both simulation results carried out by PSCAD/EMTDC and experimental results are presented.

These results show the validity and effectiveness of presented control system of AF for compensation of harmonic currents, reactive power and unbalance currents.

References

Ali Ajami was born in Tabriz, Iran in 1973. He received B. Sc. and M. Sc. degrees from electrical and computer engineering faculty of Tabriz university, Iran in the electronic engineering and power engineering at 1996 and 1999 respectively. He received the P.H.D. degree at 2005 in the electrical and computer engineering faculty of Tabriz university, Iran in the power engineering. In 2006 he joined the electrical engineering department of Azarbijan University of Tarbiat Moallem, Iran. His main research interests include the dynamic and steady state modeling and analysis of FACTS devices such as SSSC and STATCOM, UPFC, harmonics and power quality compensation systems such as Active Filters, UPQC. He has over 30 papers in journals and conferences.

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Professor Hosseini was born in Marand, Iran in 1953. He received the M.S. degree from the faculty of Engineering University of Tabriz, Iran in 1976, the DEA degree from INPL, France, in 1981 and Ph.D. degree from INPL, France, in 1981 all in electrical engineering. In 1990 he joined the University of Tabriz, Iran, as an assistant professor in the Dept. of Elec. Eng., from 1990 to 1995 he was associate professor in the University of Tabriz and since 1995 he has been professor in the Dept. of Elec. Eng. University of Tabriz. From Sept. 1990 to Sept. 1991 he was visiting professor in the University of Queensland Australia; from Sept. 1996 to Sept. 1997 he was visiting professor in the University of Western Ontario Canada. His research interests include Power Electronic Converters, Reactive Power Control, Harmonics and Power Quality Compensation Systems such as SVC, UPQC, FACTS devices and Active Filters. He is IEEE member and has over 200 papers in journals and conferences.