Real Time DSP Based Implementation of a New Control Method of Active Power Filter

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Abstract - This paper deals with a DSP based implementation of a new control method of a 3-phase active filter (AF) to compensate harmonics and reactive power of non-linear loads. A current controlled voltage source inverter (CC-VSI) based configuration is used as the AF and PWM current control technique is used to derive gating signals to the devices of the AF. A 3-phase diode bridge rectifier with resistive-inductive loading is taken as the non-linear load. Steady state as well as transient test results on a developed prototype are given to validate the new control method for the AF.

I. Introduction
The use of solid state power conversion is rapidly increasing in adjustable speed drives (ASDs), power supplies etc. These solid state converters inject harmonics and cause low power factor of ac mains. The Active Filter (AF) has been considered as a standard solution in the last two decades [1-6]. Several topologies of Active Filters (AFs) such as active shunt, active series, hybrid of active series with passive shunt, unified power quality conditioner (UPQC) and multistep are reported either in current source inverter (CSI) or voltage source inverter (VSI) configurations [6]. Several control approaches, namely instantaneous power theory [2], notch filters [3], flux based controller [4], predictive current control [5] have been implemented to control AFs. Most of these controllers [2-6] need a number of transformations and are complicated in implementation. In this paper, a simple and straightforward control algorithm is implemented for an active shunt filter to compensate the harmonics and reactive power of a typical non-linear load. A TMS320C31 DSP [7] with five ADC channels and three DAC channels is used to implement the proposed control algorithm. An IGBT based VSI with PWM current control is employed to realize the AF. A 3-phase diode bridge rectifier with R-L loading is taken as a non-linear load. The control algorithm is tested through simulation and thereafter, experimental verification is also carried out.

II. Control Strategy
Fig. 1 shows the developed control algorithm of the AF.

Fig. 1 Control Scheme of the Three-phase Active Filter as Implemented by the DSP
2.1 Description of Control Algorithm

The sequence of implementation of control algorithms is shown in Fig. 1. The main functions of the software implementation are the following.

- Sense the dc bus voltage \( (v_{dc}) \), two-phase ac supply voltage \( (v_{sa} \) and \( v_{sb} ) \) and two-phase ac load currents \((i_a, i_b)\) from ac supply voltages \( (v_{sa}, v_{sb} \) and \( v_{sc} ) \).
- Compute peak of supply voltage \( (V_{sc}) \) and three-phase unit current vectors \((u_{sa}, u_{sb} \) and \( u_{sc} )\) from ac supply voltages \( (v_{sa}, v_{sb} \) and \( v_{sc} ) \).
- Compute instantaneous load power and add to previous value of it.
- At the time of an interrupt signal, compute average load power and dc bus voltage of the AF. Compute the previous value of it.
- Compute instantaneous reference supply currents \((i_{sa}^*, i_{sb}^* \) and \( i_{sc}^* )\) using their amplitude \((I_{zm}^*)\) and unit current vectors \((u_{sa}, u_{sb} \) and \( u_{sc} ))\.
- Compute instantaneous AF reference currents \((i_{ca}, i_{cb} \) and \( i_{cc} ))\) using the sensed supply voltage as:
  \[
  V_{sc} = \frac{2}{3}(v_{sa} + v_{sb} + v_{sc})
  \]

From the amplitude of the supply current \( (I_t) \) and along with the unit current vectors \((u_{sa}, u_{sb} \) and \( u_{sc} ))\), the 3-phase reference supply currents are computed as:

\[
4 = C_{i_{sa}^*} u_{sb} \text{ and } 4 = I_{sm} u_{sc}^* \]

The reference AF currents are computed as:

\[
\begin{align*}
  i_{ca}^* &= i_{ca} - i_{la}^* \cdot i_{cb} = i_{sb} - i_{lb} \cdot i_{cc} = i_{sc} - i_{lc}
\end{align*}
\]

These 3-phase reference AF currents after proper scaling are sent to the 12-bit DACs and fed to the PWM current controllers.

111. Performance of AF System

The mathematical model of the AF system is developed and simulated results are obtained. Experimental validation of simulated results is also carried out with the help of a laboratory prototype of the AF system. The following tests are performed on the laboratory model with a view to examining the performance of the AF system.

3.1 Steady State Performance of AF

Active power filters are mostly employed for steady state conditions of the non-linear loads, therefore steady state performance of the AF system is expected to be good and system should be capable of compensating the harmonics and reactive power of the non-linear loads. Fig. 2 shows the steady state response of the system with 61 V (rms) at the input of the laboratory prototype. This figure shows experimental as well as simulated results. Fig. 2(a) shows simulated results of the system during steady state, while Fig. 2(b) relates to its experimental counterpart. Supply voltage \( v_{sa} \), supply current \( i_{sa} \), load current \( i_{lb} \), and filter current \( i_{lc} \) for phase V are shown in this figure. From this figure it is revealed that the supply current is close to sinusoidal and it remains in phase with the supply voltage therefore unity power factor is maintained at the output of supply system. The AF supplies the reactive power demand of the load locally and compensates its harmonics thereby bringing down the THD (total harmonics distortion) of supply current to 10.3% from 29.1% (THD of load current). Values of all the quantities of interest are shown in this figure. It is also observed in this investigation that the laboratory prototype consumes only 50 watts (at 30 V supply voltage) and 90 watts (at 61 V supply voltage). This is necessary for a self supporting dc bus of AF. The switching frequency at which the AF offers best performance is 11.2 kHz. The relative reduction of various harmonics is given in Table 1.
From the measured results shown in Fig. 2 and Table 1, it is confirmed that the AF designed and developed in the present investigation offers desired performance with the new control algorithm proposed in this paper.

3.2 Transient Response of AF System
The laboratory prototype is tested for variation in the load current. In practice the load changes with time. With a view to this it is considered necessary to examine the performance of the system for the case pertaining to variations in the non-linear load. Fig. 3 shows the response of the system when the load power is increased from 1.35 kW to 1.95 kW. It is observed from this figure that as soon as load current is increased supply current also increases. In response to this the AF current is also increased in order to meet the increased amount of harmonics and reactive power of the load. It is observed that there is smooth changeover from the old condition of the load to its new value. The values of all the quantities of interest are shown in this figure.
IV. Conclusions
A new and simple control algorithm for the shunt AF has been simulated and validated on a DSP based system. It is found that the AF can effectively eliminate the harmonics and compensates for the reactive power of the load resulting in unity power factor and sinusoidal supply currents. The relative reduction in the different harmonics has been shown in order to establish the effectiveness of the AF. It has been also found that the new control technique takes care of the cycle to cycle energy balance in dc link of the AF thereby providing a self supporting dc bus voltage, which is necessary for proper current control. It is hoped that new control method of AF system developed in this investigation will find applications wherever non-linear loads are fed from ac mains to overcome the problems of harmonics and reactive power.

V. Appendix
The system parameters are given here:
$L_1 = 3.94$ mH, $R_1 = 0.1$ ohm, $C_1 = 3000$ micro farads, $L_2 = 8.3$ mH, $R_2 = 9.7$ ohms (at 1.95 kW load power) and 14.2 ohms (at 1.35 kW load power), DSP computation time = 200 micro secs.

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VII. References