A Study on DSP Based Power Factor Improvement using Single Phase Active Power Filter

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Abstract— This project presents a technique for single phase power factor correction of non-linear loads employing an active power filter. The current control strategy is the same used in the boost pre-regulator, which is the average current mode technique. The project will focus on the design methodology and the analysis of the control strategy which allows the compensation of harmonics and phase displacement of the input current, for single and multiple non-linear and linear loads. Experimental results of an active filter controlling a 200W to 1KW rectifier with a capacitive filter, an 8OOW AC chopper and a 58OW multiple load, which consists of a rectifier with a capacitive filter and an AC chopper, are presented. In the last years the use of electronic equipment has been increasing rapidly. This equipment draws The current from the AC mains has harmonic components, which leads to low power factor, low efficiency, interference in some instruments and communication equipment by the EMI, overtaxed electrical-distribution systems, overheated transformers and electromagnetic fields. However, passive filters have many disadvantages, such as large size, resonance, and fixed compensation characteristics. Therefore, it does not provide a complete solution. The most usual single phase non-linear load is the frontend rectifier followed by a bulk capacitor, which draws current from the input during its charging. The boost pre-regulator is used to reduce the harmonic contents and improves the power factor. The current control loop consists in the average current mode technique. The boost pre-regulator has some disadvantage because it cannot be used in equipment already in service, and it is applied only to one kind of non-linear load which is the front end rectifier followed by a bulk capacitor. A very interesting solution is the use of a single-phase active power filter, which is connected in parallel with then on-linear loads. The active power filters concept uses in power electronics to produce harmonic components which cancel the harmonic components from the non-linear loads. It can limit harmonics to acceptable levels and can adapt itself in case of harmonic component alteration or even changes in then on-linear loads types. Usually the technique used to control the single-phase active filter senses the non-linear load current and calculates its harmonics. This project will focus on the design and the control strategy for a shunt single-phase active power filter.

Key words: Controller, control strategy, Harmonic reduction, power factor, active power filter

I. INTRODUCTION

In the last years the use of electronic equipment has been increasing rapidly. This equipment draws The current from the AC mains has harmonic components, which leads to low power factor, low efficiency, interference in some instruments and communication equipment by the EMI, overtaxed electrical-distribution systems, overheated transformers and electromagnetic fields. A classical solution is the use of passive filters to suppress harmonics in power systems. However, passive filters have many disadvantages, such as large size, resonance, and fixed compensation characteristics. Therefore, it does not provide a complete solution.

The most usual single phase non-linear load is the frontend rectifier followed by a bulk capacitor, which draws current from the input during its charging. The boost pre-regulator, shown in Fig.1 is used to reduce the harmonic contents and improves the power factor. The current control loop consists in the average current mode technique. The boost pre-regulator has some disadvantage because it cannot be used in equipment already in service, and it is applied only to one kind of non-linear load which is the front end rectifier followed by a bulk capacitor.

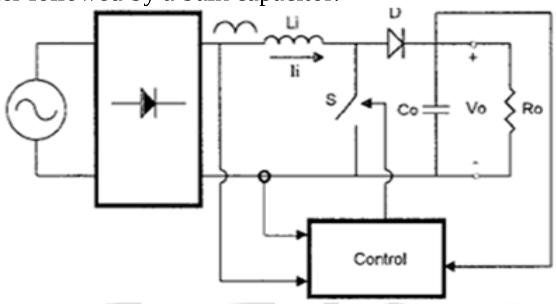

Fig. 1: Boost pre-Regulator

A very interesting solution is the use of a single-phase active power filter, which is connected in parallel with then on-linear loads as shown in Fig 2. The active power filters concept uses in power electronics to produce harmonic components which cancel the harmonic components from the non-linear loads. It can limit harmonics to acceptable levels and can adapt itself in case of harmonic component alteration or even changes in then on-linear loads types. Usually the technique used to control the single-phase active filter senses the non-linear load current and calculates its harmonics. This project will focus on the design and the control strategy for a shunt single-phase active power filter. The active filters are able to compensate the displacement of the input current in relation to the AC mains voltage and the harmonics components of single and multiple non-linear loads, through the sensing of the input current.

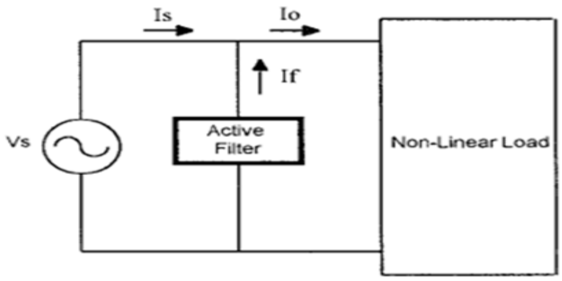

Fig. 2: single phase active filter

II. LITERATURE REVIEW

Literature survey of earlier research work made by various researches on power factor correction of non-linear loads employing a single phase power filter, power factor correction in audio applications, a novel technique of optimizing the harmonics and reactive power under non sinusoidal voltage condition, harmonic reduction system using active filter, advanced DSP based single phase power factor correction approach and DSP based algorithm for optimizing the harmonics and reactive power under non-sinusoidal supply voltage condition. This section presents the overview of the research work.

Fabiana Pottker and Ivo Barbi presented a design methodology of an active filter, its new control loops strategy, power factor correction of non-linear loads employing an active power filter, the analysis of the control strategy which allows the compensation of harmonics and phase displacement of the input current, for single and multiple non-linear and linear loads. Simulation results of an active filter controlling a single load, which consists of a 1600W rectifier with a capacitive filter, and a multiple load, which consists of 8OOW rectifier with a capacitive filter and a 8OOW AC chopper, are provided. Experimental results of an active filter controlling a 400W rectifier with a capacitive filter, 8OOW AC chopper and a 58OW multiple load, which consists of a rectifier with a capacitive filter and an AC chopper [1].

Bhim Singh, Kamal Al-Haddad and Ambrish Chandra A in this paper author found that, simple P-I controller based APF has been found effective to provide reactive power and harmonic compensation for the variety of loads. An excellent performance of APF system has been observed as a universal power-factor controller and an ideal reactive power compensator. APF is able to reduce the harmonics well below 5 % in all the cases of extremely reactive and harmonic polluted loads. APF has maintained sinusoidal supply current in phase with the supply voltage resulting in unity power-factor of the supply both in steady state and transient conditions. It is concluded that the proper selection of value of dc bus capacitor and P-1 controller parameters results in satisfactory performance of the APF system. Experimental verification of the proposed APF is being performed and test results will be reported in future [2].

T. Mahalekshmi in this paper the current harmonic can be compensated by using the Shunt Active Power Filter, Passive Power Filter and the combination of both. The system has the function of voltage stability, and harmonic suppression. The reference current can be calculated by dq transformation. An improved generalized integrator control was proposed to improve the performance of APF. The simulation results of the non- linear systems have been carried out with MATLAB [3].

Antonio P. Martins This paper addresses the problem of active filtering in low power single phase networks and medium/high power three phase networks. Harmonics generated by nonlinear loads are one of the major causes of a poor power quality. So, harmonic elimination, in the source or with active filtering, is needed to achieve a better power quality. Results obtained with a three phase active filter prototype show its effectiveness both in static and dynamic operation, namely with a high nonlinear load [4].

Vinod Gupta, Kamlesh Keharia, R. B. Kelkar and M. Ramamoorty in this paper a single-phase active power filter employed to correct the power factor of groups of loads is presented. The full-bridge voltage source inverter controlled through the sensor of the AC load current is used as the active filter. Sine multiplication theory is implemented using microcontroller. Theoretical analysis and experimental results of the active filter compensating for a group of loads validates the analysis. The main characteristics of the presented active filter are: the employed control technique is very simple and easy to implement, the AHF is able to compensate for the fundamental load current phase displacement and the load current harmonic distortion, a high power factor is achieved. Thought the proposed control technique has a drawback of slow initial response time i.e. one cycle for start of compensation but it is very efficient, cost effective and simple to implement for small distributed networks [5].

S. Srinath, S. Prabakaran, K. Mohan and M.P. Selvan in the present work, there is no separate measurement for the phase angle of supply voltage, which makes the controller implementation simple in real time. The simulation results show that the performance of SAF is satisfactory in elimination of source current harmonics and improving the input power factor. The experimental results confirm the satisfactory operation of SAF in distribution system with non linear loads. The SAF is found to be effective in both simulation and practice to meet IEEE 519 standard recommendation on harmonic levels in source current [6].

Joao L. Afonso, H. J. Ribeiro da Silva and Julio. S. Martins this paper deals with problems related with harmonics in power system networks. Several international standards issued to control power quality problems are briefly described and some important methods to analyze electrical circuits with non-sinusoidal waveforms are introduced and evaluated. One of these methods - the p-q theory -was used to implement the control algorithm of a shunt active filter, which is also described in this paper as an application example. The filter can compensate for harmonic currents, power factor and load unbalance. Both simulation and experimental results are presented, showing that good dynamic and steady-state response can be achieved with this approach [7].

Michael C. Pacis, Jesus M. Martinez Jr., and Jaypee V. Tecson this study aims to create three models of active power filters that compensate the harmonics, mitigate the voltage sags and swells, and also correct the power factor. The models were simulated to know which of the three active power filter models gives the best performance. The simulation tools that were used in this study were MATLAB/Simulink and TINA PRO. Based on the results, the active power filter models compensate the harmonics, mitigate the voltage sags and swells, and correct the power factor of the system. Evaluating the models, the active power filter Model-A gave the best performance by reducing the total harmonic distortion of the system [8].

III. PROPOSED SYSTEM

A. *Block Diagram Description*

The diagrammatic representation of power factor of nonlinear load using active power filter as shown in fig.1 in this fig the active filter is connected in parallel to AC mains. The converter which is used as the active filter is a full bridge voltage source inverter due to current reversibility characteristics. The boost pre-regulator is used to reduce the harmonics and improves the power factor. And the active filter is cancelling the harmonics components from nonlinear load. A current transformer (CT) is used for measurement of alternating electric currents. Potential transformers (PT) (also called voltage transformers (VT)) are a parallel connected type of instrument transformer. Isolation amplifiers are a form of differential amplifier that allows measurement of small signals in the presence of a high common mode voltage by providing electrical isolation and an electrical safety barrier. In this project we use DSP controller. The controller DSPIC33FJ64MC is used for control strategy a regulated power supply is an embedded circuit; it converts unregulated AC into a constant DC. With the help of a rectifier it converts AC supply into DC. On LCD we can see the result.

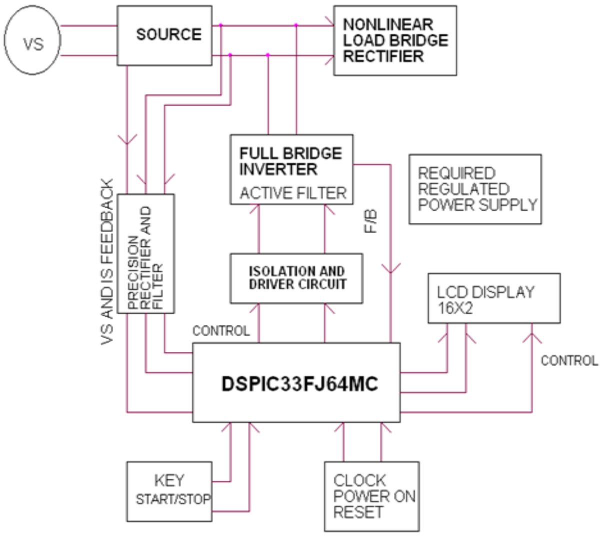

Fig. 3: power factor correction of nonlinear load using active power filters

1) *Active Power Filters Topology*

The converter, which is used as the active filter, is a full bridge voltage source inverter, due to its current reversibility characteristics. The full-bridge inverter is connected in parallel with the AC mains through a filter inductance Lf, and the DC side of the inverter is connected to a filter capacitor Cf, as shown in Fig 4. Thanks to the appropriate control of the full bridge switches, the current If cancels the harmonics components of the non-linear loads, resulting in a sinusoidal input current in phase with the AC mains voltage. The switching frequency is constant and the SI and S2 gate signals are complementary to S3 and S4 ones. If the output voltage of the active filter (VF) is kept constant, then the active power flowing in the active filter is zero. Thus, in the active filter flows a reactive power that cancels the reactive power generated by the non-linear loads, emulating a resistive load for the AC mains. The outer voltage loop consists in the comparison AF the voltage VF with a reference voltage. The resulting error is injected in an appropriate voltage controller. The output of the voltage controller is then multiplied by a sinusoidal signal proportional and in phase with the input voltage. The result of this multiplication is a reference current I ref. The inner current loop consists of the comparison of the reference current with the input current. The resulting error is injected in an appropriate current controller that in this case uses the average current mode technique. The output of the current controller is then compared with a triangular signal, generating the drive signals to the switches. The control strategy of the active filter allows the compensation of harmonics and phase displacement of the input current for any non-liner load and nonlinear load.

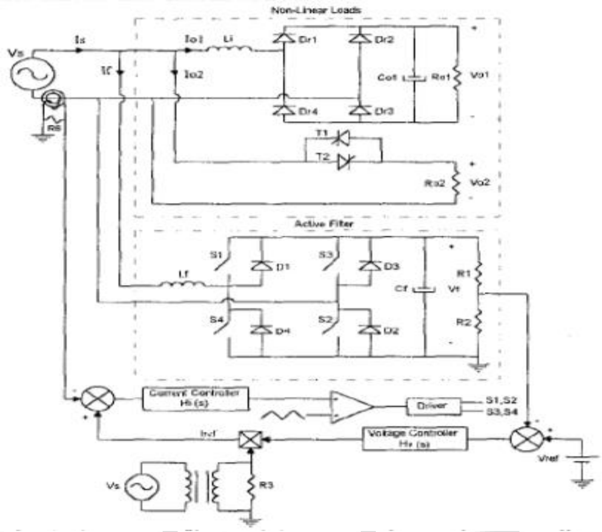

Fig. 4: Active power filter and the proposed control strategy diagram

2) *Relevant Analysis Results*

The relevant equations used to design the active filter; its outer voltage control loop and the inner current loop are presented below. The active filter capacitor Cf is calculated using equation (1). The voltage ripple is defined about 10% VF, Po is the active power of the non-linear load and fline is the frequency of the AC mains. The active filter inductance Lf is calculated using equation (2).AI is the maximum current ripple and f is the switching frequency. The smaller the inductance Lf, the better the ability to track the desired input current. However, the maximum ripple increases. The choice of the maximum current ripple depends on the harmonics components of the non-linear loads. The bigger the harmonic distortion of the load, the bigger should be the tolerated ripple; otherwise the inductor will not track properly the input current.

$$C_f \geq \frac{P_o}{2.f_{line}.\left(V_{f\,max}^{2} - V_{f\,min}^{2}\right)} \qquad (1)$$

$$L_f = \frac{0{,}5.V_f}{\Delta I_{max}.f_s} \qquad (2)$$

The DC voltage-to-inductor current transfer function is presented in equation (3). The controller is a one pole one zero configuration. The zero must be located at a small frequency (around 1 Hz), and the pole must be located at about two decades above the zero. The voltage controller transfer function is presented in equation (4).

$$G_v(s)=\frac{\Delta V_f(s)}{\Delta I_f(s)}=\frac{V_{S_{rms}}}{V_f}\cdot\frac{1}{C_f s^2} \quad (3)$$

$$H_v(s)=k_v\cdot\frac{(1+s/w_{zv})}{(1+s/w_{pv})} \quad (4)$$

The inductor current-to-duty- cycle (D) transfer function is presented in equation (5). As can be noticed the difference between this transfer function and the one obtained in the boost pre regulator is the gain. Thus the controller is the same used for the boost pre-regulator, which is a one, zero two poles configuration. However, due to the different gain, the position of the poles and zero are different. The zero must be located about two decades above the switching frequency, one pole is located at 0 Hz and the other pole must be located around the switching frequency. The current controller transfer function is presented in equation (6). The transfer function of the ac line current sampling effect is shown in equation (7) and must be taken in consideration in the current controller design.

$$G_i(s)=\frac{\Delta I_f(s)}{\Delta D(s)}=\frac{-2.V_f}{L_f}\cdot\frac{1}{s} \quad (5)$$

$$H_i(s)=k_i\cdot\frac{-(1+s/w_{zi})}{s.(1+s/w_{pi})} \quad (6)$$

$$H_e(s)=1-\frac{s}{2.f_s}+\left(\frac{s}{\pi.f_s}\right)^2 \quad (7)$$

IV. Conclusions

In this project would be presented a design methodology of an active filter and its new control loops strategy. The Experimental results of an active filter compensating an uncontrolled rectifier with RC filter would be used for validating the theoretical analysis. In despite of a simple control strategy, a high power factor is obtained. The active power filter combined with the control strategy is a very attractive solution, because a high power factor can be achieved to any type of non-linear load, including equipment already in service.

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