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# IMPLEMENTATION OF ADAPTIVE SLIDING MODE CONTROL THEORY ON SINGLE PHASE ACTIVE POWER FILTER

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**ABSTRACT**

*In recent years, active power filters has been widely studied. A lot of active power filtering methods has been proposed to reduce total harmonic distortion (THD) of source current and to improve the power factor on electrical system. Several advance control strategies are based on some advance technologies such as neural network, genetic algorithm and fuzzy logic. These advance control strategies gives high performance and flexible designs. On the contrary the cost of implementation of these control algorithms is very high.*

*The main aim of this paper is the application of the Adaptive sliding mode control theory to single-phase shunt active power filter, since this technique has been successfully applied to other areas of power electronics. Sliding mode controller is able to design a low cost active filter with low THD and high robustness under external disturbances. A complete analysis of sliding mode control theory is given and MATLAB/Simulink based simulation results are reported to verify the theory.*

***Keywords: Active Power Filter, , Power quality, Sliding mode controller***

## I. INTRODUCTION

Nowadays the use of non linear load is increased rapidly in industry and in electronic equipment. All the power electronic devices are considered as non linear load. Television, Refrigerator, Air Conditioner, Inverters, Printers, Fax machines are some example of non linear load[1]. Increased use of non linear load has increased the amount of distorted currents on electrical system.Therefore, interest has been shown as to the effect of power factor and the extent of harmonics currents being generated and injected in power lines.

Traditionally, passive filters have been used to compensate voltage and current harmonics generated by constant non linear loads. Passive power filters provide low impedance path for distorting harmonics in voltage and current, resulting in improvement of power quality. Passive filters can be easily designed and have low cost. However there are some drawbacks of passive filters such as

1. Mistuning
2. Resonance
3. Bulky implementation
4. No possibility of using same power filter for different load

These drawbacks of passive filters can be overcome by use of active power filters.

Several control topologies functioning with power semiconductor switches have been developed for high-quality requirement. These topologies are designed to call off the original voltage and current harmonics deformation by injecting the same detected deformation, but with reverse polarity, thereby recuperating the power quality. Active power filters are connected between source and load. Depending upon the type of connection it can be classified as:

1. Series Active power filter
2. Shunt Active power filter
3. Universal Active power filter

Shunt active power filters are most widely used solution to reduce current harmonics, while series active power filters are used to reduce voltage harmonics. Universal active power filters are used current harmonics as well as voltage harmonics. Shunt active power filters are usually applied to three phase systems whereas single phase active filters can be applied in adjustable speed motor drive.

Different control methods have been reported to control shunt active power filters. These can be classified as:

1. Time-Domain Control Techniques
2. Frequency-Domain Control Techniques

Both time-domain and frequency-domain control techniques have well-known disadvantages as these provide non-linear dynamics of the closed loop system.

Also some advance control methods have been reported, such as sliding mode control, artificial neural networks, and optimization. Of the above mentioned control methods, the sliding mode control have been extensively applied to the power converters because it has natural tendency to control time varying topologies. Sliding mode control is the non linear control strategy. The principle for applying sliding mode control strategy is to propose a sliding surface or switching function. Sliding mode control has inherent characteristics such as insensitivity to system parameters variation, robustness and simple control implementation. In this study, sliding mode control is proposed which leads to sliding surface which is linear combination of system state variables and the generated references. This control design results in sliding mode controller, which makes the system robust, insensitive to system parameter variation and simple implementation.

## II. DYNAMIC MODELLING OF ACTIVE SHUNT POWER FILTER

Dynamic modelling of a single phase shunt active power filter as shown in figure. 1. is described in this section. The filter capacitor voltage ($V_C$) must be adjusted at the value higher than the peak of the ac voltage source so as to control the inductor current ($I_L$) as at any instant point in a complete cycle. In the positive half cycle of the source voltage ($V_S$) i.e $V_S > 0$, $I_L$ can be made more positive by making $v_x = 0$ and $I_L$ can be stimulated towards zero by making $v_x = V_C$. In the negative half cycle of the source voltage i.e $V_S < 0$, $I_L$ can be made more negative by making $v_x = 0$ and $I_L$ can be stimulated towards zero by making $v_x = -V_C$. To analyze the operational mode of shunt active power filter, we define a switching function represented as:

$$U_i = \begin{cases} 1 \text{ if } T_i \text{ is ON} \\ 0 \text{ if } T_i \text{ is OFF} \end{cases}$$

Where i = 1, 2, 3, 4 denoting the switch number. We note that two switches from the same leg must operate complementary. Therefore we can write:

$$U_1 + U_2 = 1 \text{ and } U_3 + U_4 = 1 \quad (2.1)$$

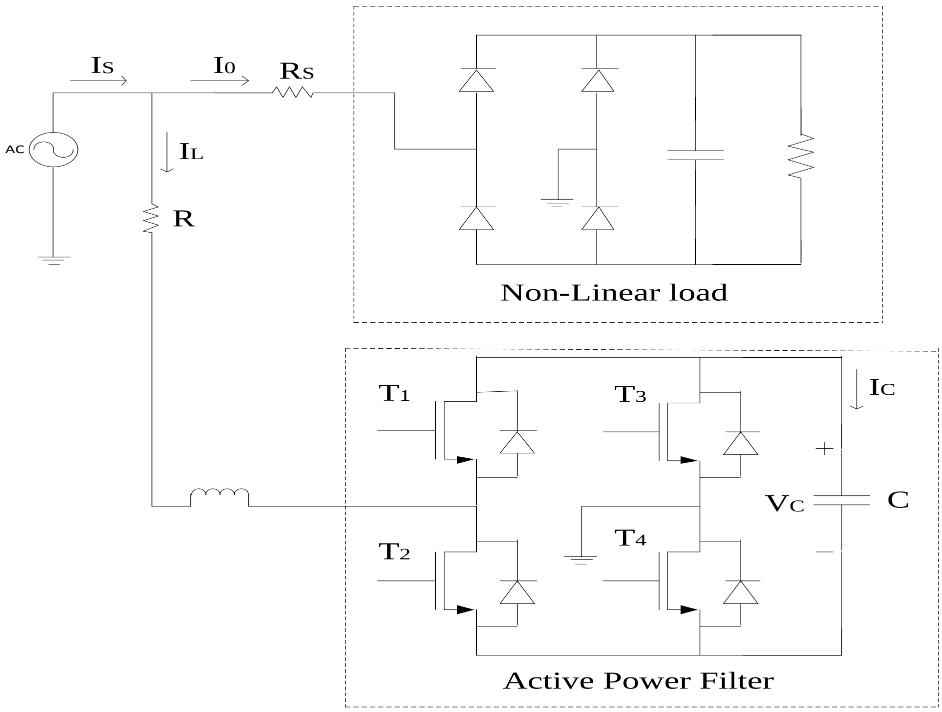


**Fig. 1 Shunt active power filter**

$$v_x = (U_1U_4 - U_2U_3)V_C \quad (2.2)$$

From equation (1.1) and (1.2) we get

$$v_x = (U_1 + U_4 - 1)V_C \quad (2.3)$$

The current flowing through filter capacitor ($I_C$) can be written as:

$$I_C = (U_1 + U_4 - 1)I_L \quad (2.4)$$

From expressions of $v_x$ (1.3) and $I_C$ (1.4), the dynamic state equations for the inductor current and capacitor voltage are as given below:

$$L\frac{dI_L}{dt} = V_S - I_L R - (U_1 + U_4 - 1)V_C \quad (2.5)$$

$$C\frac{dV_C}{dt} = (U_1 + U_4 - 1)I_L \quad (2.6)$$

Here $V_S$ is the source voltage.

Let $U_1 + U_4 - 1 = U$, the dynamic state model of shunt active power filter becomes:

$$\frac{dI_L}{dt} = \frac{1}{L}(V_S - I_L R - UV_C) \quad (2.7)$$

$$\frac{dV_C}{dt} = \frac{1}{C}UI_L \quad (2.8)$$

## III. ADAPTIVE SLIDING MODE CURRENT CONTROL OF ACTIVE POWER FILTER

The controller consists of two control loops. Outer voltage loop regulates the capacitor voltage and inner current loop tracks the reference current signal. To control the DC capacitor voltage PI controller is used and inductor current is controlled b the use of Sliding Mode control strategy.

The performance of the controller is improved by proposing a control algorithm based on sliding surface which depends on source current ($I_S$). Assume ($V_{DC}$, $I_S$) be the reference values of filter capacitor voltage and source current. The reference values assumed above are also known as equilibrium points of the control system. Now we calculate the error signal or error function $e_1 = I_S - I_S^* = 0$ which represents the sliding surface. Also it is found that system has steady state current error. So as to minimize the steady state error an integral term is introduced given by $e_2 = \int e_1 . dt$.

The proposed sliding surface or sliding function is given by:

$$S = e_1 + \lambda e_2 \text{ Or } S = e_1 + \lambda \int e_1 \quad (3.1)$$

Where $\lambda$ is a control parameter also known as sliding coefficient. Positive values of sliding surface coefficient ($\lambda$) ensures stability of active power filter. After deriving the sliding mode surface, now our aim is to define the control law based on three conditions. These conditions are as follows:

1. Reaching Condition
2. Existing Condition
3. Stability Condition

The main aim of the reaching condition is to bring the system trajectory towards the sliding surface. On reaching the sliding surface, to maintain the trajectory on sliding surface is the function of existing condition. As the trajectory reaches the sliding rule (a), follows the surface and finally settles at the equilibrium point.

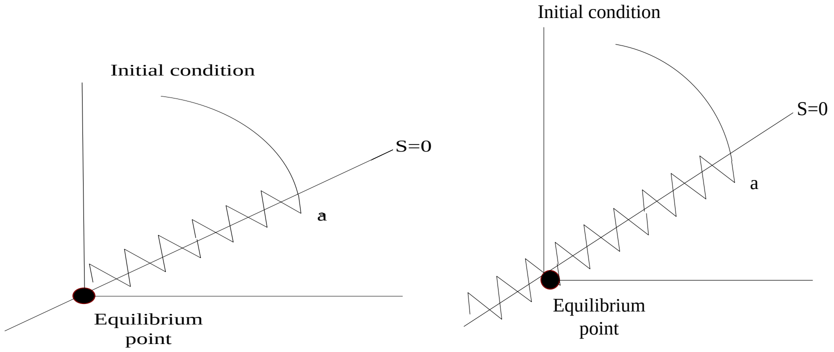


**Fig. 2. Sliding surface (a) Stable system (b) Unstable system**

The inequality which satisfies the existing and reaching condition of the system is given by:

$$\lim_{S \to 0} S . \frac{dS}{dt} < 0$$

## IV. Controller Design and Reference Current Calculation

In SM controller in order to satisfy the existence condition we usually determine as following:

$$U = \begin{cases} 1 \text{ if} & S > 0 \\ 0 \text{ if} & S = 0 \\ -1 \text{ if} & S < 0 \end{cases} \quad (4.1)$$

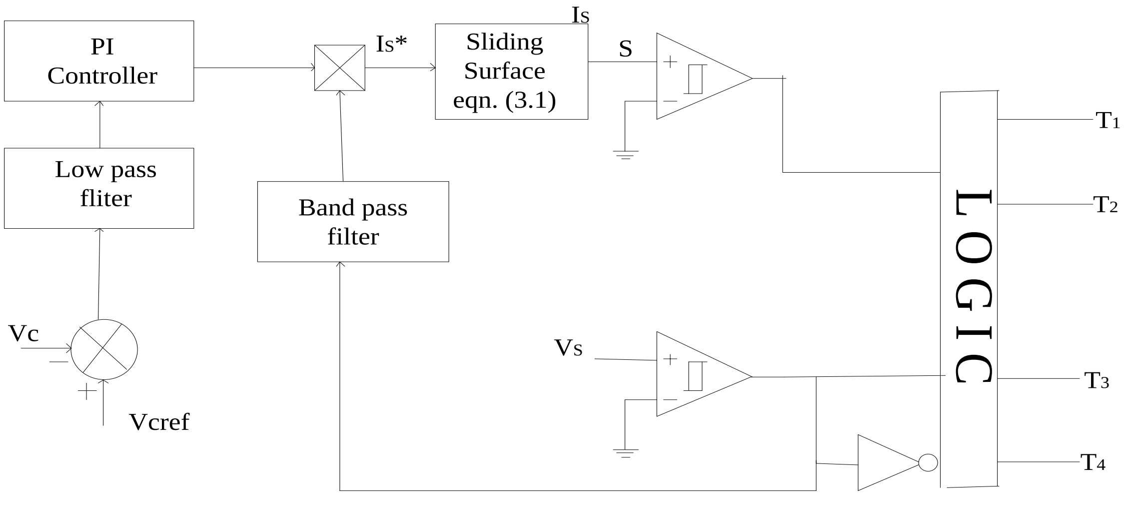


**Fig 3. Analog Sliding Mode Controller for Shunt APF**

The sign of $\frac{ds}{dt}$ should be controlled to satisfy the existence condition. This can be done by applying the control law given in 4.1. Switches of one leg of APF($T_3$,$T_4$) operates at source voltage frequency and that of other leg($T_1$,$T_2$)operate at high frequency. The control algorithm U makes the state trajectory to reach the sliding surface in finite time and then slides along the surface towards equilibrium point exponentially. The complete analog SM controller for single phase shunt APF is shown in fig. 3.

Fundamental component of the gate pulses to switch is in same phase to that of source voltage ($V_s$). So a band pass filter can be used to generate the fundamental component of gate pulse by filtering its harmonics. The characteristics of band pass filter have a significant effect on the active power filter performance. The bandwidth should be small enough to sufficiently attenuate the harmonic components of the reference current.

The capacitor voltage is put through a RC low pass filter which yields the average capacitor voltage. This quantity is compared to the reference capacitor voltage, with the difference driving the PI controller. The output of the PI controller is a slow varying variable which is the peak value of reference source current. This implies that the output of PI controller gives sum of peak value of fundamental load current and the peak value of source current required to compensate the real power loss in filter capacitor. As a result this slow varying variable is multiplied with the output of band pass filter to generate the desired reference source current.

As band pass filter is used to calculate reference current, small variation in amplitude of source voltage does not affect reference source current. This is why this active filter is applicable for both distorted and nominal source.

## V. SIMULATION STUDIES

To check the robustness and efficiency of the proposed analog SM controller, the complete shunt APF system is simulated using MATLAB/Simulink. The diode bridge rectifier having 500-μF capacitor is the non-linear load used in parallel with a 45-Ω resistor at its output side. The system parameters used in the simulation are given in Table1. Cut-off frequency of RC low pass filter has been set as 80 Hz. Cut-off frequency and bandwidth of band pass filter have been set as 50 Hz and 6 Hz respectively.

**Table1. System parameters used for MATLAB/Simulation in analog SM controller**

| | | |
|---|---|---|
| L= 5mH | $V_s^{RMS} = 110\ V$ | $\lambda = 2000S^{-1}$ |
| $V_{ref}$ = 200V | $f_{V_s} = 50Hz$ | $K_p = 0.5$ |
| C = 1100µF | $f_{Clock} = 40kHz$ | $K_i = 10$ |

The THD of the source voltage under ideal condition is found to be 0.11%. Similarly the THD of the load current considering up to 30th harmonics is calculated as 68.77%. Simulated load current and source voltage waveforms are shown in Fig.4 . it is cleared By application of proposed controller, the source current THD is reduced to 8.6%. Fig.5 shows source current and source voltage waveforms of the proposed analog SM controller.

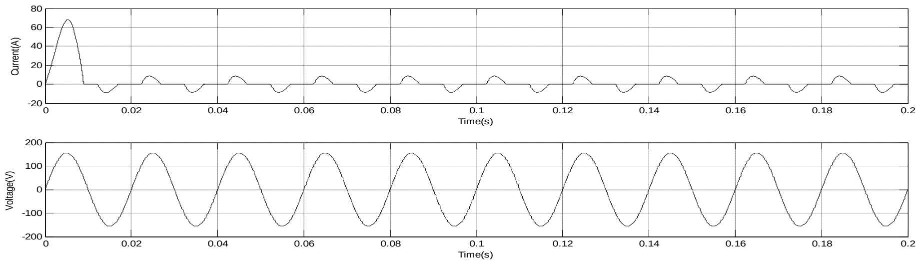


**Figure 4. Source Current and Source Voltage**

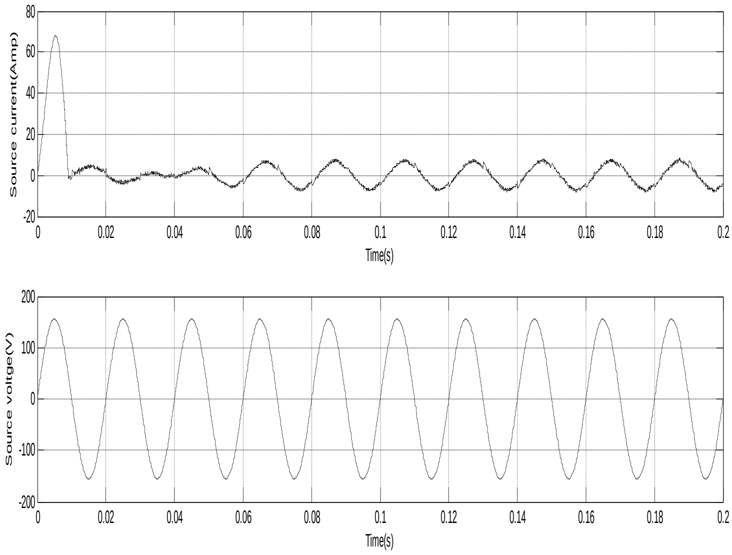


**Fig- 5. Source voltage and source current with proposed adaptive sliding mode control**

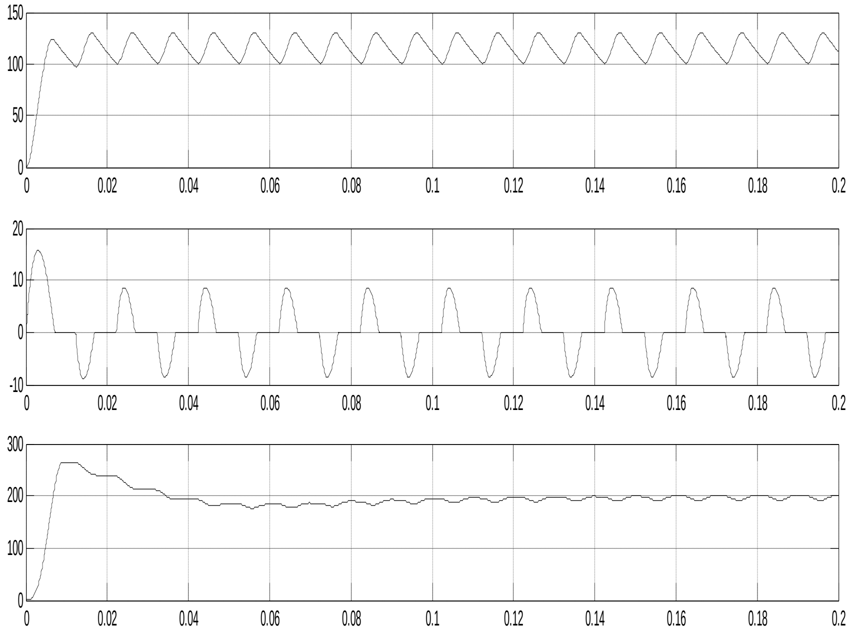


**Fig. 6.Filter Capacitor voltage (bottom), Inductor current (top) and load current**

## VI. CONCLUSION

In this work modified low cost analog SM controller for single phase shunt APF is presented. Basically two modifications have been carried out. One is the introduction of integral term in the sliding surface and another is the application of band pass filter in the reference current generation process. A brief explanation of SM current controller of APF and reference current generation method is reported. It is noticed from MATLAB/Simulink based simulation results that introduction of band pass filter in the reference current calculation method of APF makes THD of source current independent of THD of source voltage. MATLAB/Simulink based simulation results also verifies the reduction of steady state current error due to introduction of integral term in the sliding surface design.

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