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A Fuzzy Logic Controlled Sliding Mode Control (SMC) of Inverter in Shunt Active Power Filter for Power Quality Improvement

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Abstract: In this study, author proposes a fuzzy controlled sliding mode control of inverter in shunt active power filter in order to minimize the harmonics pollution and related effects in the utility which are caused by the rapid growth of active and non linear loads. we proposes a simple and new modeling approach based on Fourier transform applied to the inverter leading a state space model in the a-b-c frame. While, compared to d-q frame modeling approach, this alternative exhibit good dynamic response, simple to handle and robustness and stability. In addition the reference current is generated based on Fourier transform. Furthermore, the switching signals of the inverter are generated by sliding mode control concept and their stability condition is reviewed to prove its existence. This system is developed and simulated under MATLAB 7.3/SIMULINK package. The effectiveness of this proposed control system is high lighted in terms of THD in the source current through simulation results.

Key words: Power quality improvement, fuzzy control, harmonics, shunt active power filter, sliding mode control, total harmonics distortion

INTRODUCTION

Taditionally the majority of power consumption has been drawn by linear loads such as incandescent lighting and ac motors. This situation is rapidly changing as modern loads typically contain power electronic devices. In industry, harmonics cause excess heating in motors and transformers and can lead to overloading of neutral conductors in power lines (Arrillaga *et al*., 1985). In addition with the growth of active and non linear loads, the performance has been considered as an essential component in a power distribution Installation, because of the presence of high order Harmonics produced by the non linear loads. Harmonic elimination techniques have been widely studied and traditional solutions such as passive filters have many well known disadvantages (Fujita and Akagi, 1991). In order to reduce those effects and improve the power quality the active filtering technology is emerged. The concept of using active power filters has been so far investigated and shown to be a viable solution for power quality improvement (Singh *et al*., 1999). In connection with the control of Shunt active filters, traditional solution such as PID family of controllers are dipped due to its well known disadvantages (Sen, 1999) in order to reduce the limitation, Sliding Mode Controllers (SMC's) were introduced (Hung *et al*., 1993).

In addition, sliding mode control is theoretically excellent in terms of robustness and disturbance rejection capabilities. In this study, this control technique is hence used and developed. In addition here in this study fuzzy control is used due to the advantage of fuzzy control is that it is based on a linguistic description and does not require a mathematical model of the system. Fuzzy together with the sliding mode control is used to improve the power quality is a distribution system. A recent advance in semiconductor technology like IGBT, GTO allows us constructing active filters for power quality improvement (Duke and Round, 1993).

PROPOSED SYSTEM MODELLING

This study develops a model for the voltage source inverter that is used as the active power filter this is usually connected in between the source to the load as shown in Fig. 1. This study has elaborated the modeling of individual components involved in this proposed system.

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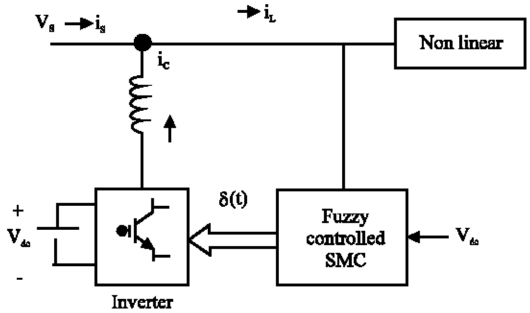

Fig. 1: Schematic diagram of proposed system

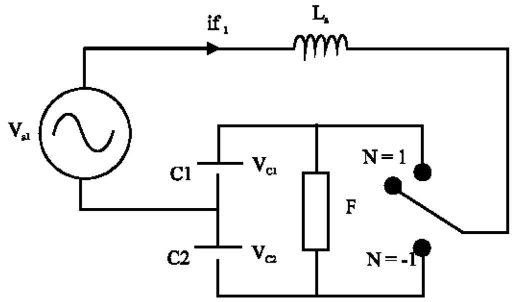

Fig. 2: Equivalent circuit for shunt active power filter modeling (one phase)

Non linear load: Usually Load is connected at the end of the distribution system. Here, Non linear Load is modeled by constructing the three phase uncontrolled rectifier with RL load.

Shunt active power filter: Voltage source inverter with dc bus is considered as a shunt active filter. As the name itself we usually connect this in parallel with the load. the connection is shown in their schematic diagram. Here we use IGBT for switching purpose. Here shunt active filter is switched such that the harmonics in the source current is reduced using fuzzy logic. Sliding mode control concept is used to generate the gating signal. The equivalent circuit for the operation mode described is shown in Fig. 2.

For the sake of simplicity, we just take one phase leg only. The position of the switch defines 2 structures

When $u_i = 1$ (i = 123), S is "on positive"
When $u_i = -1$ (I = 123), S is "on negative"

Design of shunt active power filter (SAPF): As for as the design of SAPF concerned, there are 3 steps:

- Reference current generation.
- Actual filter current extraction.
- Switching signal generation.

Reference current generation: Harmonics current is taken as the reference current which is due to non linear load. In this study, we use a simple and new modeling approach which is based on Fourier analysis. The load current i_L can be written using Fourier transform as:

$$i_L = \hat{I}_{L1}\cos(wt) + \sum_{n=2}^{\infty} \hat{I}_{Ln}\cos\left[n\left(wt + \varphi_n\right)\right] \quad (1)$$

Using Fourier transform of the inverter current gives K state variables. Where K is the rang of harmonics for compensation. Using Kirchhoff s laws at the connection Point between the supply, the load and the active filter, one can write:

$$i_s = \beta v_S = I_L + i_f \quad (2)$$

The filter reference $\overset{*}{i}_f$ is therefore expressed as:

$$\overset{*}{i}_f \,(\beta_{vs} - I_{Lf}) - i_{Lh} \quad (3)$$

Where,
i_{Lf} : Represent the fundamental components.
i_{Lh} : Represents all harmonic components of the Load. current.

Let,

$$I_c = \beta v_S - I_{Lf} \quad (4)$$

Where,

$$I_c = I_c \cos(wt) \quad (5)$$

is the fundamental active current for the regulation of vc

$$\overset{*}{i}_f = i_c - i_{Lh} \quad (6)$$

Actual filter current extraction: The instantaneous filter current is obtained by the application of Kirchhoff s laws at the connection point gives:

$$\frac{dif_i}{dt} = \frac{1}{Ls}\left(V_{si} - \frac{v}{2} - \frac{vc}{2}u_i\right) \quad (7)$$

Where,
dif_i = Represent the instantaneous filter current.

Switching signal generation: We use sliding mode control for generating the gate signal uses the current control law as implemented to generate the gating Signals one leg of the active power filter inverter. The scheme is generalized to generate the signals for 3 phase system.

Design of sliding mode control (SMC): SMC is basically an adaptive technique in which output response is forced to track the desired response. Sliding mode control offers several advantages, such as stability even for large supply and load variations, robustness, good dynamic response and simple implementation (Utkin, 1997). This study discusses a sliding mode controlled voltage source inverter (Mabrouk *et al*., 2003). In current mode control of inverter, inverter is controlled such that output current follows the reference value. The basic idea behind the sliding mode control theory is the specification of a sliding surface, is chosen in a way that the control feature in to maintain a system within the surface and hence, assuming a desired system behavior. There are three basic design steps in the sliding mode control to be followed (Hung *et al*., 1993; DeCarlo *et al*., 1998):

- Propose a sliding surface.
- Test for the sliding mode existence.
- Perform stability analysis inside the surface.

In order to control the output current of the inverter, suitable sliding surface is to be chosen, which is directly affected by switching law. In order to guarantee the sliding mode existence,

$$\sigma\overset{*}{\sigma}<O$$

must be fulfilled and this fact guarantees the attraction of the system to the surface. The proposed Sliding surface (S) is a linear combination of state variables and the references:

$$\sigma(X)=\overset{*}{X}_1-X_1=\left(IcmX_4-\sum_{n=2}^{k}I_{Ln}X_{(n+3)}\right)-X \quad (8)$$

$\overset{*}{\sigma}(X)$ Is obtained from Eq. (8) and (2):

$$\overset{*}{\sigma}(X)=\frac{1}{2L_s}\left(X_2-2VmX_4-2L_swI_{Lcm}\sqrt{1-X_4^2}\right)+ +...+2L_swI_Ln\sqrt{1-X_{(n+3)}^2}+...+2L_swI_Lk\sqrt{1-X_{(n+k)}^2} +\frac{1}{2L_s}X_3u_n \quad (9)$$

The general form of the proposed control law is:

$$u=u_{eq}-u_n \quad (10)$$

Where,

u_{eq} = Equivalent control

$$u_n = -sig(\sigma) \quad (11)$$

The first term u_{eq} is valid only in the sliding surface and the second one (u_n) assures the sliding mode existence. The existence of the equivalent control is a necessary condition for the existence of the sliding mode, With Eq. (9) and (10) $\overset{*}{\sigma}(X)$ is expressed as:

$$\overset{*}{\sigma}(X)=\frac{1}{2L_s}\left(X_2-2VmX_4-2L_swI_{Lcm}\sqrt{1-X_4^2}\right)+ +...+2L_swI_Ln\sqrt{1-X_{(n+3)}^2}+...+2L_swI_Lk\sqrt{1-X_{(n+k)}^2} +\frac{1}{2L_s}X_3u_{eq})+\frac{1}{2L_s}X_3u_n \quad (12)$$

Due to the definition of (Cardenas *et al*., 1998), the first Term in Eq. (11) is zero. Therefore, the equivalent control is given by:

$$u_{eq}=\frac{1}{X_3}(-X_2+2VmX_4+2L_swI_{Lcm}\sqrt{1-X_4^2}-... -2L_swI_Ln\sqrt{1-X_{(n+3)}^2}-...-2L_swI_Lk\sqrt{1-X_{(k+3)}^2} \quad (13)$$

And to guarantee the sliding mode existence:

$$\sigma\overset{*}{\sigma}=\frac{1}{2L_s}X_3[-\sigma sig(\sigma)]<0 \quad (14)$$

Must be fulfilled. Due to the fact that [-σ sig (σ)] is always negative, the above condition is reduced to:

$$\frac{1}{2L_s}X_3>0 et \mathbf{V}c>0 \quad (15)$$

Since, the sliding surface and switching does not depend on system operating point, load, circuit parameters, or power Supply, the converter dynamics, operating in sliding mode, is robust.

Fuzzy logic control (FLC): Among the various available power filter controllers, such as IP, RST, hysteresis and adaptive control, the fuzzy logic controller, which is used to design controllers with complex dynamics, has been tested on APF. In our application, the fuzzy control algorithm is implemented to control the DC side capacitor voltage based on processing of the DC voltage error e (t) and its variation Δe (t) in order to improve the dynamic of APF and reduce the total harmonic ratio of the source current. FUZZY control (FC) possesses several advantages such As robustness, being model free, universal approximation Theorem and rule-based algorithm (Lee, 1990; Kim and Park, 1996). In addition, the advantage of fuzzy control is that it is based on a linguistic description and does not require a mathematical model of the system. Fuzzy is used for shape the filter current in close to the reference harmonic current. Due to this inclusion, we can get reduced harmonics in our source current. This can be showed by simulation results. A fuzzy controller consists of fourth stages: fuzzification, knowledge base, fuzzification, inference mechanisms and defuzzification. The knowledge base is composed of a data base and rule base and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbances. The data base, consisting of input and output membership functions, provides information for the appropriate fuzzification operations, the inference mechanism and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert the fuzzy outputs into control signals. Figure 3 and 4 show a block diagram of the proposed fuzzy logic control of the shunt active power filter. As for as the fuzzy concerned, In the design of a fuzzy control system, the formulation of its rule set plays a key role in improvement of the system performance. The rule table contains 49 rules as shown in Table 1, where (NP, NM, …) are linguistic codes (NB:

Table 1: The rule table

e(t) / ė(t)	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

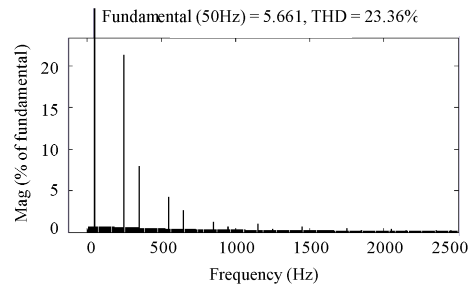

Fig. 3: Load current spectrum after compensation

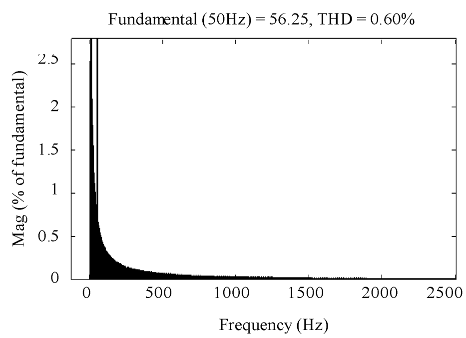

Fig. 4: Load current spectrum before compensation

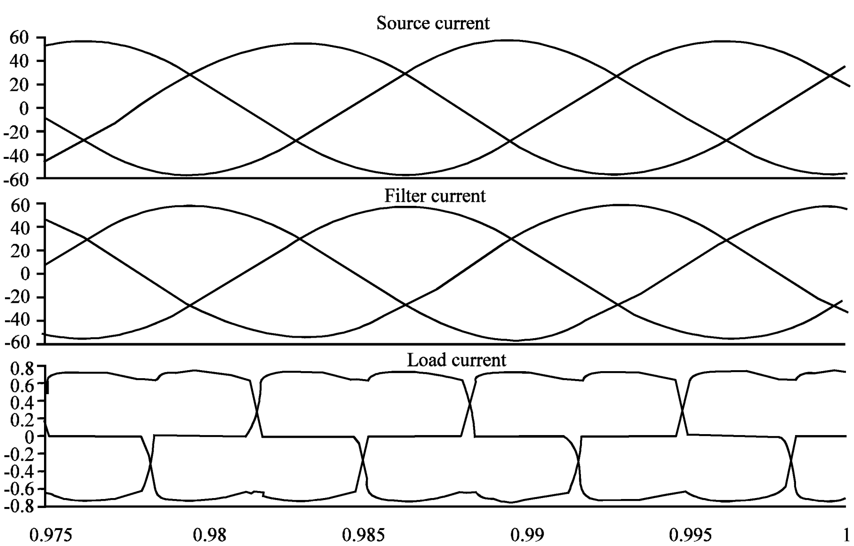

Fig. 5: Steady state simulated wave forms

Negative Big; NM: Negative Medium; NS: Negative Small; Z: zero; PS: Positive Small; PM: Positive Medium; PB: Positive Big;). a mamdani type fuzzy logic controller is proposed to limit the line current distortion using three-phase active power filter. Various inference mechanisms have been developed to deffuzzify fuzzy rules. In this study, we apply the max-min inference method to get an implied fuzzy set of turning rules (Kale and Ozedmir, 2003; Jain *et al.*, 2002). The imprecise fuzzy control action generated by the inference engine must be transformed into a precise control action in a real application. The center of mass method is used to deffuzzify the implied fuzzy control variables.

From the simulated wave forms (Fig. 5), we can come to conclusion that the total harmonic distortion (THD) is reduced from 23.36% before compensation to 0.60% after compensation which is within the permissible limit of 5% as recommended by IEEE-519.

CONCLUSION

This study has been focused on the Analysis and modeling of the fuzzy controlled sliding mode control of inverter in shunt active power filter which is able to compensate for the distortion and the reactive power drawn by nonlinear loads. The relative source current shows its harmonics in the harmonic spectrum are considerably low. In particular, the sliding mode control represents a powerful tool to enhance performance of shunt active power filters. Fuzzy controlled Sliding-mode control was used to control the active wave shaping function of the active filter without the need to calculate real or reactive power from the load current and improves the power quality in a better way.

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