# Fuzzy Sliding Mode Controlled Single Phase AC/DC Boost PFC Converter

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***Abstract:*** This paper presents a Fuzzy sliding mode controller (FSMC) used as a control technique for a Single phase AC/DC boost PFC converter for achieving high power factor and regulated voltage. The controller possesses the merits of both fuzzy controller and variable structure controller**.** The considered controller has advantages such as robustness when there is a large line and load variations. The results are observed in MATLAB/SIMULINK.The converter is designed for 110V, as input and 400V as output.

*Keywords*- power factor correction; fuzzy sliding mode controller; Boost Converter.

## I. INTRODUCTION

Sliding mode control is a nonlinear control method for power converters, which are variable structure system due to their on and off switching operation. Frequency to the line frequency is low. The deterioration of control performance is these cases stem from the fact that the current loop crossover frequency has to be limited to about one tenth of the switching frequency in order reference current requires a crossover frequency of 50-1000 times higher than the line frequency.

In General current control for single phase PFC boost converter [1], the controller is designed from a sliding mode control viewpoint. The controllers can keep the PF stay at a very high level under various line frequency and input voltage. But the derivative of the reference input current is included by using the sliding surface in [2]. Thus a differentiator is need, which can make the control loop very sensitive to noise. In this paper, we propose a new fuzzy sliding mode controller. A new sliding surface is introduced to avoid using the differentiator which is sensitive to noise.

## II. SLIDING MODE CONTROL

### *A. Theoretical Derivation*

In this section, a general current loop control rule for the boost PFC converter is derived. Conventional linear control is adopted for the outer voltage loop to regulate the output voltage and to generate the sinusoidal reference current[3]. Continuous conduction mode (CCM) is considered ,here as it is commonly used in medium to high power applications.

### *B. Deciding The Control Variables*

The proposed current controller employs the current error, $x_1$, the integral of the current error, $x_2$, and the double integral of the current error, $x_3$, as the controlled state variables. The double-integral term is included to further alleviate the steady-state error caused by the finite switching frequency [3]. The state variables are described as

$$x_1 = (i_L - i_{ref})$$

$$x_2 = \int x_1 dt$$

$$x_3 = \int x_2 dt \qquad (1)$$

Where $i_L$ denotes the instantaneous inductor current and $i_{ref}$ represent the reference input current
The switching function is defined as:

$$u = \frac{1}{2}(1 + sign(S)) \qquad (2)$$

Where *u* represents the logic state of the power switch.

### *C. Deciding The Sliding Surface*

The state variables trajectory is defined as a linear combination of the state variables, i.e., where $\alpha_1$ ,$\alpha_2$ and $\alpha_3$ represent the sliding mode coefficients. The sliding surface is defined by setting $S$=0,

$$\alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 = 0 \qquad (3)$$

Considering that the boost converter is operating in CCM, the time differentiation of (1) gives the dynamic model of the proposed system as

$$\dot{x}_1 = \frac{d}{dt} i_{ref} - \frac{1}{L}(v_i - \bar{u} v_0); \quad \dot{x}_2 = x_1; \dot{x}_3 = x_2 \qquad (4)$$

Where $\bar{u}$=1−$u$ represents the inverse logic of *u*, and $v_i$ denotes the rectified input voltage. Under the invariance of SM control, $S$=0and$\dot{S}$=0.

Thus, $\dot{S} = \alpha_1 \dot{x}_1 + \alpha_2 \dot{x}_2 + \alpha_3 \dot{x}_3 = 0$ (5)

### *D. Synthesizing The Control Signal By Equivalent Control*

Under the equivalent control, the logic signal $\bar{u}_{eq}$ is ,

$$\alpha_1 \frac{di_{ref}}{dt} - \frac{\alpha_1}{L}\left(v_i - u_{eq} v_0\right) + \alpha_2\left(i_{ref} - i_L\right)$$
$$+\alpha_1 \int \left(i_{ref} - i_L\right) dt \qquad (6)$$

Solving (6) for $\bar{u}_{eq}$ gives

$$u_{eq} = \frac{1}{v_0}\left[-\frac{Ldi_{ref}}{dt} + v_i - LK_1 x_1 - LK_2 x_2\right] \qquad (7)$$

where
$k1 = \frac{\alpha_2}{\alpha_1}$; $k1 = \frac{\alpha_3}{\alpha_1}$;

This is a general control rule for the boost PFC converter.

## III. FUZZY SLIDING MODE CONTROL

### *A. Design Of Fuzzy Sliding Mode Controller To Boost PFC Converter*

A Fuzzy logic is implemented to a General current sliding mode controlled single phase PFC Boost converter shown in figure 1.

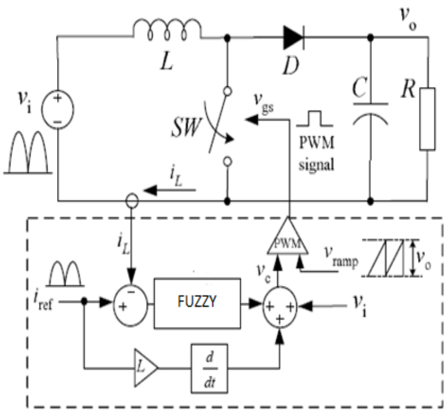

Figure 1.A Fuzzy sliding mode controlled single phase AC/DC Boost PFC converter

Design of fuzzy controllers is based on expert knowledge of the plant instead of a precise mathematical model. There are two inputs for the fuzzy controller for the buck and boost converters. The first input is the error in the output voltage, where *ADC*[*k*] is the Converted digital value of the *k*ith sample of the output voltage and *Ref* is the digital value corresponding to the desired output voltage. The second input is the difference between successive.

Errors and is given by
e[k] = Ref – ADC[k] (8)

ce[k] = e[k] – e[k-1] (9)

The two inputs are multiplied by the scaling factors *g*0 and *g*1, respectively, and then fed into the fuzzy controller. The output of the fuzzy controller is the change in duty cycle Δ*d*[*k*], which is scaled by a linear gain *h* [1]. The scaling factors *g*0, *g*1, and *h* can be tuned to obtain a satisfactory response.

### *B. Fuzzification*

The first step in the design of a fuzzy logic controller is to define membership functions for the inputs. Seven fuzzy levels or sets are chosen and defined by the following library of fuzzy-set values for the error e and change in error ce.

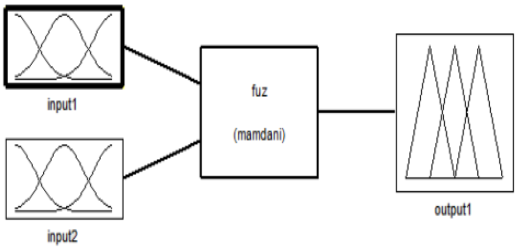

Figure 2.Membership function for e and ce.

They are as follows:
NB negative big;
NM negative medium;
NS negative small;
ZE zero equal;
PS positive small;
PM positive medium;
PB positive big.

The number of fuzzy levels is not fixed and depends on the input resolution needed in an application. The larger the number of fuzzy levels, the higher is the input resolution. The fuzzy controller utilizes triangular membership functions on the controller input. The triangular Member ship function is chosen due to its simplicity. For a given crisp input, fuzzifier finds the degree of membership in every linguistic variable. Since there are only two overlapping memberships in this specific case, all linguistic variables except two will have zero membership.

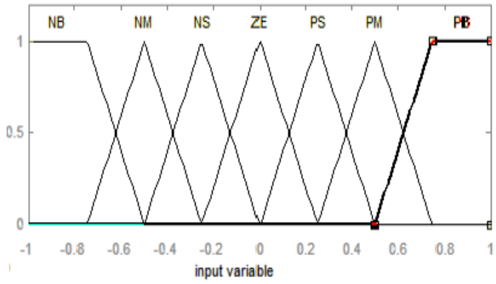

Figure 3.Member of Functions of the Linguistic Variable.

### *C. Rule Base*

The control rules for the dc–dc converter in Table 1. resulted from an understanding of converter behavior. A typical rule can be written as follows. If *e* is NB and *ce*is PS then output is ZE Where are the labels of linguistic variables of error (*e*), change of error (*ce*) and output respectively. e, ce and output represent degree of membership. To obtain the control decision, the max-min inference method is used.

### *D.Defuzzification*

Conservation of the fuzzy to crisp or non-fuzzy output is defined as Defuzzification. In the defuzzification operation a logical sum of the inference result from each of the four rules is performed. This logical sum is the fuzzy representation of the change in duty cycle(output). A crisp value for the change in duty cycle is calculated using the center of gravity method.

The product of centroid mi of Ci (obtained from control rules) and the weighting factor wi gives the contribution of the inference result to the crisp value of the change in duty cycle.

Table 1: Fuzzy Rule Base

| CE / E | NB | NM | NS | ZE | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NB | NM | NS | ZE |
| NM | NB | NB | NB | NM | NS | ZE | PS |
| NS | NB | NB | NM | NS | ZE | PS | PM |
| ZE | NB | NM | NS | ZE | PS | PM | PB |
| PS | NM | NS | ZE | PS | PM | PB | PB |
| PM | NS | ZE | PS | PM | PB | PB | PB |
| PB | ZE | PS | PM | PB | PB | PB | PB |

## IV. DESIGN EXAMPLE

A Fuzzy sliding mode controller is designed for a 110V, 50Hz input and 400V output of a single phase ac to dc PFC boost converter. The design parameters are shown in Table 2.

Table 2: Design Parameters

| PARAMETERS | VALUES |
|---|---|
| ACInputVoltage | 110V |
| DC Output Voltage | 400V |
| Switching frequency | 100Khz |
| Inductance | 0.6mH |
| Output capacitance | 470μF |
| Resistive load | 200Ω-100Ω |

## V. SIMULATION AND RESULTS

Single phase AC/DC boost PFC converter is implemented by using MATLAB/SIMULINK with the proposed Fuzzy current sliding mode controller. Simulink model is shown in Figure 4. Source voltage (Vs) and Source current(Is) waveforms is shown in Figure 5.From this source current is in phase with source voltage and the power factor is about to unity. Output voltage waveform shown in Figure 6.

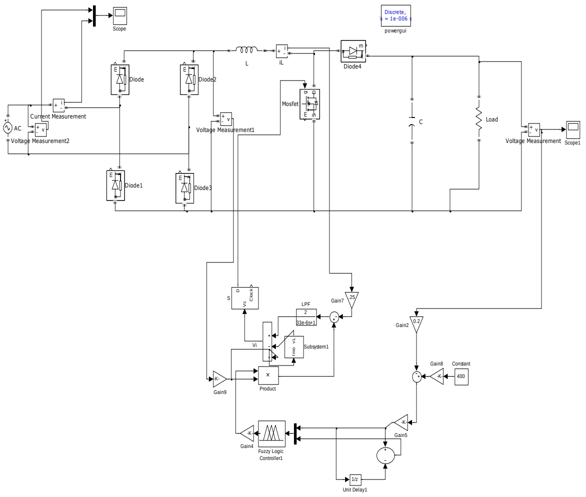

Figure 4. MATLAB/SIMULINK Model of the Fuzzy sliding mode controlled Single phase AC/DC Boost PFC converter

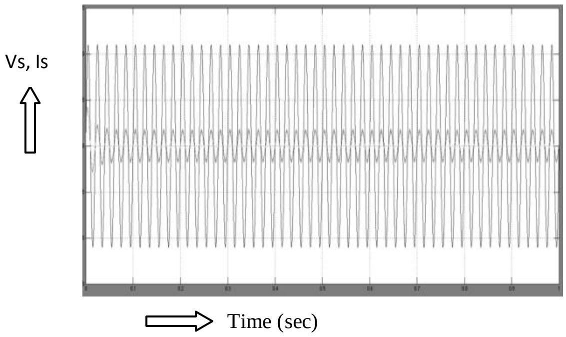

Figure 5. Source voltage (Vs) and Source current (Is) waveforms

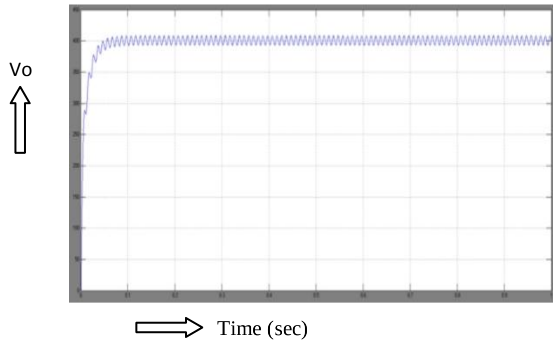

Figure 6.Output voltage (Vo) waveform

## VI. CONCLUSION

The proposed Fuzzy sliding mode controller used general current sliding mode control method to control the input current, has the advantages of the sliding mode control such as the robustness when there are large variation in line voltage and output load. It can achieve low input current distortion (4.85%) and fast response against the variation of line condition. Table 3 shows the results for the proposed controller.

Table 3: Results

| PARAMETER | VALUE |
|---|---|
| Power factor | 0.998 |
| Output voltage | 400V |
| Settling time | 0.06sec |
| Output voltage ripple | 5% |
| THD | 4.85% |

## REFERENCES

[1]. Chu. G., Siew-Chong Tan. Tse, C.K. and Siu Chung Wong "General control for boost PFC converter from a sliding mode viewpoint."In proc. PESC'08, June 2008, pp.4.

[2]. C Zhou and M.M. Jovanovic, "Design trade-offs in continuous-current mode controlled boost power-factor correction circuits," in Proc. HDPC'92, 1992, pp. 2009-220.

[3]. L. H. Dixon, "Average current-mode control of switching power suppliers," in Unitrode Power Supply Design Handbook. New York: Mc-Graw- Hills, 1990.

[4]. J. B. Williams, "Design of feedback loop in unity power factor ac to dc converter," in Proc. Proc.PESC'89, 1989, pp 959-967

[5]. K Smedley and S.Cuk, "One-cycle control of switching converters," in Proc. IEEE PESC'914, 1991, pp 814-820

[6]. Z Lai and K. M. Smedley, "A family of continuous-conduction-mode power-factor-correction controllers based on the general pulse-width modulator," IEEE Trans. Power Electron, vol 13, no. 3, pp. 501-510, May 1998

[7]. R Brown and M. Soldano, " One cycle control IC simplifies PFC designs," in Proc. IEEE Appl. Power Electron. Conf., 2005, pp. 825-829

[8]. J. Hwang, A. Chee, and W.-H, Ki, "New universal control methods for power factor correction and dc to dc converter applications," in Proc. APEC'97, 1997, pp. 59-65

[9]. J. Rajagopalan et at., "A general technique for derivation of average current mode control laws for single-phase power-factor-correction circuits without input voltage sensing," IEEE Trans. Power Electron, vol. 14, no. 4, pp 663-67, Jul 99.

[10]. M. Chen, A. Mathew and J. Sun, "Nonlinear Current Control of Single Phase PFC Converters', IEEE Trans. Power Electron. Vol. 22, no. 6, 2187-2194, Nov 2007.