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Fuzzy Logic Controller based Unity Power Factor Correction of Boost Converter

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Abstract: *This paper presents an analytical study of unity Power Factor Correction (PFC) of boost converter based on Proportional-Integral (PI) Controller and Fuzzy Logic Controller (FLC). The PI, FLC and Hysteresis Current Controller (HCC) are applied to the boost converter because of their nonlinear properties and improve the converter's performance. The FLC and PI are applied in the voltage loop controller whereas the HCC is employed in the current loop controller. The effectiveness of the controllers are verified in Matlab/Simulink environment and the comparative simulation results show that the fuzzy based controller provides the better performance than that of the PI based controller.*

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I. Introduction

DC link voltage has been widely utilized in the industrial applications and domestic applications and is mainly needed in drives of variable speed and in most of the domestic equipment. The diode bridge rectifiers are preferred to create this voltage at dc link because of its cheap, simple and robust nature. But the heavy usage of the rectifiers for the dc voltage results in the issues of harmonic pollution in the distributed electrical systems [1]. A simple rectifier's current waveform has high distortion at the input side and has low power factor. Of various methods proposed as solutions for these problems, the single-phase power factor correction (PFC) strategies based on active wave line current determination is one among them, the major advantages are:

- Input current's wave form having small distortion.
- Unity Power factor.
- Controlled DC voltage at the output.

The boost converters are more expensive compared to simple rectifiers but efficiently improves the power quality in the applications of single phase. Hence boost converters are preferred to the diode bridge rectifiers.Fig.1 depicts the single-phase PFC boost converter, and is the most simple control scheme in comparison with the other topologies. The main two objectives of the topology are: Track the current in the inductor to a rectified Sinusoid reference wave form and regulate the output DC voltage to reference voltage [2].Literature [3, 4] discusses the conventional PID controller used for regulating the voltage loop in the boost converter. As PID is mainly suitable to work with constant parameters, the system is modeled near a nominal point where the parameters and the disturbance are constant. But PID gives worst results when there are any variations in the system. Thus arises the introduction of the intelligent controllers whose control is robust and performs well even under variations in the system. Of these intelligent controllers, Proportional-Integral and Fuzzy Logic Controller (FLC) are used in this paper.

This paper presents a study and operation of single phase PFC of boost converter based on PI and fuzzy logic controllers, which are used for the voltage loop, with the conventional hysteresis current controller being used in the current loop to enhance the performance of the system without requiring a mathematical model of the PFC converter [8]. The proposed controllers have been tested using MATLAB/Simulink.

II. Circuit Description

The basic circuit diagram of the DC–DC converter with front end solid state input power factor conditioner used in the proposed scheme is shown in Fig 1a.

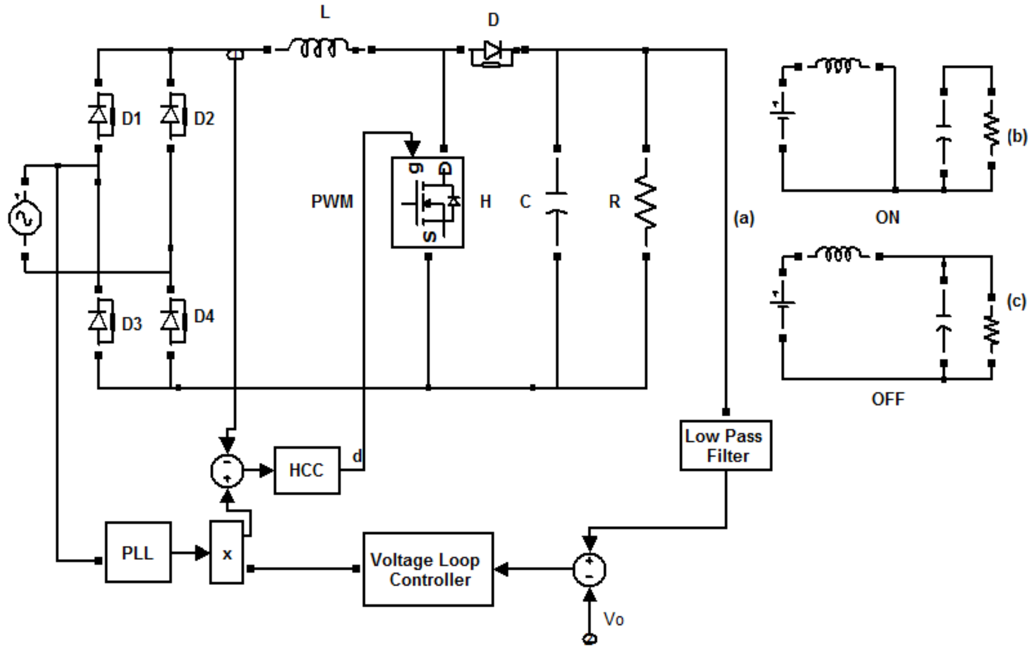

Fig. 1. Single-phase PFC boost converter control system

The power circuit is that of an elementary step-up converter. When the boost switch H is turned on (d = 1) Fig. 1b, the inductor current builds up, and energy is stored in the magnetic field of the inductor, whereas the boost diode D is reverse biased, and the capacitor supplies power to the load. This is the first mode operation. As soon as the boost switch is turned off (d = 0) Fig. 1c, the power circuit changes mode, and the stored energy in the inductor, together with the energy coming from the input ac source, is pumped to the output circuitry (capacitor–load combination). This is mode 2 of the circuit. Then the state space model for the boost PFC in continuous current mode can be found by the circuit analysis of Fig. 1a. The output voltage and inductor current dynamics are governed by the variable structure real switched system Eq. (1).

$$\frac{dv_0}{dt} = \frac{1}{C}\left[(1-d)i_L - \left(\frac{1}{R}\right)v_0\right]$$
$$\frac{di_L}{dt} = \frac{1}{L}\left[V_{in} - \left(\frac{1}{d}\right)v_0\right] \qquad (1)$$

In order to obtain a sinusoidal input current in phase with the input voltage, the control unit should act in such a way that v_{in} sees a resistive load equal to the ratio of v_{in} and i_L. This has been done by comparing the actual current passing through the inductor with a current reference, which is derived from v_{in} and have amplitude determined by the output voltage controller .Since the break frequency of the output filter is very low, one can say that the output voltage is controlled only by the average value of the on-duty ratio of the switch in half cycle of the ac input voltage.

$$V_0 = \frac{V_{in,ave}}{1-\alpha} = \frac{2}{\pi} V_{SM} \frac{1}{1-\alpha} \qquad (2)$$

Where α is the logical variable to represent the state of the boost switch, $V_{in,ave}$ is the average value of the full-wave rectified sinusoidal input voltage VSM is the peak value of the sinusoidal input voltage.

III. Voltage-loop controller

3.1. PI-controller

The transfer function for PI controller is defined as:

$$H_{PI}(s) = K_P + \frac{K_1}{s} \qquad (3)$$

The proportional gain is derived using KP = 2.ξ.ωn.C that determines the dynamic response of the DC-side voltage control. Similarly, the integral gain is derived using *KI* =Cωn2 that determines it's settling time. The PI controller for the DC-link voltage sets the amplitude of the active current of the APF inverter to regulate the DC-link voltage based on its reference value covering the inverter losses. Subtracting the measured load current, the reference value of the APF current is obtained. Hence, *KP* = 2.ξ.ωn.C and *KI* =Cωn2 , for ξ = 0,707 and C=1100×10-6 F , *Kp* and *KI* can be determined.

3.2. Fuzzy logic-controller

The fuzzy logic controller unlike conventional controllers does not require a mathematical model of the system that should be controlled. However, a comprehending of the system and the control requirements are necessary. The fuzzy controller designer must clarify how the information is processed (control strategy and decision), and information flows out of the system (solution/output variable). The fuzzy logic controller consists of three basic blocks: fuzzification, inference mechanism and defuzzification.

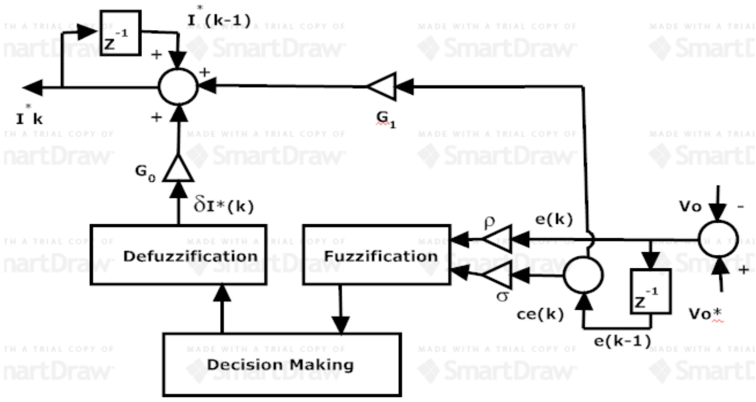

Figure 3. Fuzzy logic-controller

Figure 3 shows the block diagram of the proposed fuzzy logic control scheme of the boost rectifier with APFC. The dc-bus voltage v0 is scaled and sampled by the digital apparatus and compared with a reference value V_0. The obtained error $\varepsilon_v(k) = V_0^*(k)\text{-}v_0(k)$ and its incremental variation $C\varepsilon_v(k) = \varepsilon_v(k)\text{--}\varepsilon_v(k-1)$at the k th sampling instant are used as inputs of fuzzy controller. The output is the variation magnitude of reference current δI^*. The dc-bus voltage is controlled by adjusting the magnitude of reference current I* where ρ and σ are the constants used to normalize the error and the change of error (Tab. 2).

Table 1. Fuzzy Control Rules

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. Current-loop controller

Fig.4 shows the hysteresis current control principle with fixed band. The input of the HCC is the current error and the output is the control command of the switch. This HCC control technique is a nonlinear control. It has the advantages of robustness and implementation simplicity. It has a fast response time, stability and satisfactory accuracy. This command has only one control parameter; it is the hysteresis band width. The inductor current in the output of the diode bridge is controlled using a hysteresis regulator. The comparator determines the control command of the boost converter switch associated with the bridge. The PFC circuit analyzed here has a feedback loop such that the switching mode is determined by comparison of the actual current and sinusoidal reference current supplied from voltage loop controller in both ways, the actual current oscillates in fixed band hysteresis (FBH) as shown in Figure 5. In the second way, the actual current oscillates invariable band hysteresis (VBH).The fixed band Hysteresis Current Controller (HCC) is used to maintain the current in a band. When the difference between the measured and the reference current is out of the band, the controller gives a switching command.

4.1. Conventional hysteresis current control

In this scheme, the hysteresis bands are fixed throughout the fundamental period. The algorithm for this scheme is given as:

Upper band (i_{upper}) $=I_{refM}\sin(wt)+\Delta I = I_{refM}\sin(wt)+\frac{\beta}{2}$ (4)

Lower band (i_{lower}) $=I_{refM}\sin(wt)-\Delta I = I_{refM}\sin(wt)-\frac{\beta}{2}$ (5)

$i_L > i_{upper},$ d=0, then $v_H = V_0$ (6)

$i_L < i_{lower},$ d=1, then $v_H = 0$ (7)

Where $\beta = 2\Delta I$ is band hysteresis.

The switching frequency is calculated using the following equation,

$$f_{sw} = \frac{\psi(V_0 - \psi)}{L\beta V_0} \quad (8)$$

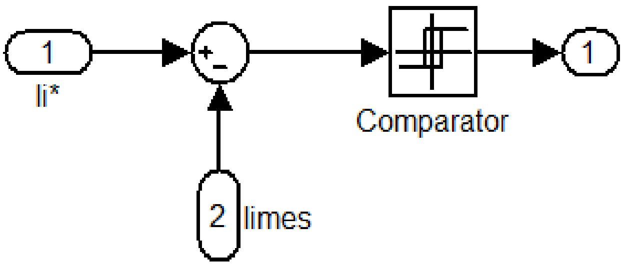

Fig. 4 Hysteresis current control

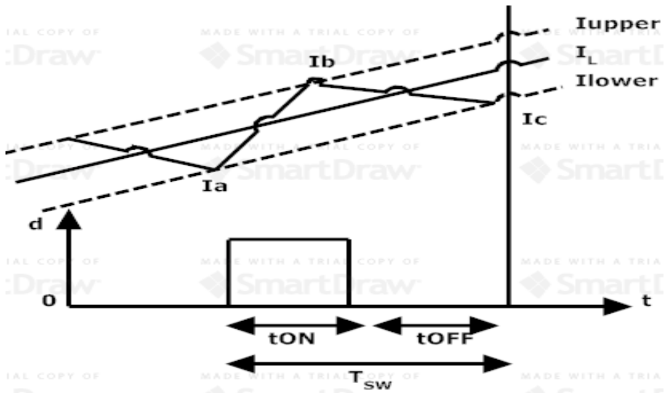

Figure 5. Switching frequency.

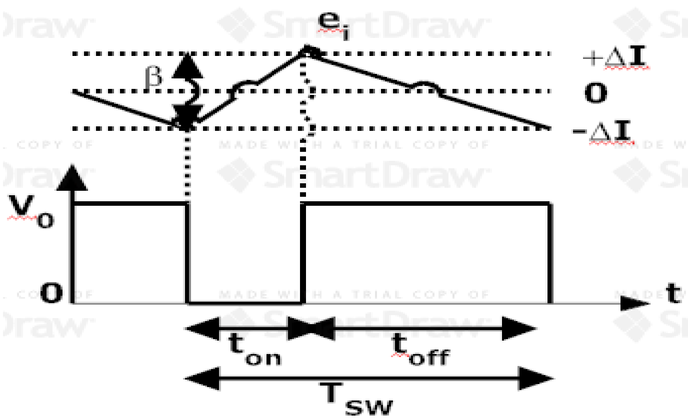

Fig. 6. Current error and switch voltage H.

4.2. Hysteresis current control with constant switching frequency

From Equation (10), if β is constant and the time t varies, then f_{sw} also varies. To get f_{sw} constant, the hysteresis band has to be dynamically changes, according to the following equation,

$$\beta = \frac{\psi(V_0 - \psi)}{L V_0 f_{sw}} \quad (9)$$

V. Simulation results

The Matlab/Simulink software is used to validate the effective performance of the fuzzy logic based Power Factor Correction of boost converter. In the converter employing Proportional Integral controller in the voltage loop, the line current have more distortions with poor power factor and the current waveform is not sinusoidal as shown in Fig. 7. Fig. 8 shows the output voltage using PI controller.

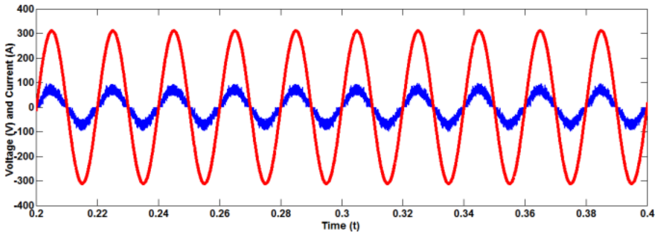

Fig. 7 Source Voltage and current using PI

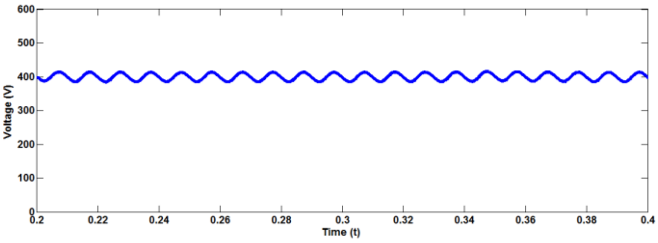

Fig. 8 Output voltage using PI

Whereas with the use of Fuzzy Logic Controller in the boost converter, the distortions in the line current are reduced, unity power factor is maintained and the waveform is almost sinusoidal as shown in Fig. 9. Fig. 10 depicts the constant output voltage using Fuzzy logic.

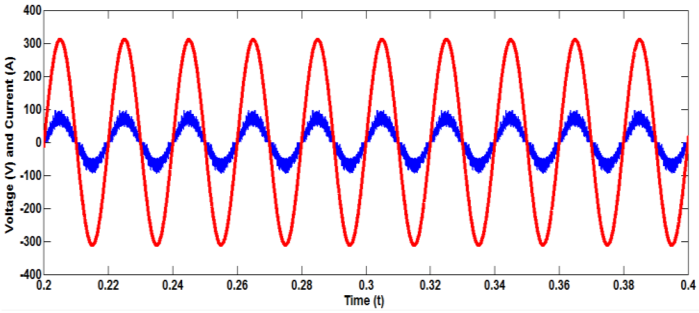

Fig. 9 Source voltage and current using Fuzzy Logic Controller

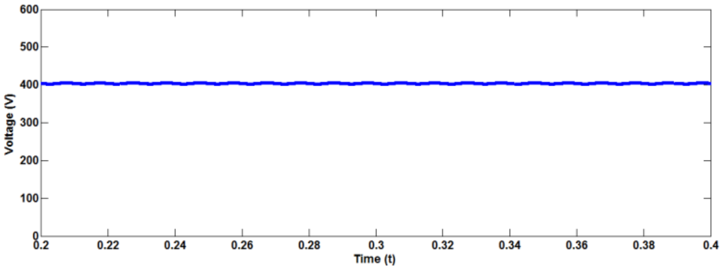

Fig. 9 Output voltage using Fuzzy Logic Controller

In addition to the above, the results the improved power factor is indicated in the tabular column from PI controller to the Fuzzy logic controller as shown in Table.2

Table. 2. Results comparison between PI and Fuzzy

S.NO	Type of controller	Power Factor
1	PI controller	0.9249
2	Fuzzy controller	0.9987

VI. conclusion

In this paper the unity power factor correction of single phase boost converter by employing Proportional-Integral and Fuzzy Logic controllers in the DC-voltage controller loop is discussed. The techniques were employed because of their robustness and efficiency. The proposed methods were simulated using Matlab/Simulink software and are compared. The comparative simulation results show the better efficiency of the FLC based controller than that of the PI based controller.

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