Power Factor Correction Based On Fuzzy Logic Controller With Average Current-Mode For DC-DC Boost Converter

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ABSTRACT

Power Factor Correction (PFC) provides well-known benefits to electric power systems. These benefits include power factor correction, poor power factor penalty utility bill reductions, voltage support, release of system capacity, and reduced system losses. The performance of fuzzy logic controller only depends on the selection of membership function and Inference of fuzzy rules, fuzzy logic controllers have an advantage in coping with the time varying non-linearity of switches. The Proportional & Integral controllers (PI) controller design requires an accurate mathematical model of the plant. Also it fails to perform satisfactorily performance under various parameters such as voltage variations, nonlinearity, load disturbance, etc. The paper presents an advanced PFC technique by using average current-mode control for DC-DC boost converters. The PFC strategy uses PI controllers to correct the input current shape and fuzzy controller to control the output voltage. A model for Power Factor Correction has been formed by using the MATLAB software. The produced model has also been simulated by using fuzzy logic tools. The simulation results show that the fuzzy controller for output voltage can achieve better dynamic response than its PI counterpart under lager load disturbance and plant uncertainties.

Keywords- Converter, Average current mode, Fuzzy inference systems, Fuzzy rules, Membership function.

1. INTRODUCTION

Worldwide, the markets of internal and external switch mode ac/dc power supply (SMPS) have been growing at a faster rate for several applications such as communications, computers, instrumentation, Industrial controls, and military/aerospace area. Majority of present day SMPS employ analog control and are under going slow evolution. A conventional SMPS employs a diode rectifier for ac to dc conversion. This type of utility interface generates harmonics and the input power factor (PF) and total harmonic distortion (THD) are poor. Most usage converter for SMPS design is boost converter.

Due to the increased awareness of the many undesirable consequences of harmonic distortions in line currents drawn by switch-mode power supplies (SMPS's), high power factor and low line current harmonic distortion are expected to be mandatory requirements for SMPS's in coming years. Traditionally, the implementation of switching power supply has been accomplished by using analog power factor correction (PFC). Critical to the performance of PFC pre-regulator is the choice of current mode and control methods. The three mode of control based on inductor current are the average current-mode control [2],[7],[12]. the peak current-mode control and the inductor current hysteretic control. The main distinguishing feature of ACMC, as compared with peak current mode control, is that ACMC uses a high gain, wide bandwidth Current Error Amplifier (CEA) to force the average of one current within the converter, typically the inductor current, to follow the demanded current reference with very small error, as a controlled current source.

The superior characteristics of an average current mode control such as a good tracking performance of an average current, no slope compensation, and noise immunity have been discussed. In an average current mode control, the compensation network is presented in a current control loop to use the average current as a controlled quantity. Traditional frequency domain analog control methods are predominantly used in controller design for PFC pre-regulator [3], such as PI controller. However, there are a number of drawbacks that found in a analog controller, such as temperature drifts and aging effect of the components. The digital controller has many advantages [3],[6] over analog counterpart one, including programmability, adaptability, less susceptibility to environmental variations, no temperature and aging effect, and more immunity to the input voltage distortion, etc…

Research on the theory and application of fuzzy logic has been growing since its first introduction in the mid-1960s. Among its many applications, fuzzy logic has been shown to be a powerful tool in dealing with uncertainties and nonlinearities in control systems. In the past decade, fuzzy control has been used in many industrial applications, such as control of the PWM inverter for an ac drive [7], performance control of a dc drive, and switch control in dc/dc converters [5],[10]. In response to the concerns, this article evaluates the feasibility employing state of the art digital control of power factor correction stage with fuzzy logic algorithm. Result of simulation shows the current loop with PI controller proposed in paper obtains a high steady performance and the fuzzy controller for output voltage can achieve better dynamic response than its PI counterpart under lager load disturbance [11].

2. METHODOLOGY

2.1 Circuit Description

The power factor correction circuit [13], has been shown in Fig.1. The power circuit is a dc-dc boost converter. The command circuit is the one described in [9], in which the analog controller was replaced with a Fuzzy one. The output of the Fuzzy controller is V_c. The Fig. 2 shows the command principles of wave shapes. In average current control method, an input voltage sensing required to obtain a sinusoidal reference, an analog multiplier to combine this reference with the output information, and an error amplifier in current loop to extract the difference between the input current and the reference to generate the control signal for modulating the input current.

In average current control method [13], an input voltage sensing required to obtain a sinusoidal reference, an analog multiplier to combine this reference with the output information, and an error amplifier in current loop to extract the difference between the input current and the reference to generate the control signal for modulating the input current. Average Current Mode Control (ACMC) as a general purpose, high-performance all-round control method for AC-DC conversion, DC-DC conversion, and DC-AC conversion (including grid-feed inverters). ACMC achieves superior performance. Average Current Mode Control (ACMC) is typically a two loop control method (inner loop, current; outer loop, voltage) for power electronic converters. Single phase 230V, 50Hz AC supply given to the circuit. The PFC Circuit bridge rectifier converts ac supply to dc supply. smoothing capacitor or filter capacitor used to obtain smooth rectified output wave form. The DC-DC Boost convertor output is V_o.

Fig.1 Power factor correction circuit that uses the Average current-mode

Fig.2 Waveforms of the reference current and inductor current for average current-mode

Multiplication and Division Block (MDB)[13], is used to obtain the reference current I_{ref}. The MDB has three input voltage. First input is the fuzzy output voltage V_c (input A). second one the rectified sinusoidal waveform with the line frequency V_s (input B) and third input is the fundamental harmonic of the voltage V_d (input C). Input B is taken from line current. This line current convert to voltage by adding resistor in series. The MDB is multiply the fuzzy output voltage (input A) and rectified sinusoidal voltage (input B). this multiplication voltage is divide by fundamental harmonic voltage(input C). The output of the MDB is V_{ref}. V_{ref} is converted to I_{ref} by adding resistor in parallel.

Current error control circuit is used to obtain I_{in}. Inductor current has high harmonics. So Current wave shape in irregular form. average current- mode technique is used to minimize the harmonics and obtain regular current wave shape. Pulse Width Modulation (PWM) gives gate signal to driver circuit by comparing of reference signal and carrier signal. Driver circuit gives the triggering pulse to the MOSFET in the proper sequence. Driver circuit get input from PWM. The MOSFET switch ON and OFF corresponding to triggering pulse. PI controller to correct the input current shape and a fuzzy controller to control the output voltage. So the power factor is improved near unity.

2.2 . Single Phase Boost PFC Converter

There are a lot of very sophisticated researches of boost converter dynamics [1],[8],[13] The most of PFC is based on boost converter, because of its input inductor which reduces the total harmonics distortion and avoids the transient impulse from power net, the voltage of semiconductor device below output voltage, the zero potential of Q's source side which makes it easy to drive Q and its simple structure. Therefore, satisfied teaching of advanced power electronics should be introduced by unity power factor and high efficiency by dc-dc boost converter.

2.3. Simulation Model

This section will focus on implementation of the PFC in MATLAB. The PFC with Fuzzy controller and the average current-mode control is described in Fig.3 In digital implementation of average current-mode control DSP, microprocessor or FPGA are used to calculate the duty cycle in every switching period based on the feedback current and the reference current The switch Q is controlled by the calculated duty cycles to achieve unity Power factor. From Fig. 3 can be distinguished the following essential blocks: the single-phase supply; the rectifier; the boost converter; the Fuzzy controller; a block used for the PI transfer function and the PWM & Drive block.

Fig.3 Schematic of PFC using Mat Lab.

2.4. Fuzzy Controller

Fig.4 shows Block diagram of typical fuzzy logic controller. Fuzzy controller is based on a Mamddani Fuzzy system with contain two input variables that are defined by Eqn.1, Eqn.2 and only output variable Eqn.3.

$$e = V_{ref} - V_o \quad (1)$$

$$\Delta e = e_{(k)} - e_{(k-1)} \quad (2)$$

$$\Delta U = k_1 e + k_2 \Delta e \quad (3)$$

Where e and Δe are the input variables, k_1 and k_2 are nonlinearity coefficients. e_k and e_{k-1} are the output voltage error at k_{th} and $(k\text{-}1)_{th}$ control period.

The fuzzy controller [13], control the output voltage(V_o). Fuzzy controller has two input that, error voltage(e) and change in error voltage (Δe). The error voltage is obtain from difference between output feedback voltage(V_o) and reference voltage(V_{ref}). The change in voltage(Δe) is the difference between error voltage and previous error voltage. FIS Editor as shown in fig. 5.

Fig.4 Block diagram of typical fuzzy logic controller

Fig.5 FIS Editor

The input error voltage(e) has seven membership function and changing error voltage(Δe) has seven membership function. Fuzzy controller compare the two voltage membership function and produce one output voltage membership function. This is called fuzzy output voltage(V_c).

The first input variable e in the fuzzy system has seven membership functions and represented in Fig.6. The second input variable Δe in the fuzzy system has seven membership functions and represented in Fig.7. The output variable has seven membership functions as shown in Fig.8. The rules table according to which the decisions are made is represented in table1.

Fig.6 Membership functions shapes for e

Fig.7 Membership functions shapes for Δe

Fig.8 Membership functions shapes for output variable

Table.1 The fuzzy rules

FAM table contain seven linguistic variable for error voltage and seven linguistic variable for changing error voltage. Increasing of number of linguistic variable gives the accurate output. The 49 fuzzy rules are made by using the two input variable membership function. For example,

If error voltage NB and change in error voltage NB then output voltage NS
If error voltage NB and change in error voltage NM then output voltage NM
If error voltage NB and change in error voltage NS then output voltage NB
If error voltage NB and change in error voltage Z then output voltage NB
If error voltage NB and change in error voltage PS then output voltage NB.

Fig.9 to fig.11 show the rule editor, rule viewer and surface viewer of the fuzzy controller.

Fig.9 Rule Editor

Fig.10 Rule Viewer

Fig.11 Surface Viewer

3. RESULTS & DISCUSSIONS

Simulations are performed by MATLAB to verify the proposed PFC control algorithm. Under the parameters of input voltage Vl=220V (rms), output voltage V_{out}=400V, inductor value L=800µH, capacitor value 1700µF. Fig.12 shows sinusoidal waveform of the input voltage and rectified positive half cycle voltage wave form. Input voltage 220V is given to the rectifier circuit. output of the rectifier circuit voltage is 218.5V. Fig.13 shows the Input current waveform of the boost converter. Average Current Mode Control (ACMC) is typically a two loop control method (inner loop, current; outer loop, voltage) for power electronic converters. Average Current Mode Control is used to correct the input current shape. Fig.14 shows Inductor current waveform with some harmonics but Fig.15 shows output current waveform without harmonics. output of the boost converter is 300V and output voltage waveform represented in Fig.16. an output voltage wave form maintain around a specified average value with low ripple. PI controller output current and fuzzy controller output voltage are represented in Fig.17 & 18. Table.2 shows the parameter value of the converter.

Fig. 12 input voltage and rectified voltage

Fig. 13 Input current wave

Fig. 14 Inductor current wave

Fig. 15 output current wave

Fig. 16 output voltage wave

Fig. 17 PI output current

Fig. 18 fuzzy output voltage

Table.2 Parameter values of the converter

In Conventional Method buck converter is used for power factor correction. It has more losses, less power factor &less efficiency. In Proposed system, Boost converter is used for power factor correction. It has several advantage, high power factor, high efficiency, less losses. Analog controller is used for correcting power factor. Analog controller has several disadvantages, A Number of parts required in the system and their susceptibility to aging and environment variations, which lead to high cost of maintenance, Analog control once designed is inflexible and performance cannot be optimized for various utility distortions, there are a number of drawbacks that found in a analog controller, such as temperature drifts and aging effect of the components.

Digital control is used for power factor correction and it has several advantages such as programmability, adaptability, less susceptibility to environmental variations, no temperature and aging effect, and more immunity to the input voltage distortion no losses, simple control strategy. Research on the theory and application of fuzzy logic has been growing now a day. Among its many applications, fuzzy logic has been shown to be a powerful tool in dealing with uncertainties and nonlinearities in control systems. Result shows that current loop with PI controller obtains a high steady performance and the fuzzy controller for output voltage can achieve better dynamic response than its PI counterpart under lager load disturbance. In this Proposed system Achieve high power factor during steady-state operation with constant load and Respond quickly to load disturbances with minimum harmonics.

1. FIGURES AND TABLES

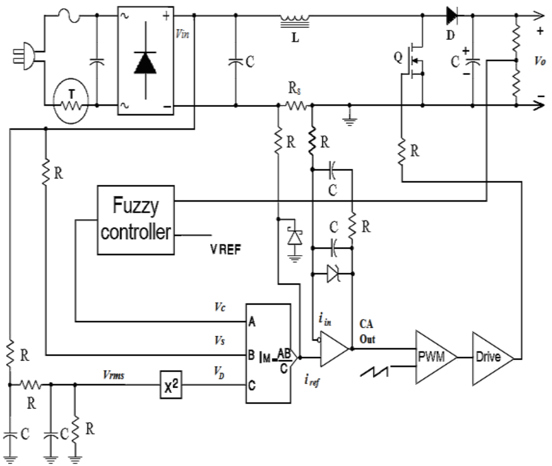

Fig. 1 Power factor correction circuit that uses the Average current mode

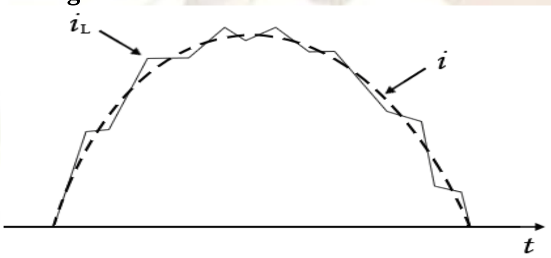

Fig. 2 Waveforms of the reference current and inductor current for average current-mode

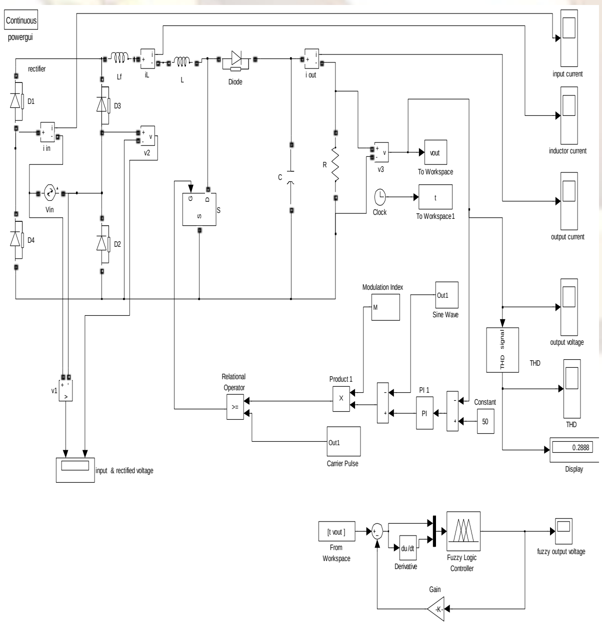

Fig. 3 Schematic of PFC using Mat Lab

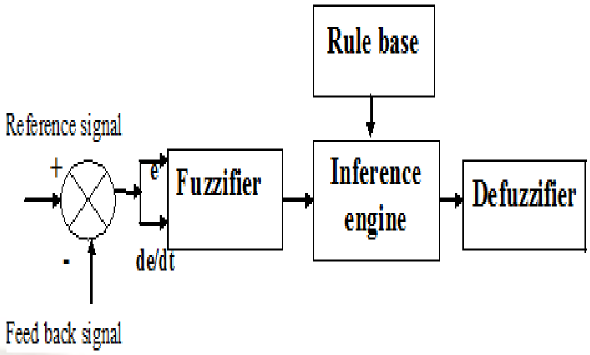

Fig. 4 Block diagram of typical fuzzy logic controller

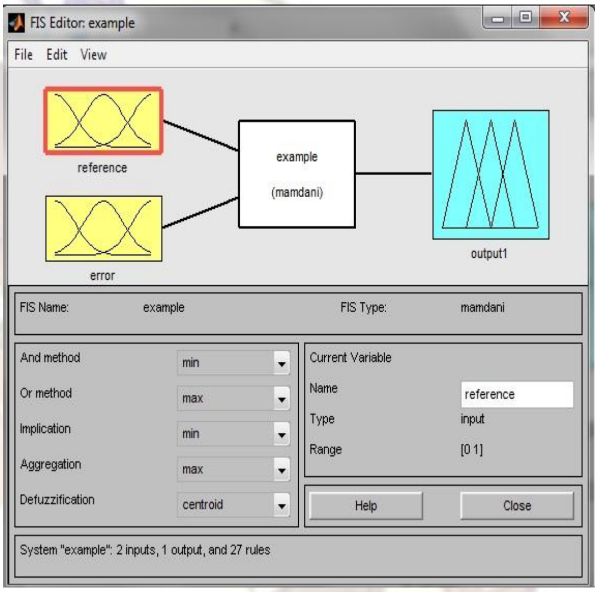

Fig. 5 FISEditor

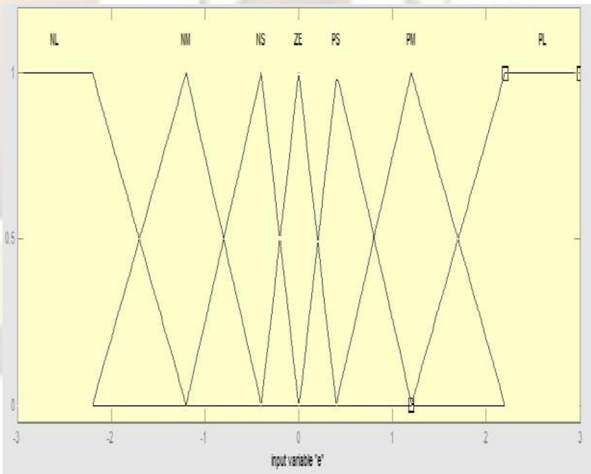

Fig. 6 Membership functions shapes for e

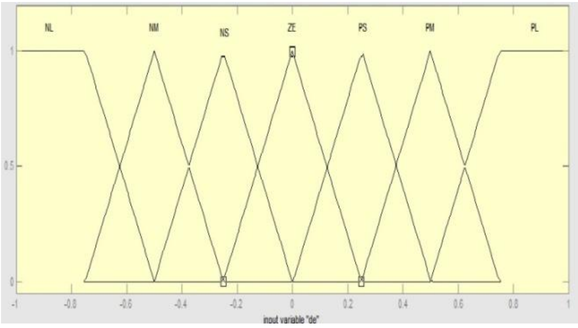

Fig. 7 Membership functions shapes for Δe

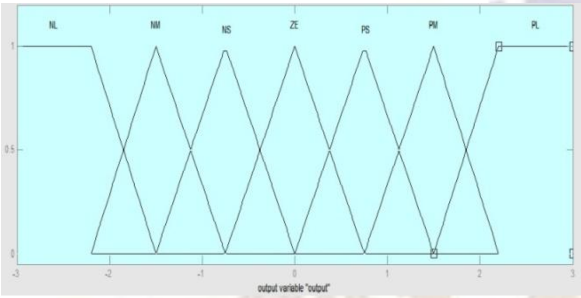

Fig. 8 Membership functions shapes for output variable

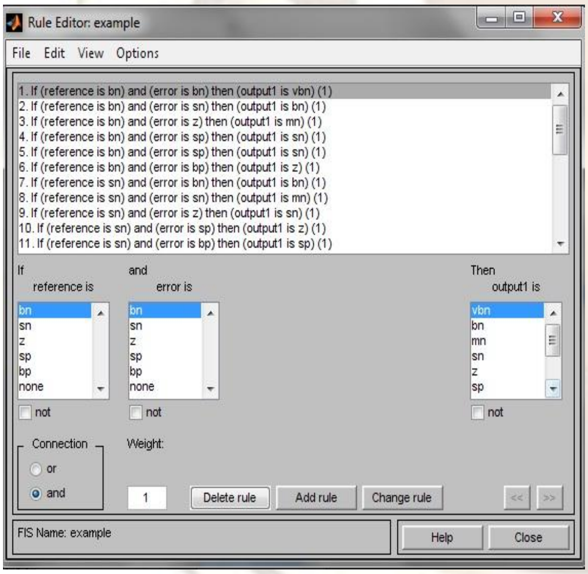

Fig. 9 Rule Editor

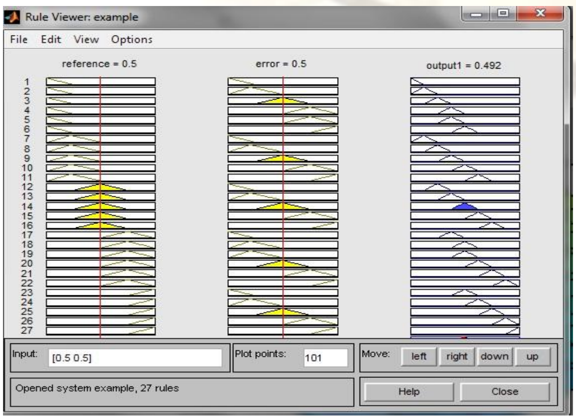

Fig. 10 Rule Viewer

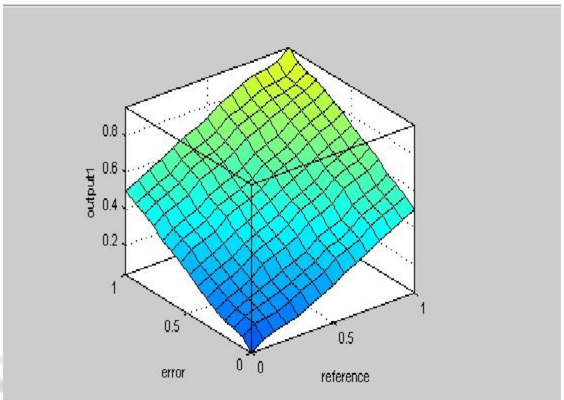

Fig. 11 Surface Viewer

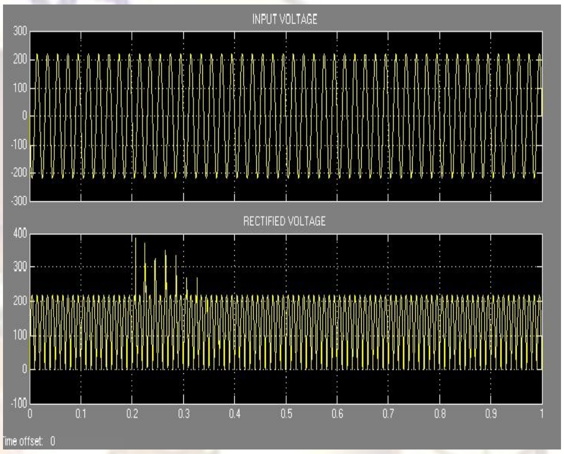

Fig. 12 input voltage and rectified voltage

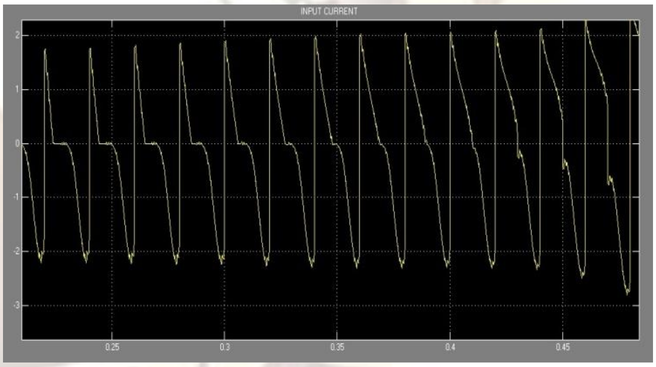

Fig. 13 Input current wave

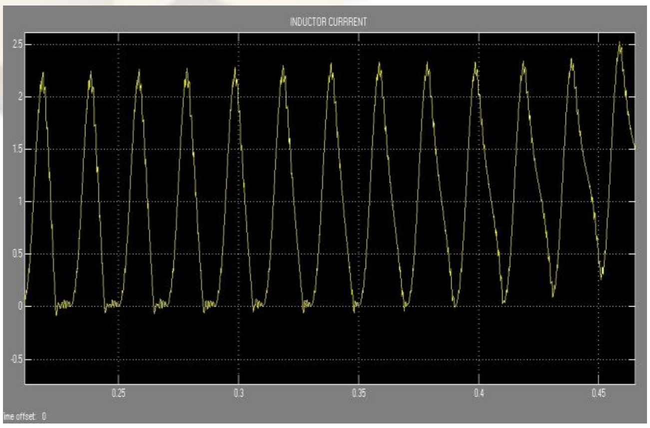

Fig.14 Inductor current wave

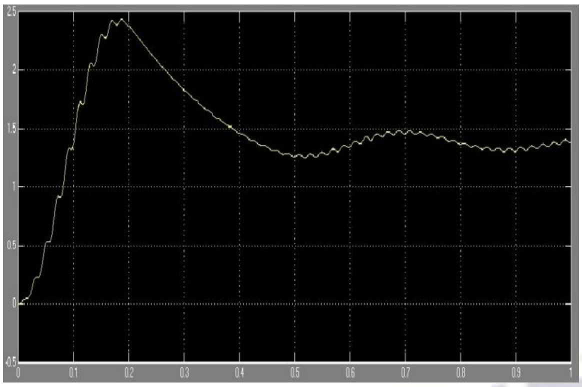

Fig. 15 output current wave

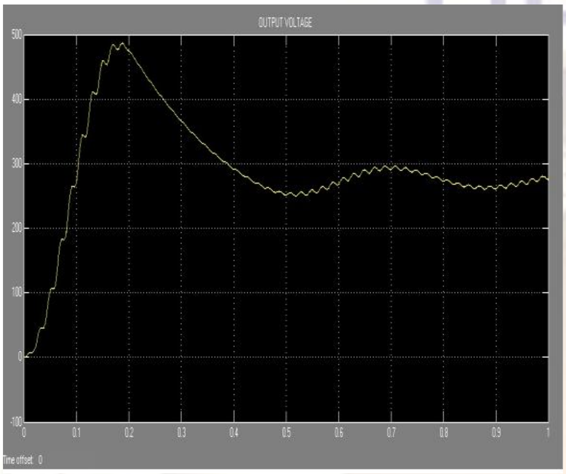

Fig. 16 output voltage wave

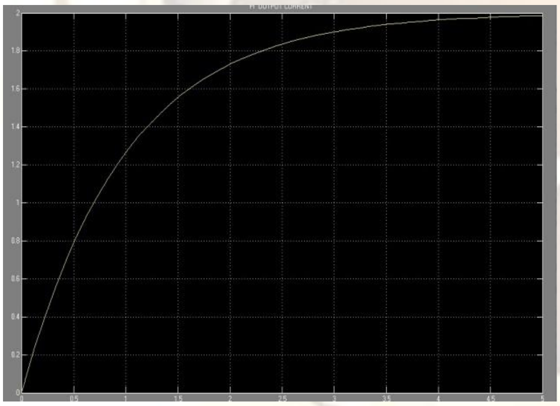

Fig. 17 PI output current

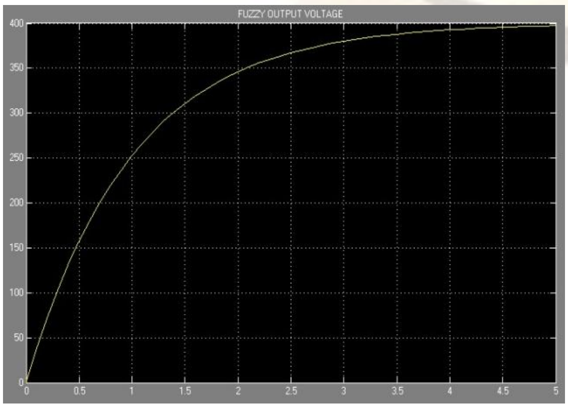

Fig. 18 fuzzy output voltage

Δe \ e	NB	NM	NS	Z	PS	PM	PB
NB	NS	NS	Z	PM	PB	PB	PB
NM	NM	NS	NS	PS	PM	PB	PB
NS	NB	NM	NS	Z	PM	PM	PB
Z	NB	NM	NS	Z	PS	PM	PB
PS	NB	NM	NS	Z	PS	PM	PB
PM	NB	NB	NM	NS	PS	PS	PM
PB	NB	NB	NB	NM	Z	PS	PS

Table 1. The fuzzy rules

PARAMETER	SYMBOL	VALUE
Input voltage	V_{in}	220rms V
Rectified voltage	V_{rec}	218.5 V
Input current	I_{in}	2 Amps
Inductor current	L_i	2.2 Amps
Output current	I_{out}	1.4 Amps
Output voltage	V_{out}	300 V
Fuzzy output voltage	V_{fuzzy}	400 V
Resistor	R	200 Ω
Capacitor	C	1700μ F
Inductor	L	800μ H
PI controller constant	K_p	0.00001
Diode	D	0.001 Ω
MOSFET	S	0.1 Ω
Sine wave	Ref signal	1 Amplitude
Triangular wave	Carrier wave	1 Amplitude
Modulation index	M	1

Table 2. Parameter values of the converter

5. CONCLUSION

The single-phase boost PFC converter, using the classic control strategy for current loop, requires that a sinusoidal reference for the current is created by MDB. The fuzzy controllers are designed by using the output voltage error and the change of voltage error. The simulation results show that the high power factor can be achieved under wide output power conditions. Fuzzy logic control has a advantage of coping with larger parameter variation of the system and it overshoot limitation and sensitivity to parameter variation.

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