PFC of SMPS using FLC based Boost Topology

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Abstract: *The never ending drive towards the smaller and lighter products lead to the development of switch mode power supply (SMPS), which is smaller in size , lighter in weight and having higher efficiency and greater design flexibility. The recent advances in magnetic, passive and semiconductor technologies make the SMPS an ever more popular choice in power conversion arena. To meet the wide range of power supply applications the designers developed a number of SMPS topologies. Out of which nonisolated boost topology of SMPS is widely used. The output voltage of this topology is always higher than the input voltage. In this paper, the boost topology of SMPS controlled by average current mode (ACM) technique based on a fuzzy logic controller is explained in detail. In the proposed method the fuzzy logic controller is presented only in the inner current loop and there is no controller presented in the outer voltage loop. The fuzzy logic controller presented in current loop is used to control the power switch (MOSFET) of the boost converter in order to improve the power factor and output voltage regulation of SMPS even in the presence of uncertainties and load variations. The fuzzy logic based ACM control technique for boost PFC SMPS is developed in MATLAB SIMULINK environment and the experimental results are obtained to evaluate the feasibility of these controllers.*

Keywords- Average current mode control (ACMC); boost converter; fuzzy logic controller (FLC); power factor correction(PFC); switched-mode power supply (SMPS)

I. Introduction

Nowadays the rapid advances in communication, digital, ICs (Integrated Circuits) and power electronics technologies lead to the increased use of DC power supply for most of the appliances such as monitors, TVs, portable CD players, fax machines, Photocopiers, VCRs, VFDs, servers, and micro-electronics-based devices in communications, instrumentation, computing, networking, military/aerospace, industrial, automotive and consumer electronics applications etc. There are mainly two types of DC power supply designs; they are linear and switching mode power supplies. Even though linear power supplies are simple and require few external components to design, cheap and quieter (low noise) it suffers from heavy weight due to its large transformer at mains and poor conversion efficiencies due to its dissipative series regulator consists of resistors and a linear transistor for output regulation. Linear regulators can only step down the input voltage to produce DC output voltage. On the other hand, SMPSs are very compact and light weight and also provides high power conversion efficiencies due to its switching transistor (which dissipates a very little power in on and off states), capacitor, magnetic and rectifier (diode bridge rectifier) components[1]. Hence SMPS has become the dominant and most prevailing DC power supply architecture in the most modern systems. SMPS can be stepped up or down the input voltage by selecting proper converter (DC-DC converter) topology to produce the regulated DC output voltage [2-3].However, due to the nonlinearity of diode-bridge rectifiers used in the SMPSs for AC-DC power conversion, introduce harmonics into the utility system and thereby reduces the power factor of apparatus. In order to reduce total harmonic distortion and to improve the power factor it is necessary to incorporate the PFC techniques into SMPS [4]. The nonisolated boost converter, which provides the DC output voltage always higher than the input DC voltage is the most widely used SMPS topology for PFC because its input inductor draws sinusoidal current from utility when it is switched properly. There are several proposals for power factor correction of SMPSs [5-7], which are mainly categorized into analog and digital PFC techniques. But most of the digital PFC techniques implement the laws of analog PFC techniques in digital format [8]. Average current mode, hysteresis current mode, peak current mode, borderline, zero current switching (ZCS), zero current transition (ZCT), zero voltage switching (ZVS), zero voltage transition (ZVT) etc, are the commonly used analog techniques for active power factor correction [9-10]. In this paper the average current mode technique based on fuzzy logic controller discussed in detail. There are several proposals for ACM control technique which uses PI controllers in both inner and outer loops [11] and a fuzzy logic controller in the outer loop and PI controller in the inner loop [12] etc. But in the proposed method no controller is implemented in the outer voltage loop and a fuzzy controller is implemented in the inner current loop to control the power switch of boost converter for power factor correction of SMPS.

II. Boost Topology of SMPS And Power Factor Correction

This SMPS which regulates the output voltage through PWM has been attracting the world of power supply design since its first introduction in late 1970's by putting back the preceding linear power supplies. The basic design of SMPS consists of a diode bridge rectifier, a DC-DC converter, and a ripple filter. The high-frequency switch (MOSFET or IGBT) of DC- DC chopper offers fast switching times, high efficiency with low heat dissipation and can withstand erratic voltage spikes. Hence to days SMPSs are more efficient ranging from 65 to 95% and are having the ability to handle variable loads efficiently.

Presently there are several topologies of SMPSs are available. However, the selection SMPS topology from a wide choice of topologies strictly depends on the specific applications of power supplies and advantage and disadvantages of each topology. Buck, boost, buck-boost are the three basic nonisolated versions of converters from which most of the topologies used in today's SMPSs are derived. Among all the boost (step-up converter) is the popular topology of SMPS because its configuration is simple, component count is low (one inductor, capacitor, transistor, and diode), source grounded switch facilitates easy operation and input inductor draws smooth current from the line and reduces input filtering requirement and EMI. There are three different operating modes of boost converter depends on the continuity of current flows in its input inductor namely CCM, DCM and BCM. Even though the controlled operation of discontinuous conduction mode and boundary conduction mode are easy they are limited to low power applications due to their higher magnetic and conduction losses and switching noise. Hence boost converter in continuous conduction mode is used for wide range of applications. The operating principle and modelling of CCM boost topology of SMPS are clearly explained in [13].

The uncontrolled AC-DC converter with an output filter capacitor is the very used power supply for low power electronic equipment because it is very cheap and robust. A large number of these power units connected to the same power line exhibits a strong nonlinear behaviour which results in high total harmonic distortion, increased electromagnetic interference, and poor power factor. The power factor associated with these nonlinear loads has a close relation with THD of input current. This relation is expressed as follows [14].

$$PF = \frac{(\text{AVERAGE POWER})}{(\text{RMS VOLTAGE}) \times (\text{RMS CURRENT})} \quad (1)$$

$$PF = \frac{V_{rms} I_{1rms}}{V_{rms} I_{rms}} \cos \emptyset = \frac{I_{1rms}}{I_{rms}} \cos \emptyset \quad (2)$$

$$PF = \text{Distortion factor} \times \text{Displacement factor} \quad (3)$$

$$PF = K_d \cos \emptyset = K_d K_\theta \quad (4)$$

$$PF = \frac{1}{\sqrt{1 + THD^2}} \cos \emptyset \quad (5)$$

From the above relation, it is clear that as the THD increases the power factor decreases as a result, the extraction of maximum power from the utility decreases and also the interference with other electrical equipment increases.

For counteracting the undesirable effects of these nonlinear loads and complying with the standards it is necessary to incorporate power factor correction techniques into the power supply system. Depends on the components (passive or active) used PFC solutions can be categorized as passive PFC and active PFC. Passive PFC uses only the passive elements for shaping the line current alone but not for controlling the output voltage. On the other hand active PFC uses the active switches in conjunction with reactive elements for the effective shaping of line current and also for obtaining the controllable output voltage irrespective of system loading conditions. The block diagram of active power factor correction technique is shown in Fig, 1.

In this section, the active PFC of SMPS using boost converter with average current mode control technique will be discussed in detail. This technique has two basic compensating loops, one is outer voltage feedback compensating loop to keep the DC bus voltage fixed at the predefined reference value and the other one is the inner current loop to control the shape of inductor current for achieving almost unity power factor and a stable power supply system with a tolerable dynamic behavior.

The control method which overcomes the problems of peak current control such as the need of compensation ramp, sensitivity to communication noises etc., and allows a better-improved input current waveform by introducing a high gain current error amplifier or fuzzy logic controller into the current loop is the average current control represented in Fig. 2. The current error amplifier filters the sensed inductor current (since inductor current and input current are same in boost topology because the switch is source grounded) and drives the PWM modulator through its output. In average current mode control method, the reference current signal is obtained by multiplying the sinusoidal voltage sensed from the input with the output information (voltage error obtained from output comparator) through the analog multiplier. The waveforms of average inductor current and reference current are shown in Fig. 3.

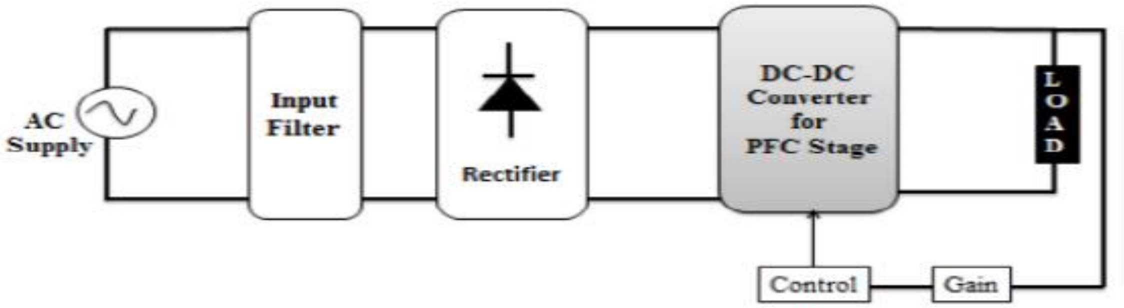


Fig. 1. Block diagram of active PFC technique

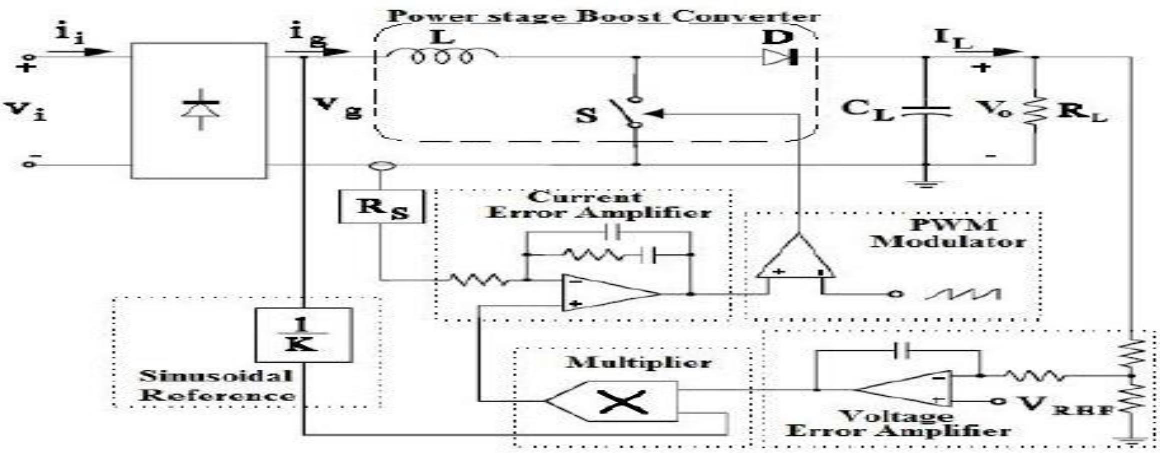


Fig. 2. Conventional Average current mode control scheme

Fig. 3. Waveforms of reference current and inductor current

In this method, the inner current loop tends to reduce theerror between the reference (i_{ref}) and inductor average current (i_g) signals. Average current control tracks the current program with a high degree of accuracy and enables less harmonic distortion and high power factor with a relatively small inductor. The average current control method has excellent noise immunity, constant switching frequency, does not require slope compensation for achieving stability, and can control the input current of buck, flyback topologies, and output current of boost, flyback topologies accurately.

In this paper the fuzzy logic controller is implemented in average current mode control technique because it is a powerful tool in dealing with uncertainties and nonlinearities of power factor pre-regulators and it can provide an optimal covenant between the needs for improving dynamic response and reducing the total harmonic distortion by properly weighting the output voltage and input current errors. The fuzzy logic control approach can be applied to several power factor pre-regulator topologies with almost same control rules by tuning some scale factors according to converter topology and parameters. The design of fuzzy logic controller is simple, since it is based on linguistic (IF THEN) rules derived from the heuristic knowledge of the system's behaviour. These rules are of the type: "if the DC output voltage error is positive and their rates of change are negative then reduce the duty-cycle slightly", and so on.

III. Simulation and Experimental Results

The system which consists of lineal elements such as resistors, capacitors, inductors and transformers is called linear system. These linear elements may displace the current waveform away from the voltage wave form but not introduce harmonics in to the system hence power factor is simply the displacement factor. The nonlinear elements such as diodes, transistors and other semiconductor devices etc., introduces harmonic content into the system, which results in high total harmonic distortion poor distortion factor which affects utilization of real power badly. Therefore the power factor of the nonlinear system is the product of displacement and distortion factors. The SMPS is a class of nonlinear system because it uses diode rectifiers for AC-DC conversion. The active PFC circuit associated with SMPS reduces the THD to emulate linear power supply. The simulation diagram of an uncontrolled AC to DC converter or SMPS without PFC is shown in Fig. 4. This simulation diagram consists of a diode bridge rectifier which converts the 18V, 50Hz AC voltage to a DC voltage and fed to the 1000Ω load resistor through the 6000μF capacitor. The experimental results of SMPS without PFC are shown in Fig. 5. These results are obtained for understanding the nonlinear behavior of SMPSs without PFC.

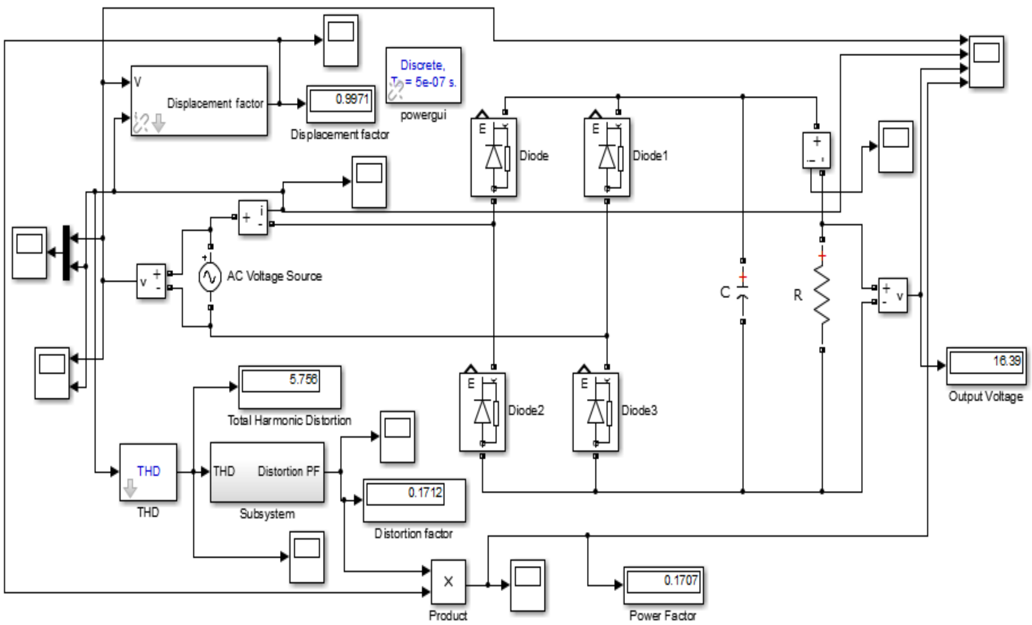
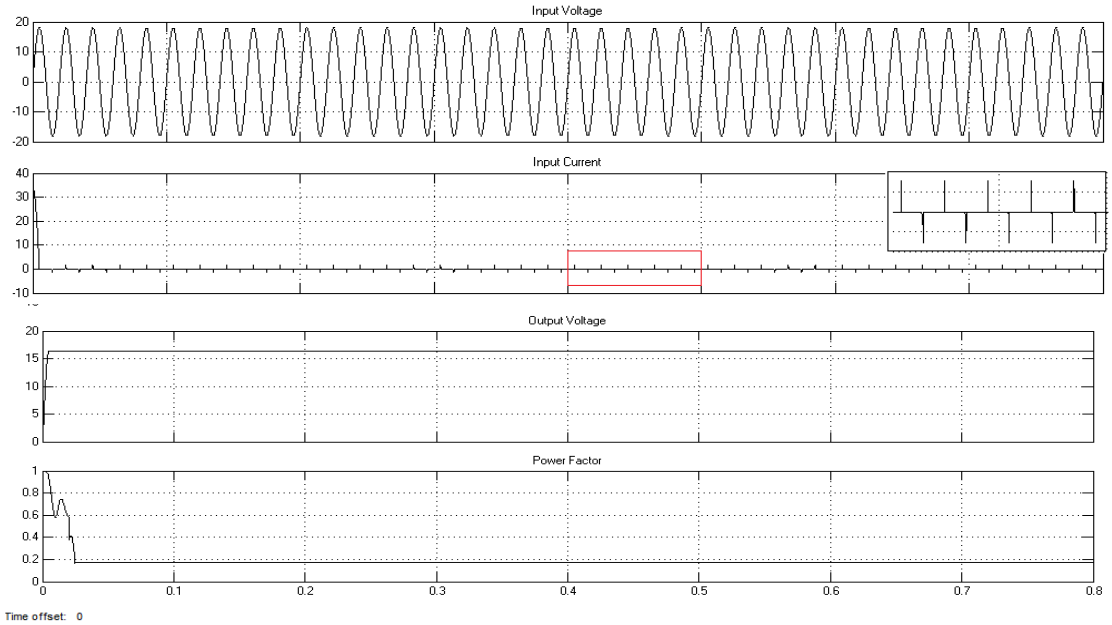


Fig. 4. Simulation diagram of SMPS without PFC



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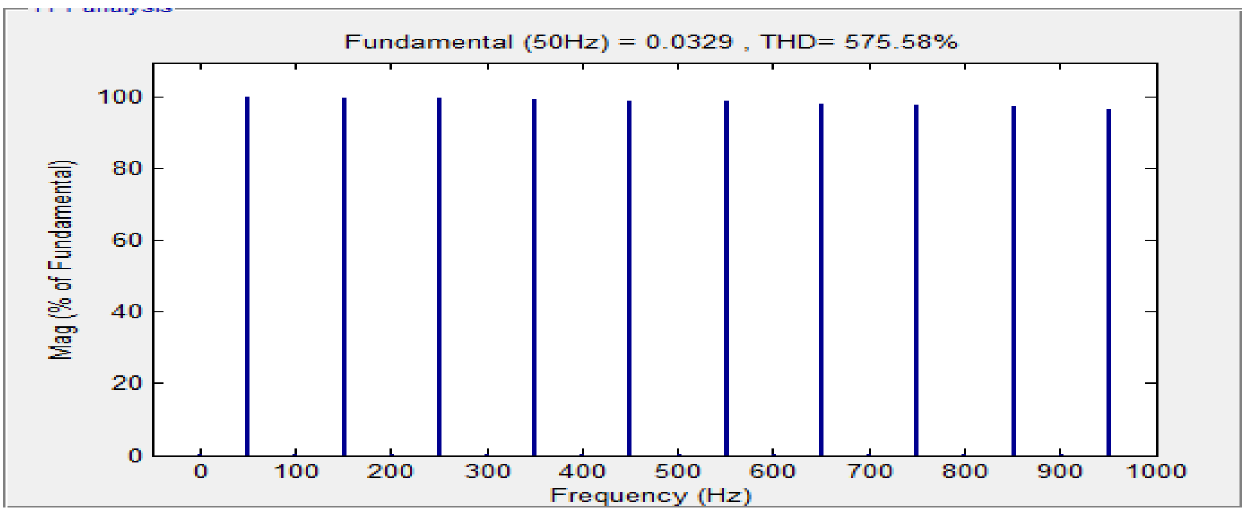

(b)

Fig. 5. Experimental results of SMPS without PFC (a). Waveforms of the input voltage, input current, output voltage and input power factor respectively (b). Total harmonic distortion of input current

From the experimental results it is observed that this circuit suffers from high total harmonic distortion (575.58%), and low power factor (0.1707). even though displacement factor (0.9971) is not much deviated from unity the distortion factor (0.1712) is very much less hence power factor is poor. The unregulated DC output voltage is 16.39V. The bulk capacitor placed at the output side draws high current only at line voltage peaks to maintain the DC voltage approximately equal to the peak voltage of input sine wave. Therefore input current is pulsating repeated regularly at line voltage peaks and the magnitude of the pulse current is (1.5214A) 5 to 10 times the average current. In the top right corner of input current waveform the zoomed view these current

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pulses are clearly shown. In order to avoid these undesirable effects and to allow smooth input current from the ACmains, a fuzzy logic based boost PFC using average current mode control is implemented for SMPS.

The simulation diagram of fuzzy logic based average current mode control scheme for boost PFC SMPS is shown in Fig. 6. From the simulation diagram, it is observed that the proposed system consists of a fuzzy logic controller only in the inner loop and in the outer loop no controller is observed. In the output voltage loop the reference and actual DC output voltages are compared and the error voltage obtained is given to multiplier. The output voltage of diode bridge rectifier with some gain is given as second input to multiplier block which acts as a sinusoidal reference to produce reference current. In the inner current loop, the boost inductor current (input current) is compared with the reference current obtained from the multiplier block, the resultant current error and its change in error are given to fuzzy logic controller as inputs. The output of the fuzzy logic controller is given to a relational operator which produces PWM pulses to drive the boost converter switch by using a high-frequency carrier signal. The proposed SMPS consists of a bulk capacitor at the output side to filter AC ripples in the output and to maintain constant voltage throughout the switching cycle. There is a small filter at the input side to filter the source voltage. The parameters used in simulation of proposed PFC system are shown in Table 1.

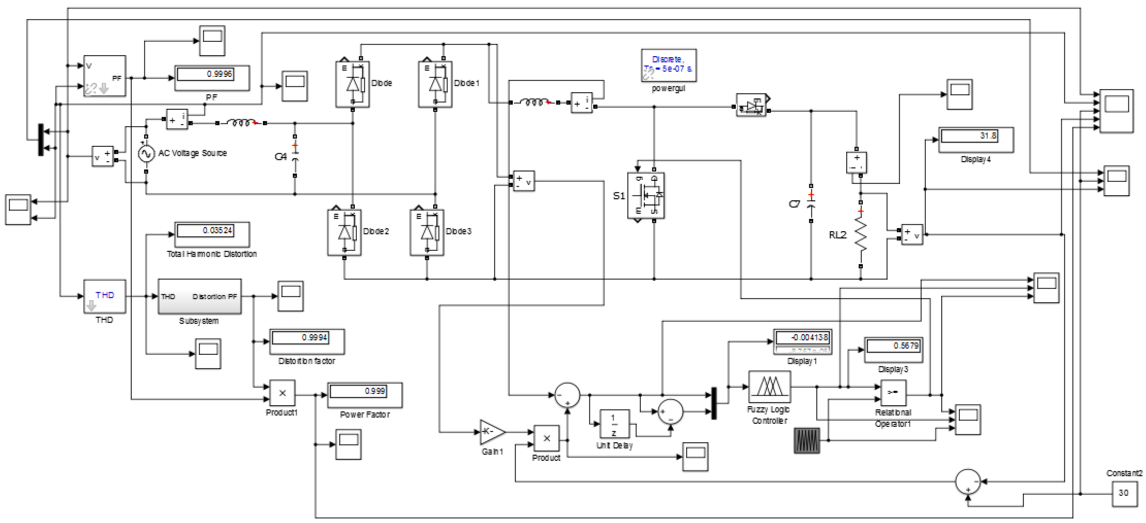


Fig. 6. Simulation diagram of SMPS with proposed PFC

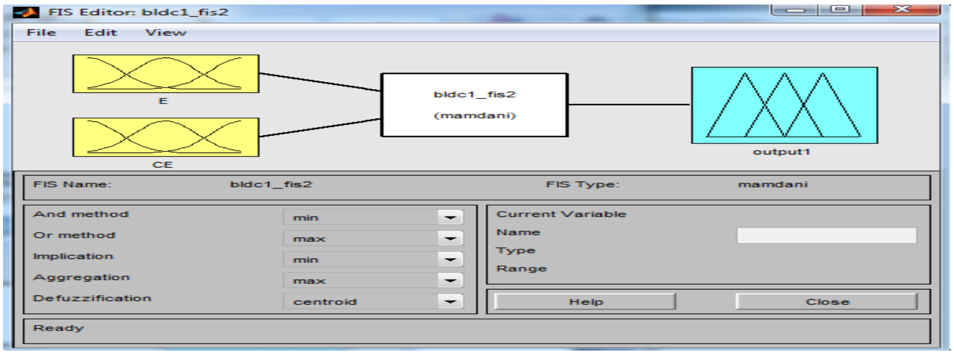
Table 1.Parameters used in the simulation of proposed PFC system

SNO	Parameter	Value
1	Input voltage	18 V
2	Frequency of input voltage	50 Hz
3	Filter inductance	1 mH
4	Filter capacitance	1 μF
5	Gain of sinusoidal reference	0.1
6	Inductance of boost inductor	10 mH
7	Output capacitance	6000 μF
8	Load resistance	1000 Ω

The Mamdani fuzzy controller system developed for proposed PFC system not only smoothen the input current waveform to achieve unity PF but also regulate the output voltage irrespective of uncertainties and input voltage variations. The Mamdani fuzzy controller model is discussed in [15]. The MATLAB implementation of fuzzy logic controller for proposed PFC system is shown in Fig. 7. The fuzzy control rule base according to which the decisions are made is represented in Table 2, in which the seven output membership functions are distributed among two input variables error and change in error each having seven membership functions. The experimental results of SMPS with proposed PFC system are shown in Fig. 8.

Table2.Control rule base of fuzzy logic

E / CE	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



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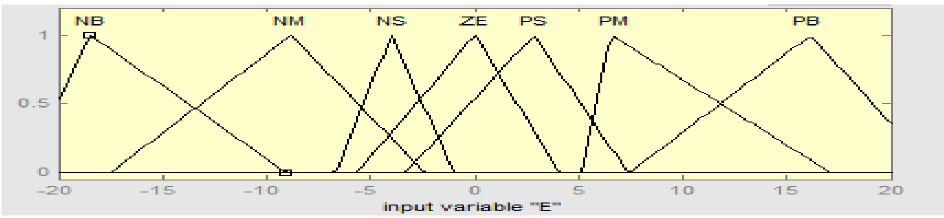

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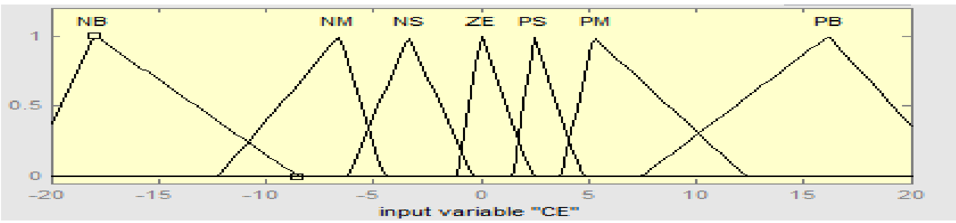

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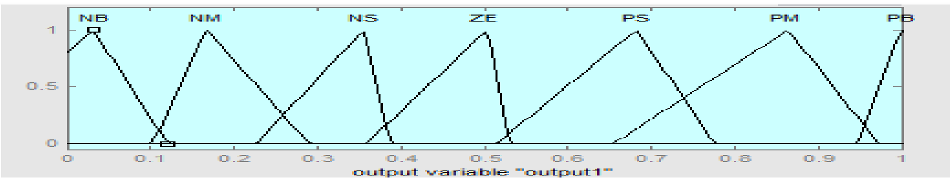

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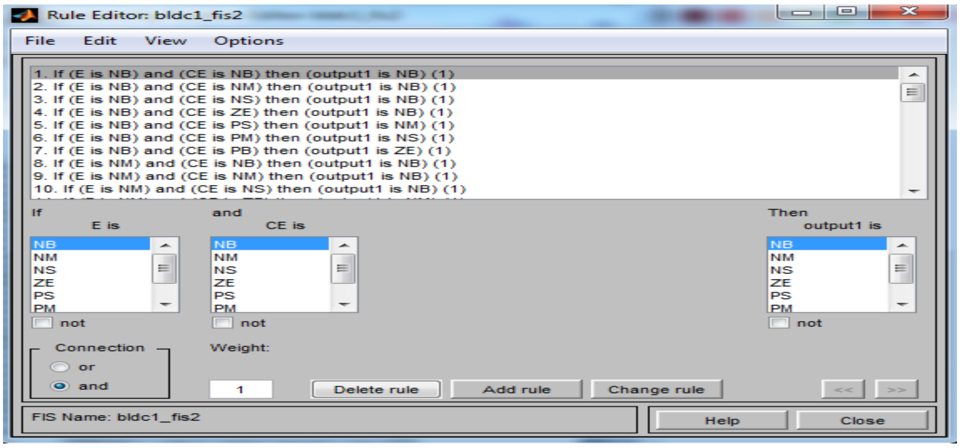

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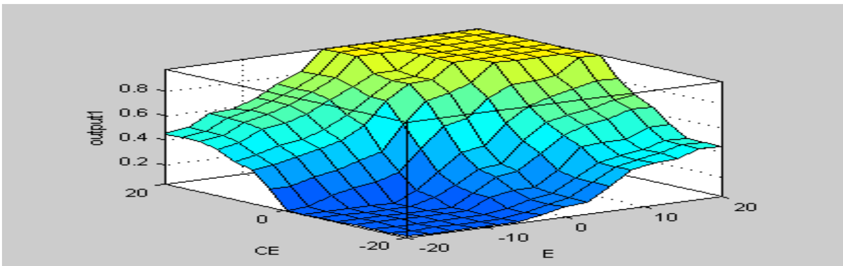

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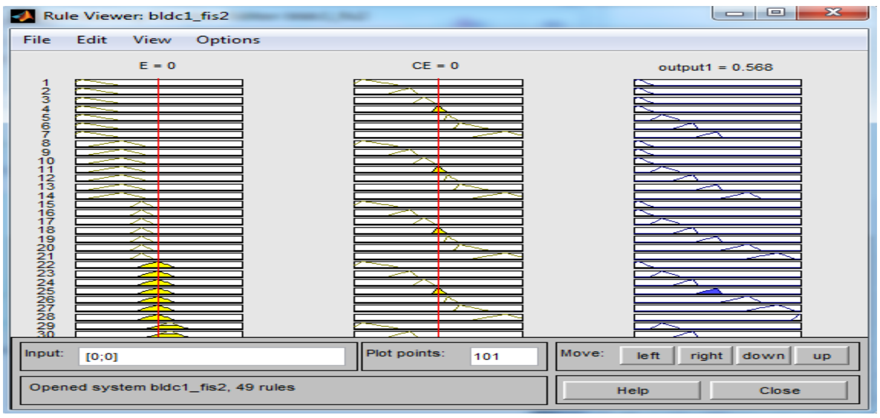
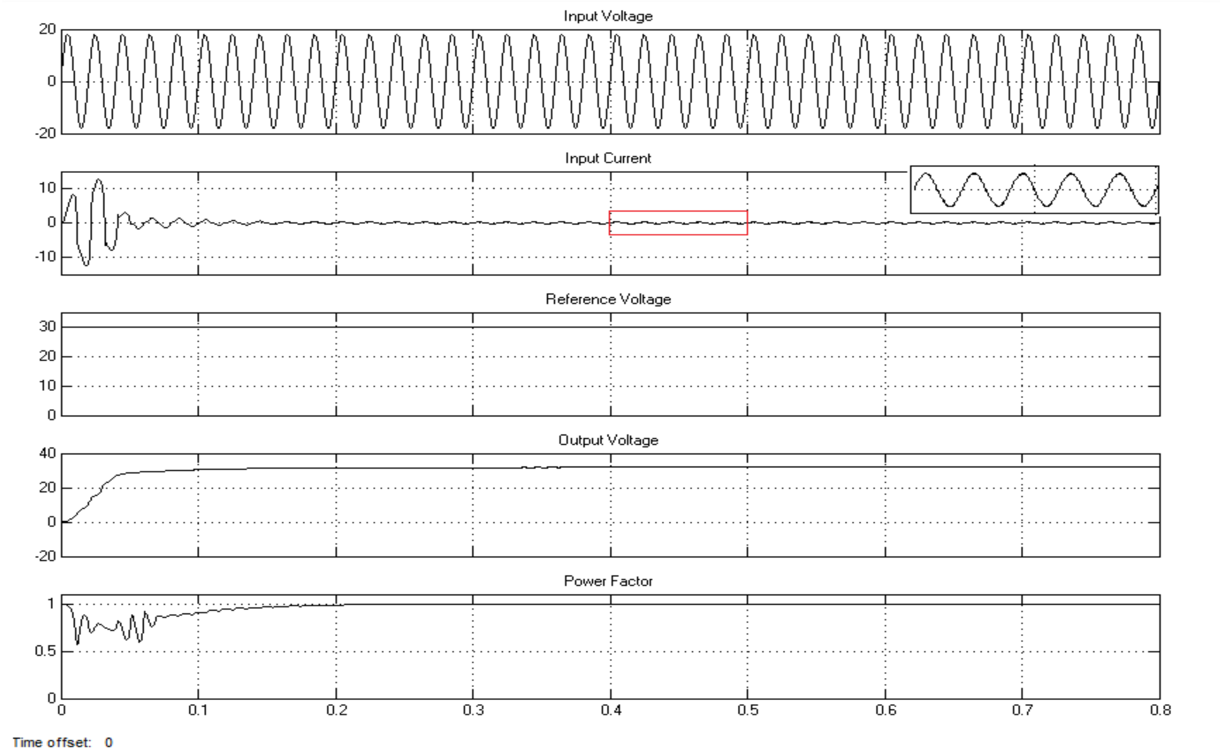


(g)

Fig. 7.MATLAB implementation of fuzzy logic controller (a). FIS Editor (b). Membership function shapes for error (c). Membership function shapes for change in error (d). Membership function shapes for output (e). Rule Editor (f). Surface Viewer (g). Rule Viewer



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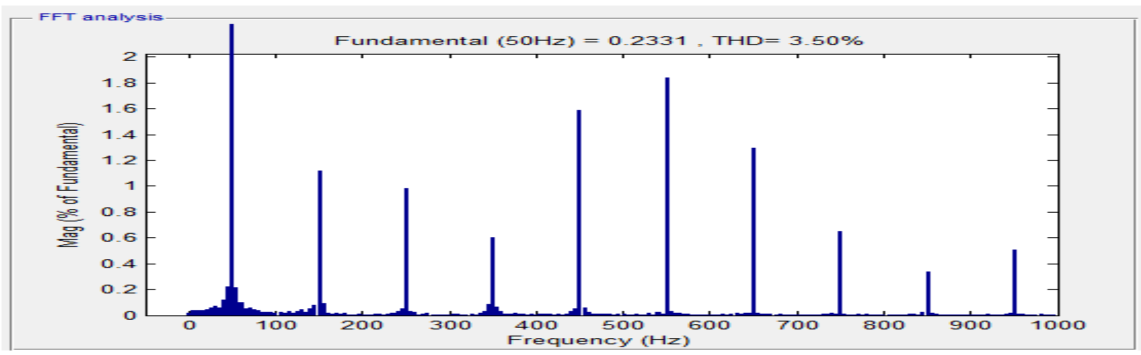

(b)

Fig. 8. Experimental results of SMPS with proposed PFC method (a). Waveforms of the input voltage, input current, reference voltage, output voltage and power factor (b). Total harmonic distortion of input current

The performance of proposed fuzzy logic based ACM control technique for boost PFC SMPS is represented in Table 3.From the experimental result, it is observed that the transient peak input current is reduced to 12A from 32A without PFC, current draw from the input is almost sinusoidal shown in the top right corner of input current waveform, the power factor is almost unity and THD is below 5%. The output voltage obtained is approximately equal to a reference voltage (30V). The steady-state average input current with PFC is reduced to 0.2356A. The performance of proposed fuzzy logic based ACM control technique for boost PFC SMPS under input voltage variations and load variations is represented in Table 4 and Table 5 respectively. The load (1000Ω) is fixed to obtain the system performance with input voltage variations. To obtain the performance of the system with load variations the input voltage (18V) is fixed.

Table 3.Performance of proposed PFC system

S No.	Performance factors of source and load side	Value
1.	Displacement factor	0.9996
2.	Distortion factor	0.9994
3.	Power factor (PF)	0.999
4.	Total harmonic distortion (THD)	3.5%
5.	Input current	0.2356A
6.	Output voltage	31.8V

Table 4. Performance of proposed PFC system under input voltage variations

Input voltage	With proposed PFC				
	Displacement factor	Distortion factor	PF	THD	Output voltage
17V	0.9993	0.9985	0.9978	5.425%	31.66V
18V	0.9996	0.9994	0.999	3.5%	31.80V
19V	0.9998	0.9984	0.9981	5.671%	31.97V

Table5. Performance of proposed PFC system under load variations

Load	With proposed PFC				
	Displacement factor	Distortion factor	PF	THD	Output voltage
900Ω	0.9994	0.9991	0.9985	4.283%	31.74V
1000Ω	0.9996	0.9994	0.999	3.5%	31.80V
1100Ω	0.9997	0.9992	0.9989	3.978%	31.86V

IV. Conclusion

This paper introduces a fuzzy logic based average current mode control scheme for boost PFC SMPS without outer loop controller and with inner loop controller. Even though no controller is presented in outer loop the output voltage regulation of proposed system for input voltage variations and load variations is good. The performance of the fuzzy logic controller presented in the inner loop of proposed PFC system is excellent in shaping the line current, reducing THD and improving power factor. The proposed PFC system is simulated in MATLAB and the experimental results are obtained with uncertainties and disturbances. The experimental results show the feasibility of proposed controller for PFC of SMPSs. The power factor of the proposed system with PFC is 0.999 and total harmonic distortion is 3.5%, hence efficiency is also high.

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