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Performance Evaluation of Fuzzy and PI Controller for Boost Converter with Active PFC

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ABSTRACT

In this paper, the problem of controlling AC-DC full bridge converter is considered. The control objectives are two, one is guaranteeing a regulated voltage for the connected load and second one is enforcing power factor correction (PFC) with input current sinusoidal. Power factor correction of Boost converter is done by using fuzzy control technique. The inner loop has a current error amplifier which improves the power factor by properly shaping the input current in accordance with its reference. This reference signal is always synchronized and proportional to the line voltage hence the input current comes in phase with the input voltage. Thus by improving the power factor maximum active power can be delivered to the load. The voltage loop is being controlled by the fuzzy controller and the multiplier. Voltage regulation is done by the fuzzy controller and input distortion is minimized by the fuzzy controller. The desired features of an active PFC technique are close to Unity Power Factor operation, less than 10 % total harmonic distortion in line current and simple control strategy. The fuzzy control technique gives better performance during different line voltage and load. The results are verified through MATLAB/Simulink.

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1. INTRODUCTION

In the attempt to meet standard requirements (like IEC 555-2), many rectifier topologies and control techniques have been proposed, which provide almost unity power factor. In most solutions, however, the main effort is dedicated to improve the quality of the input current waveform, while dynamic response of the output voltage is sacrificed [3]. In fact, due to input power fluctuation, the output voltage contains a low-frequency ripple at twice the line frequency, which must be outside the voltage loop bandwidth in order to avoid input current distortion.

In the attempt to overcome this limitation, average current control, which allows improved response to the detriment of a higher input current distortion, was proposed in [4], while other techniques, aimed to remove the low-frequency ripple from the feedback signal, were analyzed in [5]. Also the Fuzzy Logic Control (FLC) seems very powerful for this purpose: in fact, fuzzy control rules can be written so as to allow low-distorted and m-phase line current during normal operation and fast dynamic response during transient conditions.

Since the fuzzy control rules derive from a heuristic knowledge of system's behaviour neither precise mathematical modelling nor complex computations are needed [6], [7] to design the fuzzy controller. In fact, design is simple, since it is based on linguistic rules of the type: "if the output voltage error is positive and their rates of change are negative then reduce slightly the duty-cycle", and so on. This approach relies on the basic physical properties of the system and it is potentially able to extend the control capability even to those operating conditions where linear control techniques fail, i.e. large-signal dynamic and large parameter variations. Of course, fuzzy controllers cannot provide, in general, better small signal response than standard regulators. In fact the insight given by a detailed mathematical model of the system is superior to that given by a simple linguistic description of its behaviour.

In particular, in PFP's application the fuzzy logic may overcome the voltage loop bandwidth limitation provided that some input current distortion is accepted (with the limits posed by the standards). From this point of view, fuzzy logic is a powerful tool because, by properly weighting the input current and the output voltage errors, it can provide an optimal trade-off between the needs for improving dynamic response and reducing input current distortion. Another advantage of the FLC approach is its generality, since almost the same control rules can be applied to several pre-regulator topologies; however, some scale factors must be tuned according to converter topology and parameters.

In the first section, the importance of power factor and the need of fuzzy logic controller are explained. In the second section, the proposed system configuration for PFC and the fuzzy control technique are discussed. Its operation, circuit description, designing of error amplifier and its control technique are analyzed in this chapter. In third section, simulation results of boost converter without control technique and both PI and Fuzzy control techniques are discussed. The performance of evaluation for both control techniques are studied for different input voltage.

2. Proposed System Configuration

Figure 1 shows the system configuration of fuzzy control based boost converter for active PFC. It consists of two loops first one is called fast loop and second one is called slow loop. Fast one is nothing but the inner current control loop and slow one is called fuzzy control loop. The fuzzy (or) feedback control loop is responsible for regulating the output voltage and the current (or) feed forward control loop is responsible for programming the input current, so that it follows the same sinusoidal waveform as the input voltage [2].

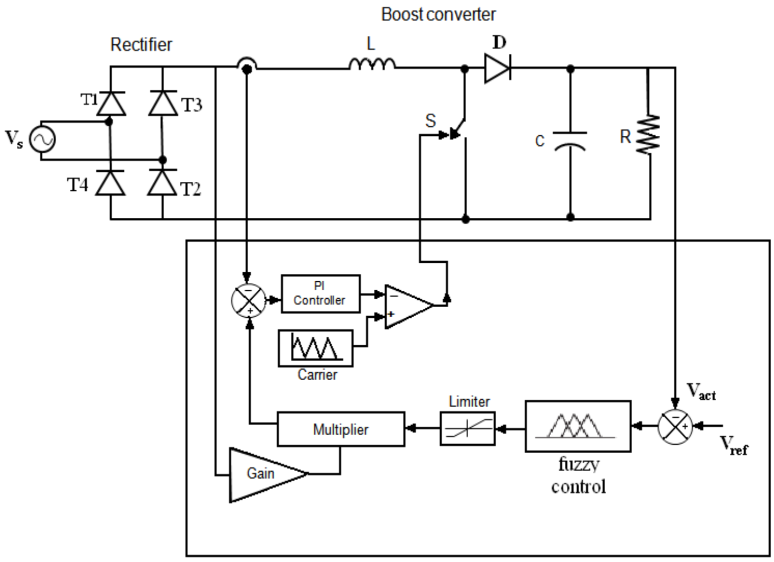


Figure 1. Boost PFC converter with proposed control

2.1. Fuzzy Control scheme

In order to implement the control algorithm of a shunt active power filter in closed loop, the DC side capacitor voltage is sensed and then compared with a reference value. The obtained error is given eqn (1)

$$e\,(n) = V_{dc} \quad (1)$$

and

Change of error signal is given in eqn (2)

$$Ce(n) = e\,(n) - e\,(n-1) \qquad (2)$$

at the n^{th} sampling instant are used as inputs for the fuzzy processing. The control scheme is shown in Figure 1. The output of the fuzzy controller after a limit is considered as the amplitude of the reference current I_{max}. This current I_{max} takes care of the active power demand of load and the losses in the system.

2.2 Basic Fuzzy Algorithm

The internal structure of the fuzzy controller is shown in Figure 2. The error *e* and change of error *ce*are used numerical variables from the real system[1]. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in Figure.2.

The fuzzy controller is characterized as follows:

(i) Seven fuzzy sets for each input and output.
(ii) Fuzzification using continuous universe of discourse.
(iii) Implication using Mamdani's 'min' operator.
(iv) Defuzzification using the 'bisector' method.

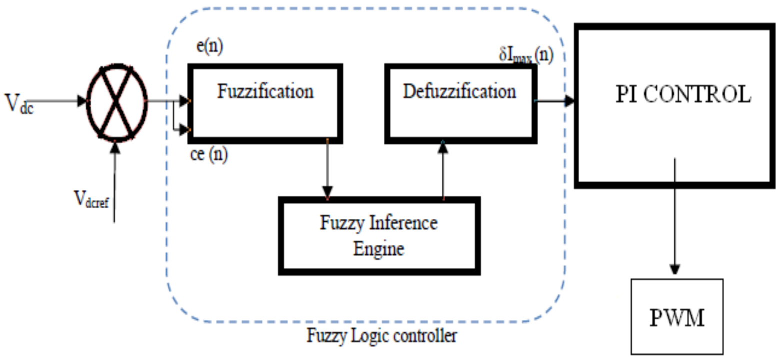


Figure 2. Internal Structure of Fuzzy controller

2.3 Rule Base

The elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with error and change in error as inputs [1].

Table 1. control rule base

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
NB	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

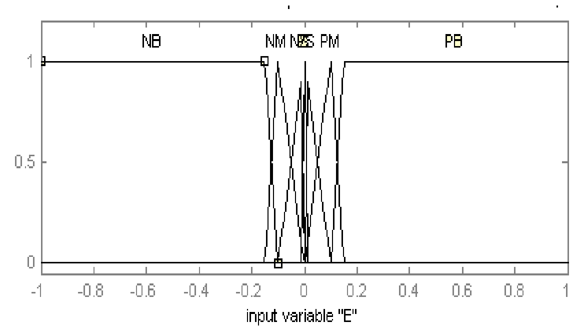


Figure 3a. Input variable ‘E’ Normalized Membership Function

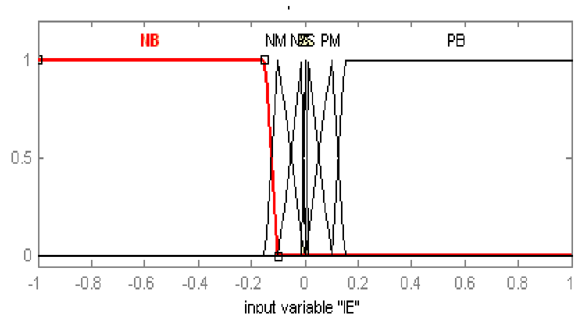


Figure 3b. Input variable ‘CE’ Normalized Membership Function

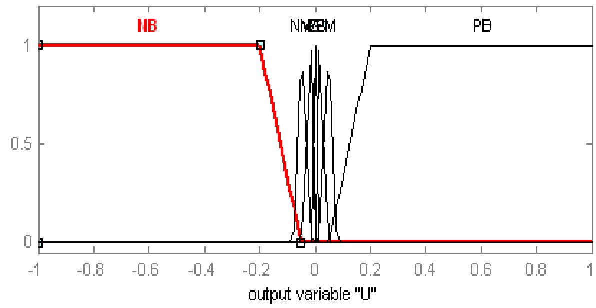


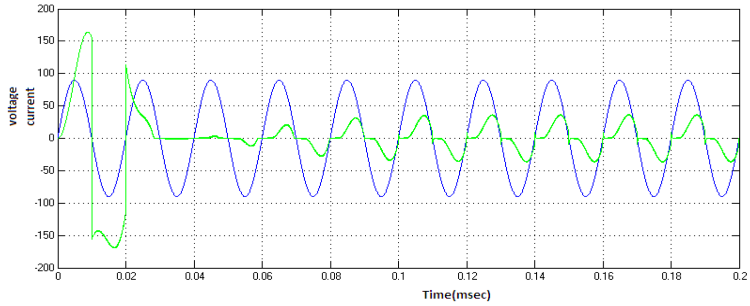
Figure 3c. Output variable ‘U’ Normalized Membership Function

2.4 Inner current loop

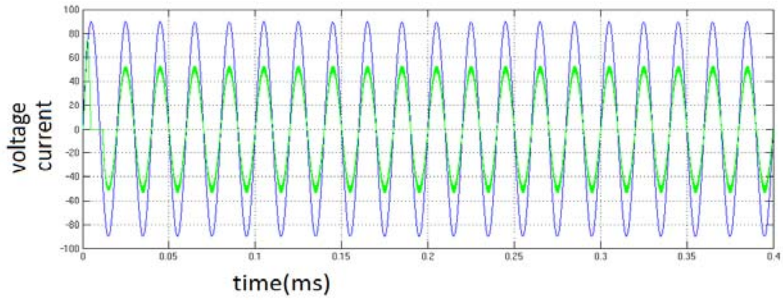
In the current loop, the sensed inductor current is compared with the reference current profile using a current error amplifier. In the fuzzy controller loop the controller generate a reference current profile and the reference current profile is employed by the inner current loop for input current shaping. In the inner current loop the current error amplifier generate a error signal is then fed into the PWM modulator, where the logical gate drive signal is produced by comparing the current error with a fixed frequency saw tooth [2]. In this way the inductor current is programmed by the current loop to follow the sinusoidal envelope of the input voltage and a near unity power factor to achieve output voltage regulation.

3. RESULT AND DISCUSSION

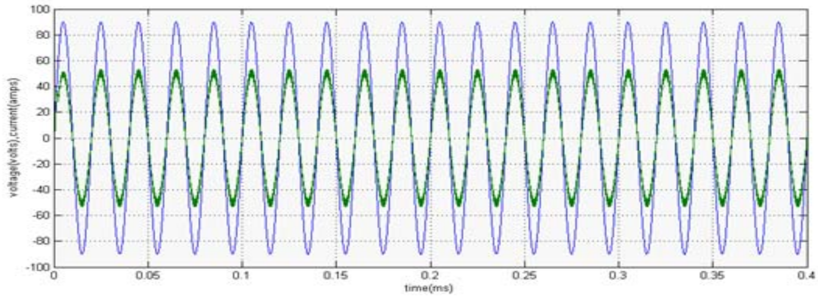
To show the effectiveness of fuzzy control based power factor correction boost converter, mathematical simulation has been carried out by using MATLAB/Simulink. The simulation parameters and specifications of boost converter used in this paper are given in Appendix. For the simulation, the reference output voltage is taken as 400V.



(a)



(b)

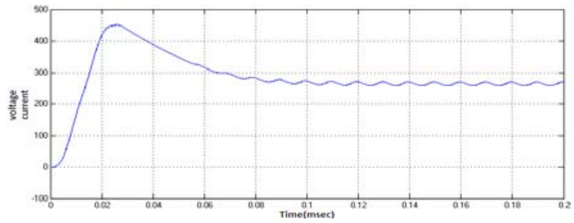


(c)

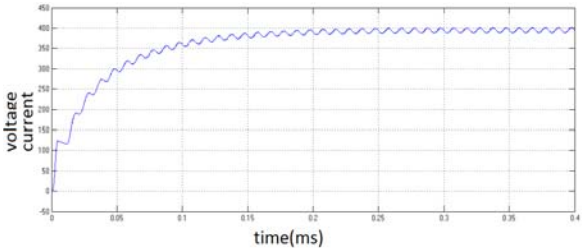
Figure 4. Simulated waveform for input voltage in phase with line current (a) Without control technique (b) PI controller (c) fuzzy controller at line voltage is 90V.

Figure 4 (a) shows the response of open loop PFC boost converter input voltage in phase with line current, figure 4 (b) shows the response of PI control PFC boost converter input voltage in phase with line current and figure 4. (c) Shows the response of fuzzy control PFC boost converter input voltage in phase with line current. Comparing all the three techniques fuzzy control PFC boost converter is optimum one and power factor of the boost converter is improved to near unity (0.999).

Figure 5 (a) shows the response of open loop PFC boost converter output voltage; figure 5 (b) shows the response of PI control PFC boost converter output voltage and figure 5. (c) Shows the response of fuzzy control PFC boost converter output voltage. Comparing all the three techniques fuzzy control PFC boost converter is optimum one, the output voltage is regulated and settling time of the output voltage improved (0.065ms) in fuzzy control technique.



(a)



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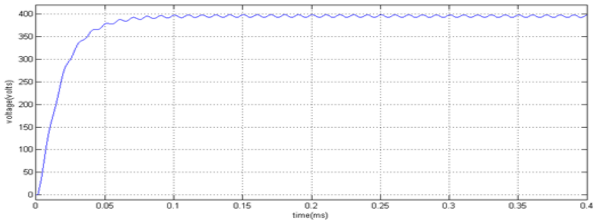
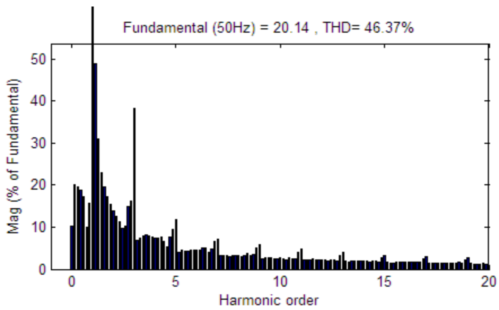
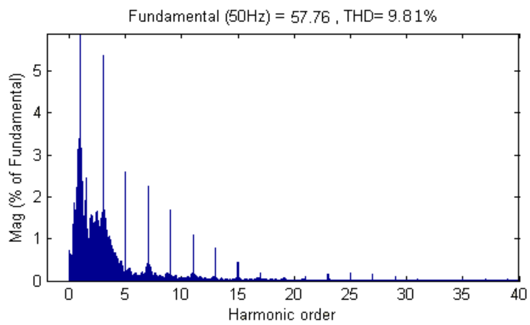


(c)

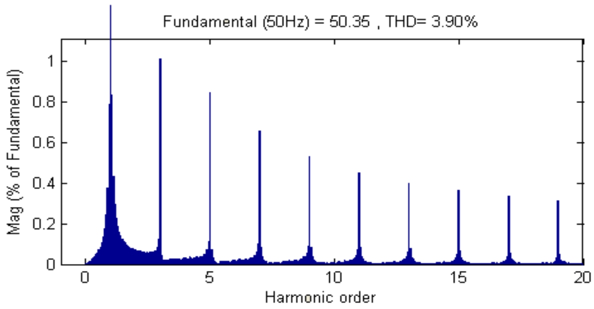
Figure 5. Simulated waveform for Output voltage (a) Without control technique (b) PI controller (c) fuzzy controller at line voltage is 90V.



(a)



(b)



(c)

Figure 6. Simulated waveform for THD (%) (a) Without control technique (b) PI controller (c) fuzzy controller at line voltage is 90V.

Figure 6 (a) shows the response of open loop PFC boost converter THD (%), figure 6 (b) shows the response of PI control PFC boost converter THD (%) and figure 6. (c) Shows the response of fuzzy control PFC boost converter THD (%). Comparing all the three techniques fuzzy control PFC boost converter is optimum one and the THD (%) of the fuzzy controller is improved to 3.90%.

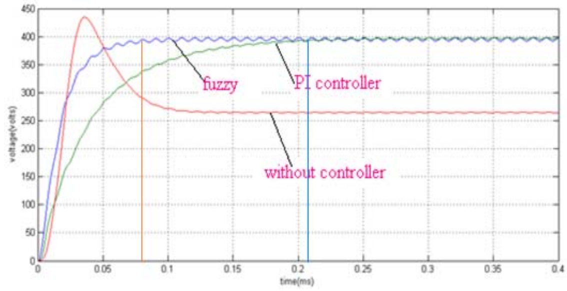


Figure 7. Simulated waveforms of Output voltage for different control techniques at line voltage is 90V

Figure 7. Shows the simulated response of output voltage for different control techniques, among all the three techniques fuzzy control technique has better performance and the settling time of the fuzzy control is improved that is 0.065ms.

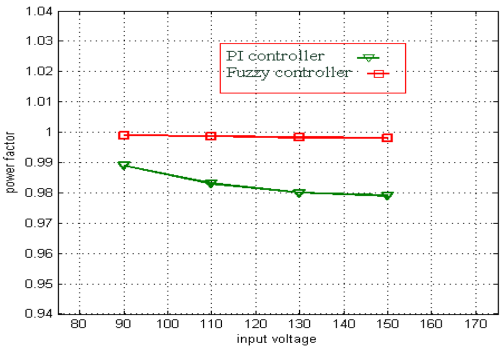


Figure 8. Waveforms for variation of input voltage versus power factor for different control techniques

Figure 8 shows the analysis of the variation of input voltage versus power factor for PI controller and Fuzzy controller. In this figure shows the input voltage increases and the power factor decreases. In these waveforms fuzzy control technique improves the power factor near unity (0.999).

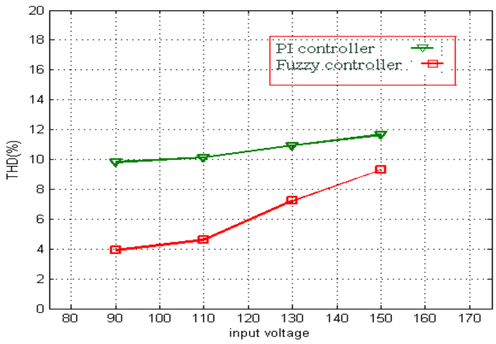


Figure 9. Waveforms for variation of input voltage versus THD (%) for different control techniques

Figure 9. Shows the analysis of the variation of input voltage vs input current THD (%) for PI controller and Fuzzy controller. In this figure shows the input voltage increases and the power factor decreases. In this waveform fuzzy control technique improves the input current THD (%) that is 3.90% as shown in the Table 2.

Table 2. Summary of PI and Fuzzy controller settling time

Sl.No	Type of Controller	Settling Time (ms)
01	PI	0.22
02	FUZZY	0.066

Table 3. Comparison of %THDs and power factor with different line voltage

PFC without control technique			Average current control technique			Fuzzy control technique		
voltage	Current THD (%)	P.F	voltage	Current THD (%)	P.F	Voltage	Current THD (%)	P.F
150	53.37	0.567	150	11.66	0.979	150	9.31	0.9981
130	50.02	0.592	130	10.92	0.980	130	7.23	0.9983
110	48.67	0.624	110	10.13	0.983	110	4.60	0.9986
90	46.37	0.676	90	9.81	0.989	90	3.90	0.999

4. CONCLUSION

The performance of a fuzzy logic controller and PI controller for boost converter with active power factor correction has been studied. It can be concluded that fuzzy controller has a better transient response compared to a conventional PI controller, and the steady state performance of the fuzzy controller is comparable to the PI controller. The performance of the different control techniques compares, the fuzzy control is better to compare with PI controller and the settling time of the fuzzy controller is 0.065ms and PI controller is 0.22ms. With reference to Table 3, it can be concluded that the dynamic performance of the fuzzy controller is also better than PI controller. Superior performance of the system with fuzzy controller has been observed, which is able to reduce the harmonics below 10% in all cases studied, the harmonic limit imposed by the IEEE-519 standard.

REFERENCES

[1] C.S. Perumalla, P.C. Panda and S. Mishra, "Fuzzy Controlled Harmonic Suppressor and Reactive Volt Ampere Compensator for Enhancing Power Quality", *proceeding IEEE 2009*, pp, 49-54.

[2] D. Lenine et.al, “A Variable Switching Frequency with Boost Power Factor Correction Converter”, *TELKOMNIKA International Journal (Indonesia Journal of Electrical Engineering)*, Vol. 9, No. 1, April 2011, pp. 47-54.

[3] Zhou, Jovanovic, "*Design Trade-offs in Continuous Current-mode Controlled Boost Power-Factor Correction Circuits'*," HFPC Cod. proc., 1992, pp. 209-220.

[4] L. Rosetta, G. Spiazzi, P. Tenti, B. Fabiana, C. Licitra, "Fast- Response High-Quality Rectifier with Sliding-Mode Control", *IEEE Trans. on Pwer Electronics*, vol. 9 , no. 2, pp. 146-152, March 1994.

[5] J. B. Williams, "*Design of Feedback Loop in Unity Power Factor AC to DC Converter*", PESC Cod. Proc., 1989, pp. 959-967.

[6] L.A. Zadeh, "Outline of a New Approach of the Analysis of Complex System and Decision Processes", *IEEE Trans. on System, Man and Cybematics*, Vol. SMG3, No. l, pp. 28-44, 1973.

[7] C.C. Lee, "Fuzzy Logic in Control System: Fuzzy Logic Controller -Part I/ Part 11", *IEEE Trans. on System, Man and Cybematics*, v 01.20, n. 2, pp 404-418, Marc W April1990.

[8] Ing. Esp. Fredy H. Martinez S., Ing. Teg. Diego F. Gomez M., “Fuzzy Logic Controller for Boost Converter with Active Power Factor Correction”, *proceeding IEEE*, 2008, pp, 936-940.

[9] Hugh Rudnick, Juan Dixon and Luis Morán, “Active power filters as a solution to power quality problems in distribution networks”, *IEEE power & energy magazine*, pp. 32-40, September/October 2003.

[10] H. S. H. Chung, E. P. W. Tam, and S. Y. R. Hui, “Development of a fuzzy Logic Controller for Boost Rectifier with Active Power Factor Correction”, in *30th Annual IEEE Power Electronics Specialists Conference*, 1999, PESC 99, pp. 149-154.

[11] A. Khoshooei, and 1. S. Moghani, “Implementation of a Single Input Fuzzy Controller for a High Power Factor Boost Converter”, in *IEEEAFRICON, 7th African conference in Africa, Technology innovation*, 2004, Gaborone, Botswana, pp. 69-72.

[12] A. Rubaai, M. F. Chouikha, “Design and Analysis of Fuzzy Controllers for DC-DC Converters”, in *First International Symposium on Control, Communications and Signal Processing*, 2004, pp. 479- 482.

[13] Singh, B., Chandra, A., and Al-Haddad K., “computer aided modelling and simulation of active power filters”, *Electr. Mach, Power system*, pp.1227- 1241, 1999.

[14] DUKE R.M., and Round S.D., “The steady state performance of controlled current active filter”, *IEEE Transactions. Power Electron*, pp. 140-146, 1993.

[15] Chatterjee, K, Feknandes, H.G., And Dubey, G.K. “An instantaneous reactive volt-ampere compensator and harmonic supperessor”. *IEEE Transactions, Power Electron*, pp. 381- 392, 1999.

[16] Parmod Kumar and Alka Mahajan, “Soft Computing Techniques for the Control of an Active Power Filter”, *IEEE transactions on power delivery*, vol. 24, no. 1, January 2009, pp. 452-461.

[17] H. Y. Kanaan and K. Al-Haddad, “A Novel Averaged-Model- Based Control of a SEPIC Power Factor Corrector Using the Input/Output Feedback Linearization Technique”, in *Proc. IEEE PESC’05*, Recife, Brazil, June 12-16, 2005.

[18] A. Pandey, Prof B. Singh, “Comparative Evaluation of Single phase Unity Power Factor ac-dc Boost Converter Topologies”, *IEEE proc.* November 30, 2004. pp, 102-109.

[19] O. Garcia, J. A. Cobos, R. Prieto, P. Alou, and J. Uceda, “Single phase power factor correction: A survey”, *IEEE Trans. Power Electron.*, vol. 18, no. 3, pp. 749–755, May 2003.

[20] D. O’Sullivan, H. Spruyt, and A. Crausaz, “PWM conductance control,” in *IEEE Power Electron. Specialists Conference*, 1988, pp. 351-359.

[21] A. S. Kislovski, “Small-signal low-frequency analysis of a buck type PWM conductance controller”, in *IEEE Power Electron. Specialists Conference.* 1990, pp. 88-95.

[22] L. H. Dixon, “Average current-mode control of switching power supplies”, in *Unitrode Power Supply Design Seminar Handbook*, 1990.

[23] A. R. Brown, “*Topics in the analysis, measurement, and design of high performance switching regulator*”, Ph.D. dissertation, Califomia Inst. Technol., Pasadena, May 1981.

[24] R. B. Ridley, “*A new small-signal model for current-mode control*”, Ph.D. dissertation, Virginia Polytechnic Inst. State Univ., Blacksburg, Nov. 1990.

[25] A. R. Brown, “*Topics in the analysis, measurement, and design of high performance switching regulator,*” Ph.D. dissertation, Califomia Inst. Technol., Pasadena, May 1981.