International Conference on Computer, Communication, Chemical, Materials and Electronic Engineering (IC4ME2), 11-12 July, 2019

Power Quality Improvement with Single Phase Boost Rectifier using Fuzzy Logic Control

Kamrul Huda,[1,*] Sabbir Ahamed Shuvo,[1] Kazi Abu Zilani[1] and Mohammad Rubaiyat Tanvir Hossain[1,º]
[1]Department of Electrical and Electronic Engineering
Chittagong University of Engineering and Technology, Chittagong, Bangladesh
*kamrulhudamishu@gmail.com, ºmrthossain@cuet.ac.bd

***Abstract*— For regulation of DC output voltage with unity power factor of AC-DC converter, a controlling procedure has been introduced in this paper which accounts for the effects of harmonics in non-linear loads. The scheme incorporates a single phase full bridge rectifier in conjunction with a PFC boost converter controlled by the fuzzy logic controller. The non-linear effects of bridge rectifier is compensated by hysteresis current control technique directed by the boost converter. The results show that the proposed controller can regulate the DC output voltage over a wide range of load and input voltage variation while making the input current sinusoidal with improved power factor.**

***Keywords*— power factor correction, harmonic distortion, switch mode power supply, fuzzy logic controller, hysteresis current control.**

I. INTRODUCTION

Currently, the demand of switch mode ac-dc power converters is rising at a faster rate for various applications such as electronic ballasts, pumps, fans, compressors, motor drives, power supply units, etc. Traditional ac-dc converter consists of a diode bridge with a large filter capacitor at the dc side in order to retain ripple free DC output voltage. As a result, rectifier draws distorted current from the utility and input power factor becomes poor [1]. In order to resolve this problem, mainly two forms of power factor correction (PFC) technique are available - active PFC and passive PFC [2].

Passive PFC is done with filter inductor and capacitor. This method is simple and reliable, but it has few drawbacks such as, bulk sized filter, high inductor current, high capacitive voltage, uncontrolled output voltage, series and parallel resonance etc. [2]. On the other hand, Active PFC technique uses high switching frequency PWM Boost converter that regulates the output voltage and shapes the input current by appropriate voltage and current control strategies [3-7].

In this paper, a PFC boost converter with fuzzy logic controller has been used the in the outer voltage control loop and hysteresis current controller has been employed in the inner current control loop in order to obtain controlled DC output voltage and high input power factor with sinusoidal input current. Among various current control methods like average current control, peak current control, hysteresis current control etc. [8-9], hysteresis current control is broadly used due to its simple implementation process, enlargement of system stability, fast response and less distortion in input current waveform [10]. Fuzzy logic controller has several advantages over conventional controller like non-requirement of mathematical model, excellent performance under large load variations, better performance under parameter variations, coping with the nonlinearity issues of switches and loads, etc. [11-12].

II. PROPOSED METHODOLOGY

Block diagram of the proposed method is illustrated in Fig. 1. Among the two control loops, outer loop is used to track the output voltage and inner loop is used to track the inductor current.

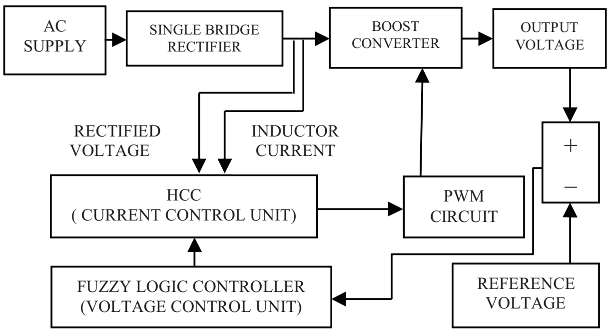

Fig. 1 Block diagram of the proposed method

The Boost rectifier which is shown in Fig. 2 has two operating states. The inductor current energizes and starts to build up through its magnetic field during the ON state of the switch. When the MOSFET switch is OFF, the inductor starts to de-energize as it supplies energy to the load and recharge the capacitor. As a result, inductor current reduces.

As inductor current changes with the change of the switching states, inductor current can be adjusted by controlling the duty cycle of the switching signal. In order to obtain sinusoidal input current in phase with sinusoidal input voltage, the rectified input voltage is compared with the inductor current. Here, the input voltage works as a reference wave for the inductor current wave and its magnitude is controlled by the output of the fuzzy logic controller.

A. Fuzzy Logic Controller

Fuzzy logic controller (FLC) is based on fuzzy logic theorem. It utilizes a simple approach to make obvious conclusions from indefinite, imprecise, ambiguous information.

In the proposed FLC, error voltage and change of error voltage are used as inputs and change in control voltage is used as output. The 'error voltage' is obtained by comparing the measured dc output voltage with the reference voltage,. The difference between present error voltage and previous error voltage is taken as 'change of error voltage'. The equations for the input variables are as follows:

$$\text{Error} = V_{ref} - V_{out} \tag{1}$$

$$\text{Ce} = \text{error}_{(k)} - \text{error}_{(k-1)} \tag{2}$$

978-1-7281-3060-6/19/$31.00 ©2019 IEEE

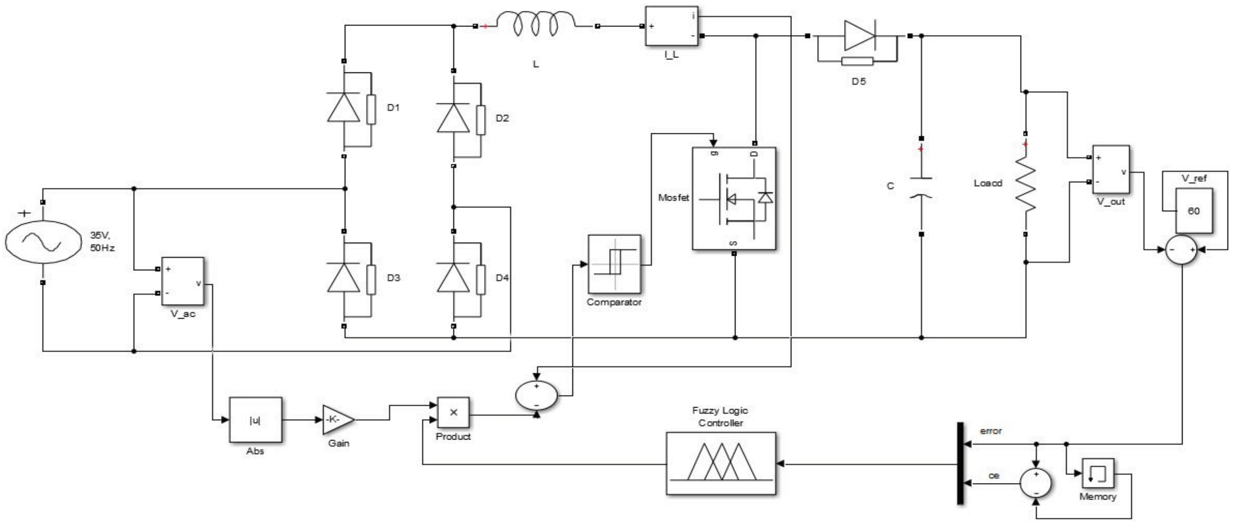

Fig. 2 Single phase bridge rectifier with PFC boost converter controlled by fuzzy logic controller

Every input and output variables of the fuzzy logic controller is allotted five linguistic fuzzy subsets [negative big (NB), negative small (NS), zero (Z), positive big (PB), positive small (PS)]. Every fuzzy subset is affiliated with a triangular membership function. For a particular fuzzy set the grade of membership can be varied between 0 to 1.

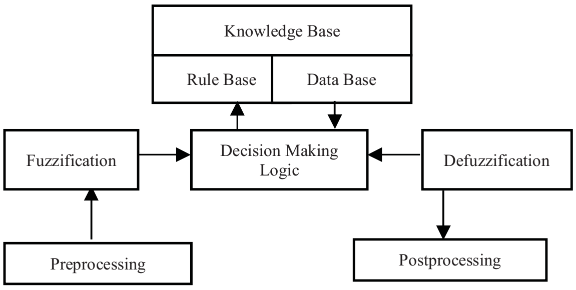

Fig. 3 Structure of the Fuzzy logic controller

Fuzzy rule table is based on the relationship of transient state errors on input-output variables. Usually, coarse control is used on the variables in question to handle large mismatches in the transient mode while small mismatches are dealt with fine controlling technique in the steady mode. This theory gives way to the Fuzzy rule table as follows:

TABLE I. FUZZY RULE TABLE

Error / Ce	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

B. *Hysteresis Current Controller*

HCC takes the current error as input which is the difference between inductor current and reference current. It produces the switching command 1 or 0 as output. HCC maintains the inductor current in a fixed band, which consists of an upper band current and a lower band current. Whenever inductor current crosses these bands, switching command changes from 0 to 1 or vice versa. According to the algorithm of this method, inductor current increases when switching command is 1 and decreases when switching command is 0. The algorithm for this HCC method is as follows:

Whenever, inductor current > upper band current, then d=0
And when inductor current < lower band current, then d=1

$$\text{Upper band current} = I_{m,ref} * \sin(\omega t) + \Delta I/2 \quad (3)$$

$$\text{Lower band current} = I_{m,ref} * \sin(\omega t) - \Delta I/2 \quad (4)$$

Here, ΔI is the hysteresis band.

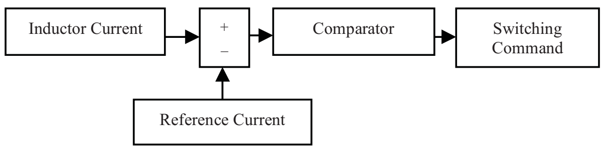

Fig. 4 Block diagram of hysteresis current control

IV. SIMULATION RESULTS

The Boost PFC circuit as shown in Fig. 2 has been simulated using MATLAB Simulink tool. Following specifications are used to simulate the circuit:

TABLE II. SPECIFICATIONS OF CONVERTER USED

Source voltage	35V(p-p)
Line frequency	50Hz
Boost inductor	2.5mH
Capacitor	2.2mF
Reference voltage	60V

Simulation of the circuit is done for the different range of the loads. Result shows that, with controlled dc output voltage the source voltage and input ac current is in phase under large load variations.

Fig. 5 shows without PFC boost circuit the waveform of the input current in the single phase bridge rectifier is highly distorted with poor power factor. Whereas with the proposed PFC boost converter controlled by Fuzzy logic controller, the input current distortion is reduced and the waveform becomes nearly sinusoidal with almost unity power factor as demonstrated in Fig. 6.

FFT analysis in Fig. 7 and Fig. 8 show that, the total harmonic distortions (THD) of the input ac current without the proposed method is 155% (Fig. 7). But with the proposed control algorithm, THD becomes 3.42% (Fig. 8). Again Fig. 9 shows that, despite a large load variation, the dc output voltage remains almost constant.

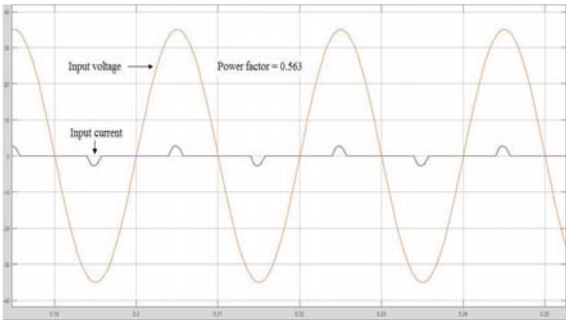

Fig. 5 Input voltage and current waveform of single phase brige rectifier with filter capacitor.

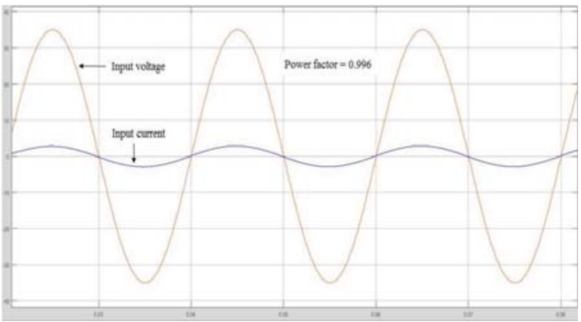

Fig. 6. Input voltage and current waveform of PFC boost converter

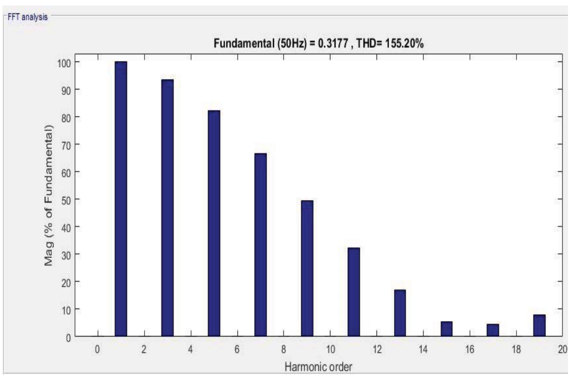

Fig. 7 Harmonic spectrum of input current single phase brige rectifier with filter capacitor.

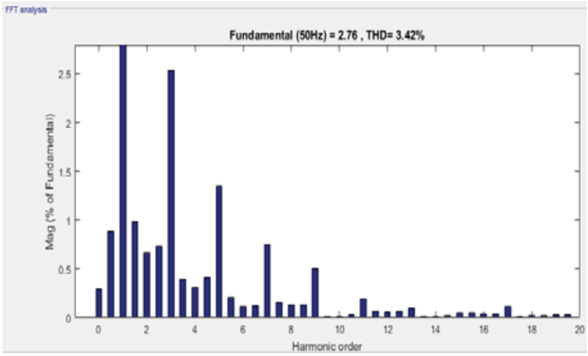

Fig. 8 Harmonic spectrum of input current with PFC boost converter

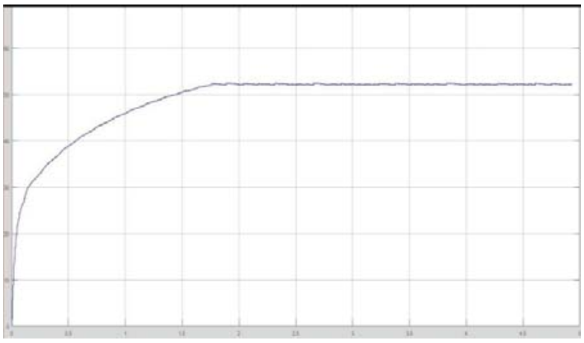

Fig. 9 Controlled DC output voltage at different loads

V. EXPERIMENTAL VERIFICATION

For experimental validation as shown in Fig. 10, the power supply has been provided by using a step-down transformer (220V/35V) at a line frequency of 50Hz. The output of the transformer is converted into 40V pulsating DC by utilizing a single phase bridge rectifier. In order to make the DC voltage ripple free, a capacitor of 2.2mF is used. To reduce the harmonic current which is drawn by this capacitor, a boost converter comprised of a ferrite core inductor of 2.78mH, a MOSFET switch (IRF30N), and a diode is implemented at the final end of the rectifier. The fuzzy logic algorithm is implemented by using ARDUINO UNO which contains ARDUINO microcontroller ATmega328. In order to control the MOSFET switch, ARDUINO UNO takes three inputs from the circuit which are rectified voltage, inductor current, and DC output voltage. As the maximum input analog voltage is 5V in ARDUINO UNO, so voltage divider with appropriate value has been used. In order to obtain a wide range of reference voltage, a potentiometer is used.

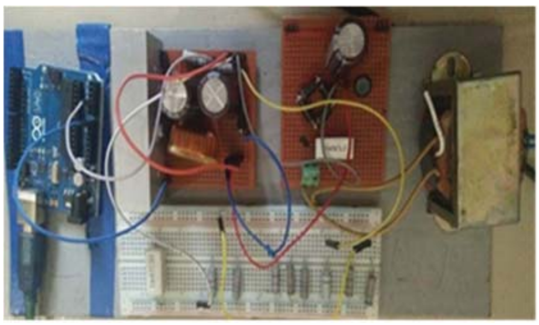

Fig. 10 Hardware implementation of the proposed method

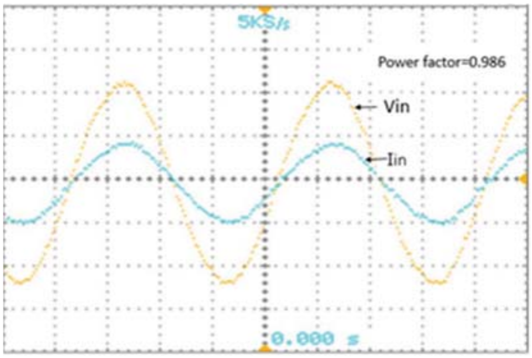

Fig. 11 Input voltage and current waveform with PFC boost converter

Fig. 11 shows that employing the proposed control scheme the input current becomes sinusoidal in shape and in phase with input voltage waveform even after a large load variation. The circuit has been tested at different loads and input voltages and the results show the regulated output voltage.

Load resistance has been changed over a wide range with fixed input voltage and later, input AC voltage is changed between $30V_{ac}$-$40V_{ac}$ while maintaining load resistance constant. The effect of these two cases over DC output volatge has been observed for both open loop control and with the proposed closed loop controller. From Figs. 12 and 13 it can be inferred that the proposed closed loop controller has better control over DC output voltage while changing the input voltage within a limited range and changing the load resistance over a wide range.

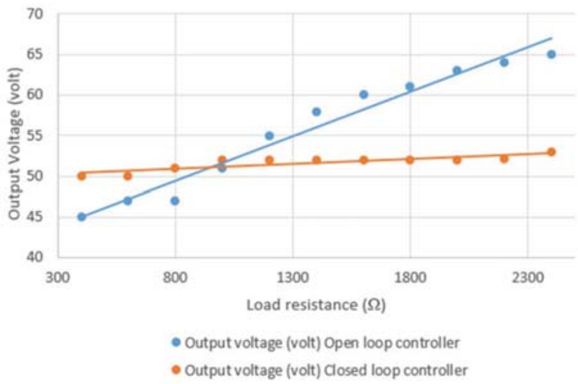

Fig. 12 Graph of change in output voltage with the change of load resistance (35V input)

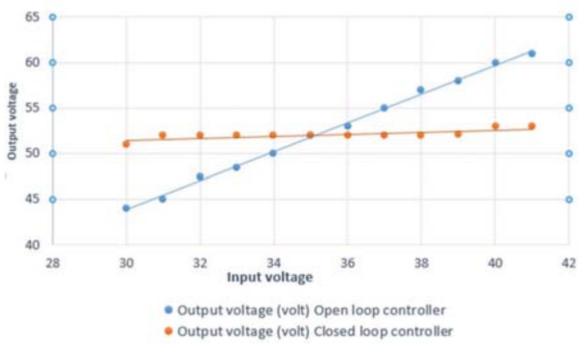

Fig. 13 Graph of change in output voltage with the change of input voltage (Fixed load)

VI. Conclusion

In this paper, the closed-loop performance of PFC Boost converter with fuzzy control scheme was verified through simulation and implementation. The undesirable impacts of the non-linear load on the system are counterbalanced by the PFC technique. The proposed controller applied to obtain the unity power factor shows better power quality indices, better command in rejection of load and input voltage disturbance and good robustness. Adding more membership functions, fuzzy rules and watchful tuning in controller parameters can increase the final outcome of the fuzzy logic controller even more.

References

[1] S. B. Mehta and J. A. Makwana, "Power factor improvement of SMPS using PFC Boost Converter," *International Journal of Application or Innovation in Engineering & Management (IJAIEM),* vol. 3, no. 4, pp. 299--304, 2014.

[2] H. Z. Azazi, E. E. EL-Kholy, S. A. Mahmoud and S. S. Shokralla, "Review of Passive and Active Circuits for Power Factor Correction in Single Phase, Low Power AC-DC Converters," in *Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10),* Egypt, 2010.

[3] M. K., P. Ramesh, and N. K. Kumari, "Analysis of Different Topologies For Active Power Factor Correction in DC-DC Converters," *Journal of Electrical Engineering*, pp. 1-8.

[4] F. H. Martinez and D. F. Gomez, "Fuzzy Logic Controller for Boost Converter with Active Power Factor Correction," in *The 7th International Conference on Power Electronics*, Daegu, 2007.

[5] T. Jayasri, D. V. Satyanarayana, S. T. P. Rajmannar and P. C. Rao, "Enhancement of Power Factor by Using Boost Converter in Non-Linear Loads," *International Journal of Innovative Studies in Sciences and Engineering Technology (IJISSET),* vol. 2, no. 4, pp. 17--21, 2016.

[6] A. Arif and D. T. Rao, "Improvement of Power Quality by Interleaved Boost Converter with Fuzzy Logic Controller," *IJREE - International Journal of Research in Electrical Engineering,* vol. 3, no. 3,pp.50--55,2016.

[7] W. Blasinski and H. Blasinski, "Large Signal Simulink Models of a Boost Converter in CCM and DCM modes," 2016.

[8] M. Hojabri, A. Z. Ahmad, A. Toudeshki and M. Soheilirad, "An Overview on Current Control Techniques for Grid-Connected Renewable Energy Systems," in *2nd International Conference on Power and Energy Systems (ICPES 2012),* Singapore, 2012.

[9] S. Zabihi and F. Zare, "An Adaptive Hysteresis Current Control Based on Unipolar PWM for Active Power Filters," in *Proceedings of the 2006 Australasian Universities Power Engineering Conference,* Brisbane, 2006.

[10] M. Kale and E. Ozdemir, "A New Hysteresis Band Current Control Technique for a Shunt Active," *Turkish Journal of Electrical Engineering & Computer Sciences,* pp. 654--655, 2015.

[11] A. Venkatesan, A. Mohan, G. K., and R. Seyezhai, "Comparative Study of Active Power Factor Correction in AC-DC Converters," *International Journal of Electrical, Electronics and Data Communication,* vol. 1, no. 1, pp. 13--17, 2013.

[12] A. I. Al-Odienat, and A. A. Al-Lawama, "The Advantages of PID Fuzzy Controllers Over The Conventional Types," *American Journal of Applied Sciences,* vol. 5, no. 6, pp. 653--658, 2008.