Fuzzy Logic Controlled Unity Power Factor Converter

Zeynep Bala Duranay, Hanifi Guldemir, Servet Tuncer

Abstract— A fuzzy logic controlled unity power factor ac-dc boost converter is simulated in this study. The dynamic behavior of an ac-dc boost converter is analysed with respect to the state of the switching element. The power factor relationship between the current and voltage is given. Fuzzy logic controlled unity power factor ac-dc boost converter is constructed and simulated. The controller is designed to drive the converter to operate in continuous conduction mode with near unity power factor with controllable output voltage. Simulations are made using Matlab/Simulink simulation package. Various reference voltages and load values are used in the simulations to see the influences of the reference and load changes. Simulation results are presented.

Index Terms— Boost, converter, fuzzy controller, fuzzy logic, harmonics, power factor correction, unity power factor

1 Introduction

Ac-dc conversion of electric power is necessary in many applications such as switch mode power supplies, battery charging systems, photovoltaic systems and variable speed systems. Ac-dc converters are used to provide dc conversion and they are very popular due to their high efficiency and small sizes. They provide power for computers, peripherals and many other electronic equipments. Ac-dc converters are the power electronic systems that convert a voltage level to another by switching the input voltage. There are different types of converters. The boost converter is the most used in many domestic and industrial electronic devices.

A diode bridge is used to convert ac voltage to dc voltage. This cause the current to be non-sinusoidal and a low power factor because of the nonlinear behavior of the ac-dc converter circuit. A Power Factor Correction (PFC) circuit added to converter to solve the low power factor problem is one of the solutions.

The PFC circuit consists of a regulator between the load and the diode rectifier. The current will be of sinusoidal shape and in phase with the input source voltage by controlling the switching scheme. Thus the Total Harmonic Distortion (THD) will also be decreased. A review of the power quality in single phase ac-dc converters is given in [1].

Different techniques are used for control of boost converters. Classical control techniques such as PI and PID [2], [3]; neural networks [4], [5]; sliding mode control [6], [7], [8] and fuzzy logic control [9], [10], [11] are the some of these control techniques. Classical controllers use state space average models linearised around an operating point with constant parameter. When the system parameters change the performance might lost [12].

- *Zeynep Bala Duranay is working in electrical electronics engineering in Firat University, Elazig, Turkey. E-mail: zbduranay@firat.edu.tr*
- *Hanifi Guldemir is working in electrical electronics engineering in Firat University, Elazig, Turkey. E-mail: hguldemir@firat.edu.tr*
- *Servet Tuncer is working in electrical electronics engineering in Firat University, Elazig, Turkey. E-mail: stuncer@firat.edu.tr*

Intelligent control techniques are used to obtain optimum performance even with parameter change and disturbances. The fuzzy logic provides a suitable control technique due to the nonlinear and ambigues structure of the systems [13]. Fuzzy logic first introduced by Zadeh in 1965 [14].

Fuzzy Logic Control is a robust control technique suitable for nonlinear systems with parametric fluctuation and uncertainties [15], [16].

It is a model independent technique and based on heuristics methods. It is used for modeling and control of uncertain systems which are difficult to be easily controlled by conventional control methods. Design of fuzzy controllers is based on expert knowledge of the system other than mathematical model. Fuzzy logic controllers provide advantages such as the dynamic performance, the robustness or the possibility to take into account an experimental knowledge of the process.

This paper presents a study of single phase PF control of boost converter using fuzzy logic and PI controllers for the voltage loop and current loop. The main objectives are to make the the current in the inductor to track a sinusoidal reference waveform and to regulate the output dc voltage to desired reference voltage. The designed controllers have been tested using MATLAB/Simulink

2 Dc-Dc Boost Convertor

The circuit diagram of an ac-dc boost converter is shown in Fig. 1. Input power supply connected to a bridge rectifier converting ac to dc which is then connected to boost converter circuit. The circuit with inductor L, diode D and switch S form a dc-dc boost converter circuit. The Capacitor C_o is used to obtain a constant output voltage and R is the load connected to the boost converter.

It has two modes of operation according to the state of the switch. In the first mode of operation the switch is turned on (u=1), the current accumulates and energy stored in the inductor and the load is supplied by the capacitor. In this case the voltage across the inductor is

$$v_L = V_s = L\frac{di_L}{dt} \quad (1)$$

and the current through the capacitor is

$$i_c = C\frac{dv_c}{dt} \quad (2)$$

The second mode of operation is obtained by turning the switch to off state (u=0). Inductor current cannot change suddenly and the diode becomes forward biased providing path for inductor current. The stored energy in the inductor together with the input source transferred to the output. In this case voltage accross the inductor becomes

$$v_L = V_s - v_c = L\frac{di_L}{dt} \quad (3)$$

the current through the inductor is

$$i_L = i_c + i_R = C\frac{dv_c}{dt} + \frac{v_c}{R} \quad (4)$$

Taking the voltage accross the capacitor and the current through the inductor as state variable and combining equations (1), (3) and (2), (4) with u which is the control input taking the discerete values 0 and 1 representing the switch position then we have

$$\frac{di_L}{dt} = -(1-u)\frac{v_c}{L} + \frac{V_S}{L} \quad (5)$$

$$\frac{dV_C}{dt} = (1-u)\frac{i_L}{C} - \frac{V_C}{RC} \quad (6)$$

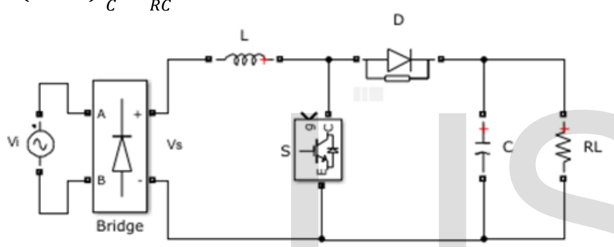


Fig. 1. Ac-dc boost converter circuit.

3 Fuzzy Logic Control

Fuzzy logic is one of the most popular control system design for uncertain nonlinear systems [14], [15], [16]. It is a model independent method and based on heuristics methods. Instead of the mathematical model, expert knowledge of the system is used in the design of fuzzy controllers.

Fuzzy control inputs are determined by a set of fuzzy rules expressed as a form of the conditional statements. Using membership functions in fuzzy model, the variables error and change of error can be related to rules to provide an output.

The error signal is the difference between the output voltage of the converter and the reference value of the output voltage. The change of error signal is obtained by applying this error to the unit delay block. Error and change of error are used as the input of fuzzy controller and the output of the fuzzy block is used as the reference value of the inner control loop as in Fig. 2.

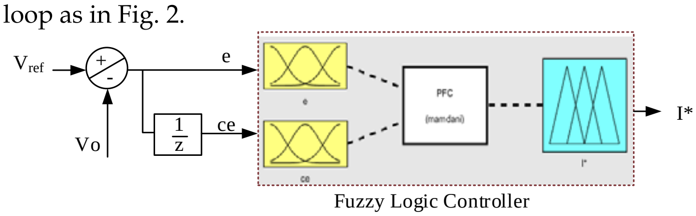
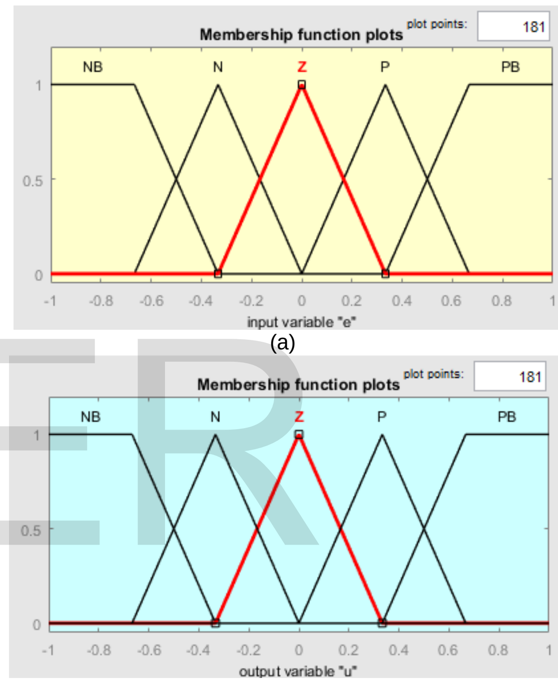


Fig. 2. Fuzzy logic control block.

Table 1 shows fuzzy rules which relates change of input variables to the output value. Five membership functions NB, N, Z, P, PB are used in both input and output variables as shown in Fig. 3. Where NB is negative big, N is negative, Z is zero, P is positive and PB is used to represent positive big.

The rules are drived from the following criteria;

1. If the error beetween the reference and measured voltage is big that is the output of the converter is far from the reference point, then I* should be big to take the output to the reference value quickly.
2. If the output of the converter is near the desired reference, a small change in I* is needed.
3. If the desired reference is achieved and the output is steady, there should be no change in reference current I*.



(a)

(b)

Fig. 3. Input and output membership function.

TABLE 1
FUZZY RULE TABLE

ce \ e	NB	N	Z	P	PB
NB	NB	NB	NB	N	Z
N	NB	NB	N	Z	P
Z	NB	N	Z	P	PB
P	Z	Z	P	PB	PB
PB	N	P	PB	PB	PB

4 Power Factor Correction

Power factor correction is used to improve the power factor and to reduce the harmonics on the supply side for single phase ac-dc converter. The power factor, PF, is the ratio of average power (P) to the apparent power (S). In the case when both voltage and current are sinusoids, the PF is:

$$PF = \frac{P}{S} = \frac{P}{V_{rms}I_{rms}} = cos\rho \quad (7)$$

Where cosφ is the phase angle between the voltage and current which is also known as the displacement factor of the voltage and current. Power factor correction may be called as compensation of the displacement factor.

In the case of nonlinear load that is the current become nonsinusoidal then the power factor is;

$$PF = \frac{V_{rms}I_{1rms}cos\rho}{V_{rms}I_{rms}} = \frac{I_{1rms}}{I_{rms}}cos\rho = K_p cos\rho \quad (8)$$

Where K_p is the distortion factor and indicates the harmonic content of the current with respect to fundamental.

Researches on power factor correction for nonlinear loads aim to reduce the harmonics of the line current. The aim in PFC is to shape the input current as close as possible to a sinusoidal waveform in phase with the line voltage.

Many different techniques are used for power factor correction. Fig. 4 shows the configuration of fuzzy control based boost PFC converter. It consists of two control loops. The outer loop is the slow voltage control loop and the inner loop is the faster current control loop. Fuzzy control is used for the voltage control and PI control is used for the current control.

The fuzzy control loop is used to regulate the output voltage and the current control loop is used to maintain the input current to follow the same sinusoidal waveform as the input voltage.

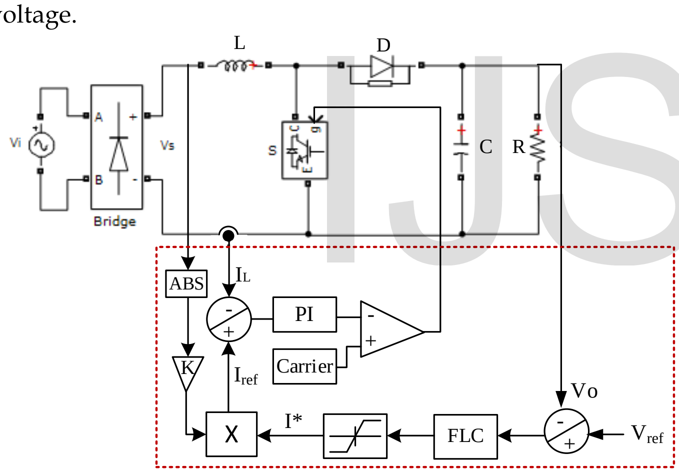


Fig. 4. Block diagram of boost PFC converter control.

The simulink program of the fuzzy logic control scheme of the boost converter with PFC is shown in Fig. 5. The dc output voltage V_o is compared with a reference value V*. The error between V_o and V* and change of error are used as inputs of fuzzy controller. The output of the FLC is taken as the reference current I*. The dc output voltage is controlled by adjusting the magnitude of reference current I*. The output of the fuzzy controller I* is multiplied by sensed magnitude of input current $|sinwt|$ to produce reference current I_{ref}. A PI controller is used for the current control. Output of the current controller is fed into a PWM modulator which generates switching signal by comparing the output of the current controller with a fixed frequency triangular signal. Thus the inductor current is proggrammed to follow the sinusoidal envelope of the input voltage providing output voltage regulation and near unity power factor.

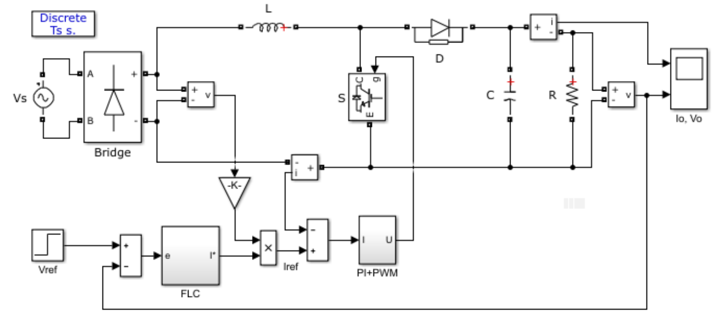


Fig. 5. Boost PFC converter control.

5 SIMULATIONS

The Simulink representation of the designed fuzzy logic based power factor controller is given in Fig. 6.

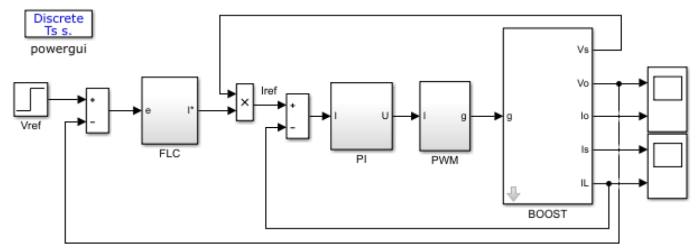
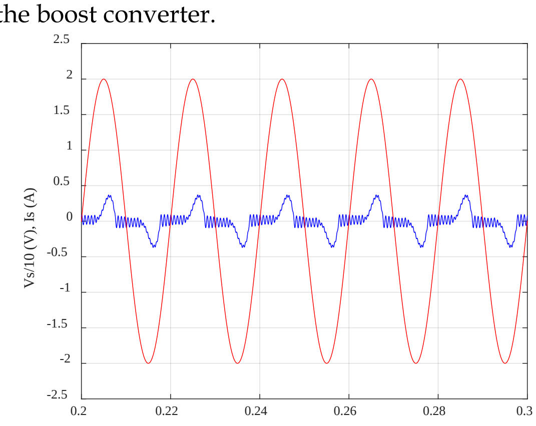


Fig. 6. Fuzzy-PI controlled boost PFC convertor Simulink representation.

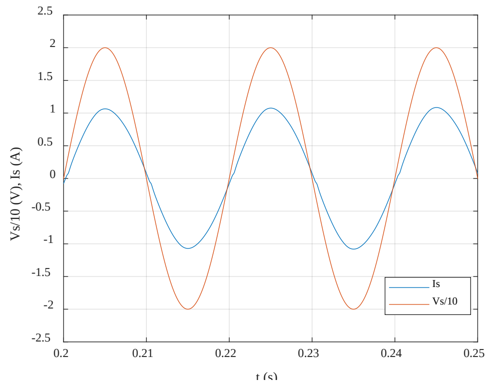
The parameter values of the boost converter used in the simulations are: V_s= 20V, L= 4mH, C= 1200µF, R=200 Ω.

Fig. 7 (a) shows the current waveform obtained without power factor correction and Fig. 7 (b) shows the current waveform with power factor correction scheme. As the diode bridge rectifier has nonsinusoidal line current due to the low ripple on the output voltage the current is not in sinusoidal form. Same load used while obtaining current waveform both with and without power factor correction. A sinusoidal source current in phase with the source voltage is obtained with power factor correction.

Both with and without power factor correction, the desired reference voltage set to 30 Volts. Fig. 8 shows the output voltage of the boost converter.



(a)



(b)

Fig. 7. Current waveforms (a) without power factor correction (b) with power factor correction.

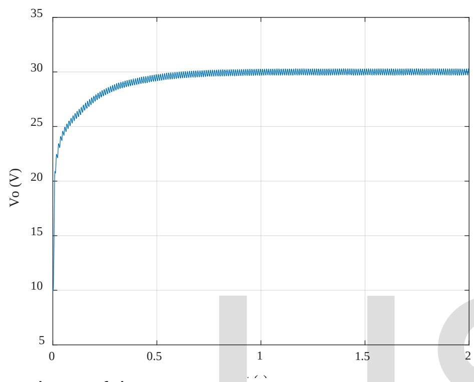
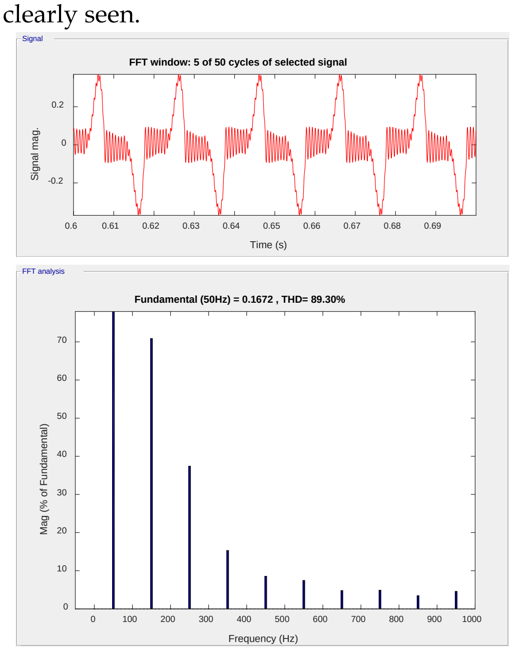
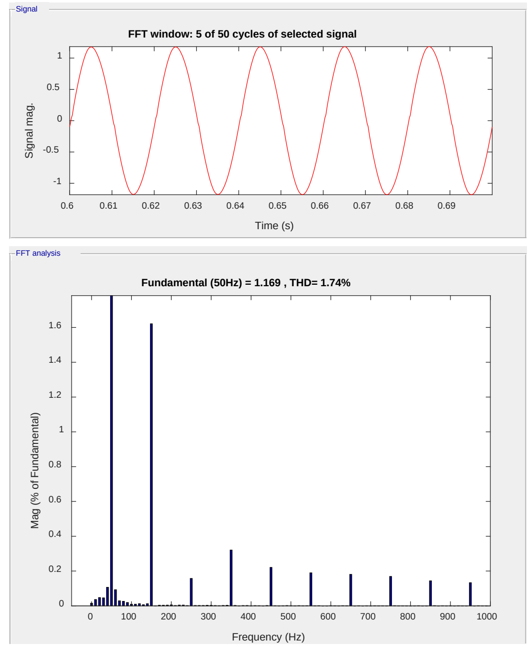


Fig. 8. Output voltage of the converter.

The total harmonic distortions of the current with and without power factor correction are given in Fig. 9 (a) and Fig. 9 (b). The reduction in harmonics and total harmonic distortion are clearly seen.



(a)



(b)

Fig. 9. THD (a) without power factor correction (b) with power factor correction.

The boost power factor correction system is simulated with different reference voltages. While the output voltage has already stabilized to 30V a step change in the reference voltage from 30 to 40 V is made at t=1s.

The performance of the PFC controlled system is given in Fig. 10 and 11. As seen in these figures both before and after reference voltage change, the current waveform is in phase with the voltage waveform keeping the near unity power factor.

To see the influence of the load change on the performance of the boost PFC system, the load connected to the boost converter is changed from 200Ω to 100Ω at t=1s. The source voltage and current waveforms are shown in Fig. 12. The output voltage and current are shown in Fig. 13-a and 13-b. These figures prove that while with improved power factor, the output voltage track the desired reference voltage.

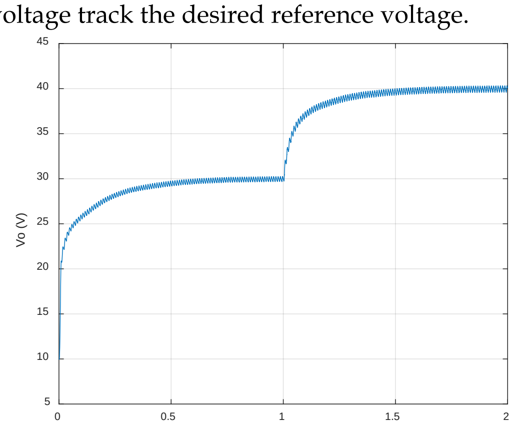


Fig. 10. Change in reference voltage from 30V to 40V at t=1s.

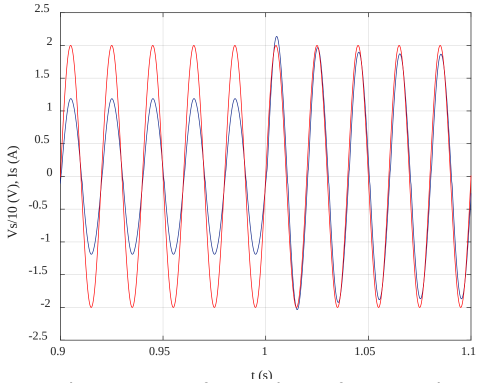


Fig. 11. Voltage and current waveforms when reference voltage changes from 30V to 40V at t=1s.

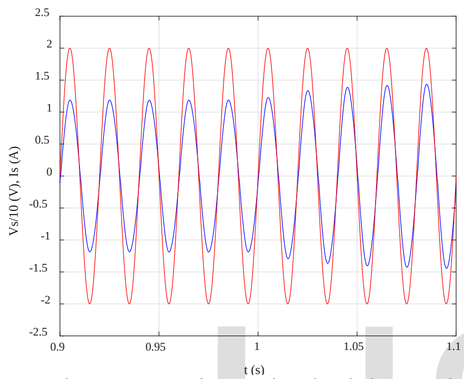


Fig. 12. Voltage and current waveforms when load changes from 200Ω to 100Ω at t=1s.

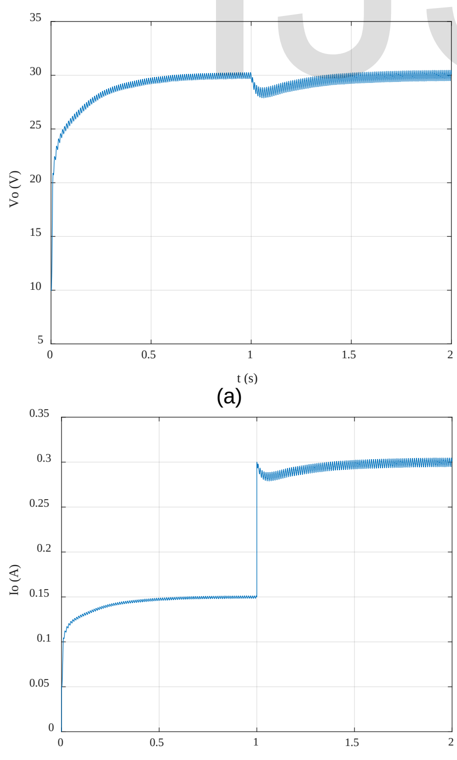


Fig. 13. When load changes from 200Ω to 100Ω at t=1s (a) output voltage (b) output current.

6 Conclusion

A dc-dc boost converter with power factor control is designed and controlled with fuzzy logic and PI controller. The inputs of the FLC are the error between the output voltage and the reference voltage and change of error. The output of the FLC is used as the reference current fort he PI current controller. The output of the PI controller is compared with a saw tooth carrier signal. The obtained signal is then applied to the switch of the converter. The designed system is simulated using Matlab/simulink. Desired output voltage with improved power factor is achieved with the use of fuzzy controller. The current ripples are also reduced.

The performances of the controller in terms of robustness and dynamic response are presented with the simulation results.

References

[1] B. Singh, B.N. Singh, A. Chandra, K. Al-Haddad, A. Pandey and D.P. Kothari, "A Review of Single-Phase Improved Power Quality AC-DC Converters," IEEE Trans. on Industrial Electronics, vol. 50, no. 5, pp. 962-981, 7 Oct. 2003, doi:10.1109/TIE.2003.817609.

[2] A. Kessal, R. Lazhar, J.P. Gaubert and M. Mohammed, "Analysis and Design of an Isolated Single-Phase Power Factor Corrector with a Fast Regulation," *Electric Power Systems Research*, vol. 81, no. 9, pp. 1825–1831, June 2011, doi:10.1016/j.epsr.2011.05.012.

[3] M. He and J. Xu "Nonlinear PID in Digital Controlled Buck Converters," *Applied Power Electronics Conference (APEC2007)*, pp. 1461–1465, March 2007, doi:10.1109/APEX.2007.357709.

[4] S. Sagiroglu, I. Colak and R. Bayindir, "Power Factor Correction Technique Based on Artificial Neural Networks," *Energy Conversion and Management*, vol. 47, no. 18-19, pp. 3204–3215, March 2006, doi:10.1016/j.enconman.2006.02.018.

[5] D.S.L. Simonetti, G. Bevilacqua, P. Mejía and J. Uceda, "A Neural Control of Power Factor Preregulators," *IEEE Industrial Electronics, Control, and Instrumentation (IECON'93)*, pp. 971–976, Nov. 1993, doi:10.1109/IECON.1993.339143.

[6] A. Kessal and L. Rahmani, "Analysis and Design of Sliding Mode Controller Gains for Boost Power Factor Corrector," *ISA Transactions*, vol. 52, no. 5, pp. 638–643, Sept. 2013, doi:10.1016/j.isatra.2013.05.002.

[7] H. Guldemir, "Sliding Mode Control of DC-DC Boost Converter," *Journal of Applied Sciences*, vol. 5, no. 3, pp. 588-592, 2005.

[8] H. Guldemir, "Study of Sliding Mode Control of DC-DC Buck Converter," *Energy and Power Engineering*, vol. 3, no. 4, pp. 401-406, Sept. 2011, doi:10.4236/epe.2011.34051.

[9] A. Kessal, L. Rahmani and M. Mostefai, "Power Factor Correction Based on Fuzzy Logic Controller with Fixed Switching Frequency," *Elektronika ir Elektrotechnika*, vol. 118, no. 2, pp. 67–72, 2012, doi:10.5755/j01.eee.118.2.1176

[10] A. Kessal, L. Rahmani, J.P. Gaubert and M. Mostefai, "Experimental Design of a Fuzzy Controller for Improving Power Factor of Boost Rectifier," *International Journal of Electronics*, vol. 99, no. 12, pp. 1611–1621, May 2012, doi:10.1080/00207217.2012.680788.

[11] 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," *IEEE Power Electronics Specialists Conference (PESC'99)*, pp. 149–154, July 1999, doi:10.1109/PESC.1999.788995.

[12] P. Mattavelli, L. Rosetto and G. Spiazzi, "Small-Signal Analysis of

DC-DC Converters with Sliding Mode Control," *IEEE Transactions on Power Electronics,* vol. 12, no. 1, pp. 96-102, Jan. 1997, doi:10.1109/63.554174.

[13] A. Bouafassa, L. Rahmani, A. Kessal and B. Babes, "Unity Power Factor Converter Based on a Fuzzy Controller and Predictive Input Current," *ISA Transactions*, vol. 53, no. 6, pp. 1817–1821, Nov. 2014, doi:10.1016/j.isatra.2014.08.001.

[14] L.A. Zadeh, "Fuzzy Sets," *Information and Control,* vol. 8, no. 1, pp. 338–353, 1965, doi:10.2307/2272014.

[15] A. Kandel and G. Langholz, *Fuzzy Control Systems*. CRC Press, New York, 1993.

[16] K.M. Passino, S. Yurkovich and M. Reinfrank, *Fuzzy Control*. Addison-Wesley, London, 1998.