A NEW INTELLIGENT POWER FACTOR CORRECTOR FOR CONVERTER APPLICATIONS

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ABSTRACT

This paper presents a new design of a unity power factor corrector for DC-DC converter applications based on an Artificial Neural Network algorithm. The controller firstly calculates the system power factor by measuring the phase shift between the grid voltage and the grid current. Secondly, the controller receives the absolute value of the grid voltage and the measured phase shift through the designed ANN, which predicts the duty cycle of the pulse width modulation (PWM) drive pulses, these PWM pulses are used to drive the Boost DC-DC converter to enforce the drawn current to be fully in phase with the grid voltage as well as to improve the level of Total Harmonics Distortion (THD) of the grid current. MATLAB/Simulink software is adopted to simulate the presented design. The analysis of the simulation results indicates the high performance of the proposed controller in terms of correcting the power factor, and improving the grid current THD.

KEYWORDS

Power factor corrector, artificial neural network, Boost DC-DC converter, Total Harmonic Distortion, MATLAB/Simulink.

1. INTRODUCTION

The usage of DC-DC converter in homes and industrial appliances leads to negative effects on the connected grid due to the non-linear and the reactive components of the electrical system. The negative effects are represented by increasing the phase shift of the grid current with respect to the grid voltage and the waveform distortion of the grid current. These effects are increasing the electrical losses due to the low system power factor in addition to increasing the Total Harmonic Distortion of the grid current due to deteriorating current waveform shape. From this fact, enhancing the power factor, which is the rate of the active power to the apparent power, becomes necessary to reduce energy loss and to enhance the THD level of the current waveform. In other words, the unity power factor of the connected loads is necessary to effectively reduce energy loss in the electrical system's components through reducing the reactive power absorption. On the other hand, the inductive, the capacitive, and the other non-linear components are negatively affecting the waveform shape of the drawn current from the grid, this distorts the current waveform and increases the Total Harmonics Distortion (THD) level [1]-[5]. Many research studies have been proposed for the objective of enhancing the rate of active power to apparent power reaching to the target of unity power factor to guarantee the removal of energy loss and to improve the level of the current THD [6]-[12].

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For a bridgeless Cuk converter, the study [1] proposed a novel power factor corrector (PFC) for better power factor performance and for lower total harmonic distortion of the grid current. The converter supplied power for the LED lamp applications, reduced the losses and improved the converter efficiency. The work in [2] presented a design, operation's principle, and simulation results analysis of a PFC through a variable switching frequency pulse width modulation controlling technique. The proposed PFC controlling system enhanced the THD, and power system efficiency through a new PFC controller. The system worked on absorbing a sinusoidal current waveform that reduced the current THD, and also regulated the load voltage. The effect of the total harmonic distortion during the power factor correcting has been shown and analysed in [3] through a non-linear load. The sinusoidal waveform of the grid current is affected by the type of the connected non-linear loads that increase the harmonic distortion. The system performance has been analysed in the study in terms of the THD level.

The work in the studies [4]-[5] presented a simple power factor controller based on micro controllers; an accurate automatic single phase power factor controller has been implemented using the micro controller type ATmega328 in [4]. Whereas, the same micro controller has been adopted in [5] to produce the PWM drive pulses to the boost converter for the power factor correcting function.

The Fuzzy logic controller (FLC) had been proposed in different researches for the objective of power factor correction [6]-[8]. The study [6] has proposed a simulation study with results analysis of a Fuzzy Logic Controller FLC based electrical power system for power factor controlling. By controlling the excitation current of the inserted synchronous motor, the proposed FLC controller compensated the requirement of the mathematical models which is needed for parameter determining of a conventional power factor control. An analytical study for correcting and enhancing the power factor through a boost converter has been presented in [7] based fuzzy logic controller, proportional-integral controller, as well as a hysteresis current controller, in study [7], the voltage loop controller has been represented by the fuzzy controller and the PI controller. Whereas, two controllers have been designed and simulated in [8] for a single phase power factor correcting function. Fuzzy logic controller and predictive controller have been presented in the study for the power factor correction aim.

2. POWER FACTOR CORRECTION BASED ON ARTIFICIAL NEURAL NETWORKS IN LITERATURE

Artificial Neural Networks (ANN) have been used for different problems solving, and currently ANN have been proposed to improve different systems' performance. ANN has been adopted for the power factor improvement as an effective power factor corrector [9]-[12]. An ANN has been presented in [9] through a novel technique for a line power factor correcting via a synchronous motor. The motor is directed by the ANN controller to have robust system of improved PF (0.984) through compensating the reactive power of the system under the test.

The study of [10] offered a developed power factor corrector for a certain power system. A clustering neural network has been adopted in the study to achieve effective performance in terms of load varying. The presented PFC of [10] optimized the power factor automatically ranging between 0.9 and 0.93. In [11], a real-time reactive power corrector has been presented based on ANN. The ANN received the active and reactive power of each load and based on the loads' values and types, the output of the ANN controlled the switching ON/OFF of the system's capacitors. The testing step of the study reflected the satisfied compensating of the reactive power with power factor records in a range of 0.94 to 1. A comparative study has been presented in the work of [12] with respect to the power factor correcting performance, the effectiveness of an ANN-based controller has compared with a conventional PI controller in terms of power quality.

Based on the above studies' findings, which show the effectiveness of the PFC controllers based on artificial neural network, this paper proposes an effective new power factor correction controller for a DC-DC converter applications based on a designed algorithm of an artificial neural network. The remaining of this paper is arranged as follows; Section 3 explains the methodology of the proposed power factor corrector based on neural network, Section 4 explains the proposed system, Section 5 shows the simulation results with results analysis, whereas Section 6 concludes the study findings and focuses on aspects of future work.

3. METHODOLOGY OF THE PROPOSED POWER FACTOR CORRECTOR BASED ON ARTIFICIAL NEURAL NETWORK

The types of the connected electrical loads to the grid are divided into active loads, reactive loads, which are either inductive or capacitive loads, and non-linear loads, which are represented by the semiconductor devices [6]. The active loads transform the grid's energy to useful energy. Whereas, the reactive loads (inductive or capacitive) are absorbing the grid energy without transforming it to useful energy, and also shifting a certain lag or lead phase of grid current with respect to grid voltage. Non-linear devices are distorting the waveform of the grid current which leads to increase the THD level of the load current [13]-[14]. Normally, the value of the power factor (*PF*), which is shown in (1), is less than 0.85 with respect to the inductive or capacitive loads.

$$PF = \frac{Active\ Power}{Appearent\ Power} = \frac{P}{S} \tag{1}$$

Where *P* is the active power in Watt (W), *S* is the apparent power in Volt·Amp (V·A), which is a vector value, as shown in (2).

$$S = P + j\,Q \tag{2}$$

Where *Q* is the reactive power in Volt·Amp (V·A). Figure 1 shows the case of active, reactive, and apparent power for the case of inductive load. From Figure 1, the power factor *PF* relation can be represented by (3).

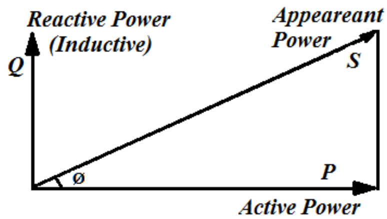


Figure 1. Vectors of active, reactive, and apparent power for inductive load condition

$$PF = \frac{P}{S} = Cos(\emptyset) \tag{3}$$

From (3), to have a better *PF*, the phase shift *Ø* should be in lower value toward zero for the case of unity power factor. In other words, to have a high or a unity power factor, the phase shift between grid voltage and drawn current should be near zero for high *PF*, or exactly zero to obtain unity *PF*. So, for the case of low *PF* inductive load, certain capacitors are necessary to improve the value of *PF*.

In the case of DC-DC converter, the instantaneous values of the PWM pulses are playing the major role to compensate the undesirable phase shift. From this point of problem solving, the neural network is adopted to predict the required compensation of the instantaneous phase shift.

Through a machine learning algorithm of neural network, a fast and accurate response can be guaranteed [15]-[17]. Big size of numerical data of input and output variables is necessary for the learning or training process. The structure of any ANN algorithm includes one input layer, one output layer, and one or more hidden layers. Figure 2 shows the basic unit of this algorithm represented by the neuron. The functions of the neuron are, firstly, adding the input variables (X_1 to X_n) after the weighting step of each input variable (W_1 to W_n) as shown in (4), secondly, passing the addition result to an activation function. This function can be one of the three activation functions, namely, the linear (5), the sigmoidal (6), and the hyperbolic (7) transfer functions respectively.

$$Z = \sum_{i=1}^{N} W_i \, X_i \, + B \tag{4}$$

$$y_n = f(z) \tag{5}$$

$$f(z) = \frac{1}{1 + exp^{-z}} \tag{6}$$

$$f(z) = \frac{1 + exp^{-2z}}{1 - exp^{-2z}} \tag{7}$$

The learning process and weight updating are done based on the back propagation process, and the accuracy of the designed ANN is evaluated by the value of the mean square error (*MSE*). This evaluating parameter represents the difference between the target value and the estimated value by the designed ANN as shown in (8).

$$MSE = \frac{1}{q} \sum_{k=1}^{q} [t(k) - a(k)]^2 \tag{8}$$

Where *t(k)* is the target , *a(k)* is the ANN estimated value, and *q* is the element number of the input variables.

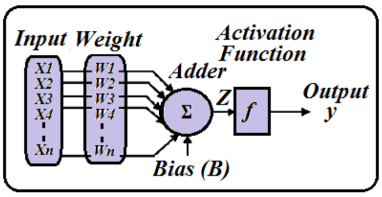


Figure 2. The structure of the neuron

4. Proposed Power Factor Correction Controller for Boost DC-DC Converter

The proposed controller works on effectively increasing the power factor of the DC-DC converter with its load to unity PF and improving the Total Harmonic Distortion (THD) of the grid drawn current through the ANN predicting function for the required opposite phase shifting based on the actual phase shift of the grid current. The presented system block diagram is shown in Figure 3. Two parts are involving in the system; the power part and the controlling part. The power part includes a rectifier, a DC-DC converter, and a resistive load. The second one is a controlling part which includes a phase shift and power factor calculator, a neural network algorithm, and a pulse width modulation drive pulses generator. The proposed controller receives the instantaneous values of the grid voltage waveform, and grid drawn current, these two sensed values are used to calculate the phase shift and power factor. The other received values by the controller are the instantaneous values of load voltage and load current, these values are needed for the controlling function.

Figure 4 shows the designed ANN of one input layer, one hidden layer, and one output layer. The algorithm includes 2 neurons in the input layer, 25 neurons in the hidden layer, and 1 neuron in the output layer. Absolute value of the grid voltage, and phase shift between grid voltage and grid current are received by the input layer of the algorithm. After the processing of the neural network, the predicted duty cycle (*D1*) is estimated and produced at the terminal of the output layer.

The drive pulses generator adopts the process of the pulse width modulation technique [18]-[23], this generator produces PWM drive pulses of switching frequency 10 kHz, the duty cycle D of these pulses is controlled based on the sensed load voltage, load current, and the predicted value on *D1*, which is produced by the designed ANN algorithm. The parameters of the boost DC-DC converter are designed based on the studies of [24], and Table 1 shows the setting of these parameters.

5. SIMULATION RESULT ANALYSIS

MATLAB Simulink software is applied to simulate the proposed power factor corrector for DC-DC converter applications. The records are collected firstly with fixed duty cycle (D = 0.6) with two values of load resistors as shown in Table 1. Secondly, the system performance is evaluated through the proposed power factor controller. The first step in simulation after designing the ANN algorithm with one input layer of 2 neurons, one hidden layer of 25 neurons, and one output layer of 1 neuron simulates the algorithm as shown in Figure 5 (a). The performance of the designed and simulated ANN algorithm reflects the best validation of 0.00096955 at the epoch 4 as shown in Figure 5 (b) in terms of estimating the instantaneous value of duty cycle.

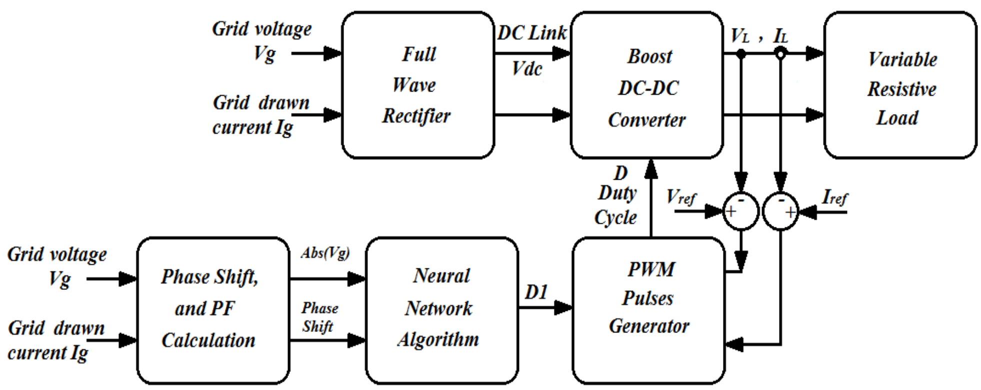


Figure 3. The proposed system block diagram

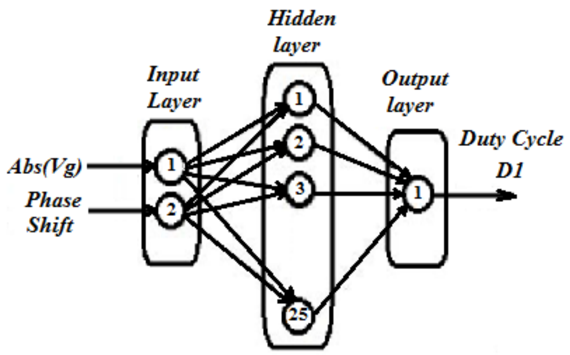
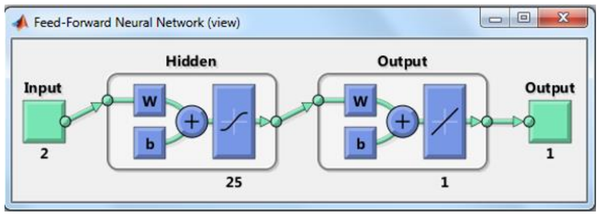


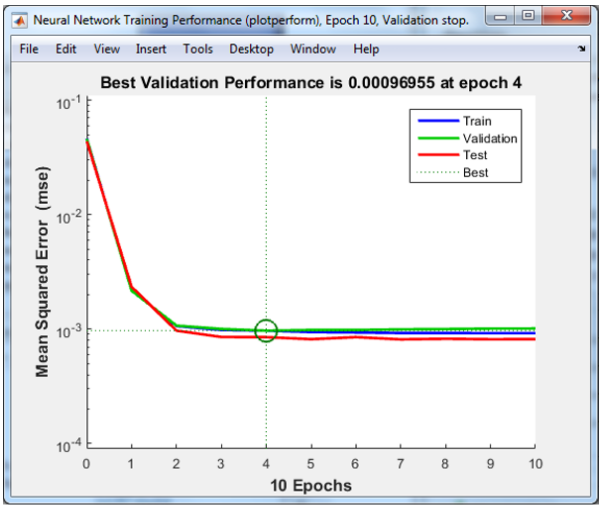
Figure 4. The designed ANN algorithm

Table 1. Converter parameters

Parameter	**Value**
Inductor	10 mH
Capacitor	1000 µF
Load Resistor	75 Ω, 150 Ω
Switching Frequency	10 kHz
Duty Cycle(without control)	0.6



(a)



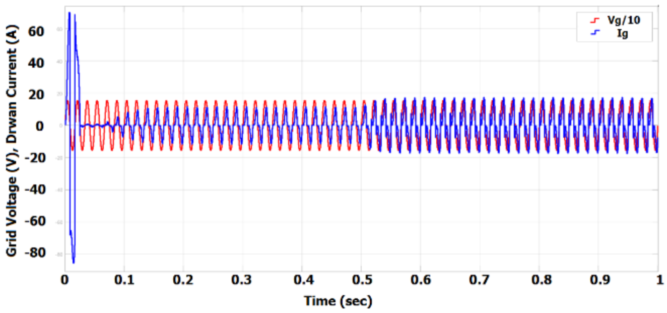
(b)

Figure 5. The designed and simulated ANN algorithm, (a) Feed-forward ANN structure, (b) ANN performance

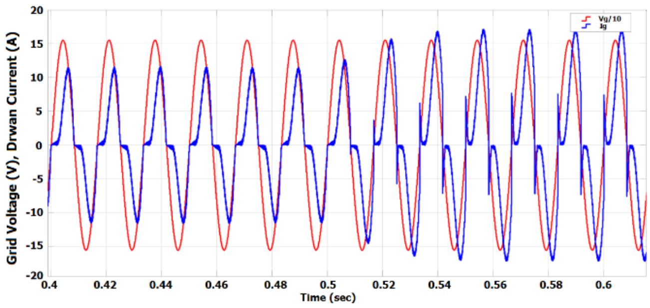
Figure 6 shows the system performance with fixed duty cycle (*D* = 0.6) in terms of the grid drawn current with respect to the grid voltage at two different loads, the distortion of grid current is clearly noticeable in Figure 6 (b). Figure 7 shows the harmonics spectrum of the grid current in which high levels of low order harmonics and THD of 44.76% are monitored. Figure 8 shows the uncontrolled load voltage during 1 sec simulation period which is divided into two equal periods. In the first period of 0.5 sec, the connected load is 150 Ω, whereas the second period is with load of 75 Ω. From Figure 6 to Figure 8, the distortion in the shape of grid current waveform as well as the marked phase shift between the grid voltage and the current are clearly noted, the phase shift between the current and the voltage, and distorted current all leading to having low power factor and high Total Harmonics Distortion THD in current waveform respectively.

The system performance through the proposed controller is monitored through Figure 9 to Figure 11. Figure 9 shows the grid current at the same considered loads, the lower level of grid current distortion is shown in Figure 9 (b). Figure 10 shows the harmonics spectrum of the grid current which involves the lower levels of low order harmonics, in addition to lower THD level. Figure 11 shows the load voltage during the same 1 sec simulation period with the same resistive loads consideration. Figure 11 proves the high priority of the proposed controller in terms of controlling the load voltage, softening the starting and transient response compared to the response of the fixed duty cycle of Figure 8.

Table 2 shows load voltage, power factor, and THD at the two resistive loads. The effectiveness of the presented controller is clear in the terms of the mentioned parameters improvement. Table 3 compares the performance of the proposed controller with respect to previous controllers in literature in terms of the power factor. The contents of Table 3 reflect the high priority of the presented controller in terms of the level and the stability of the recorded power factor.



(a)



(b)

Figure 6. Grid drawn current with grid voltage, 0 to 0.5 sec (load=150 Ω), 0.5 to 1 sec (load=75 Ω); (a) Ig, and Vg for full 1 sec simulation time, (b) Zoom in for the steady state waveforms.

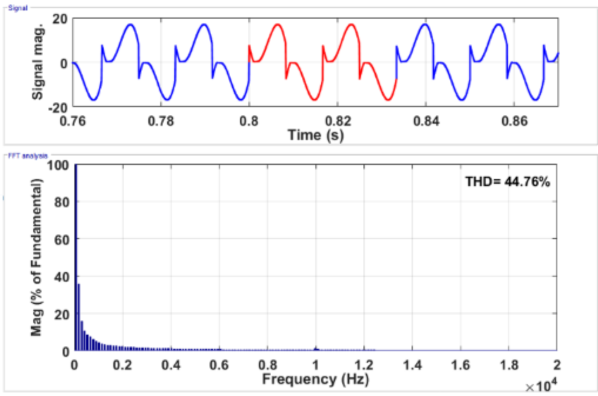


Figure 7. Harmonic spectrum of the dawn current at load R_L=75 Ω

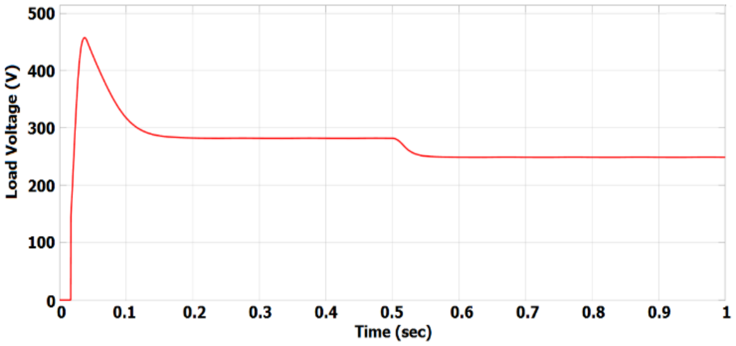
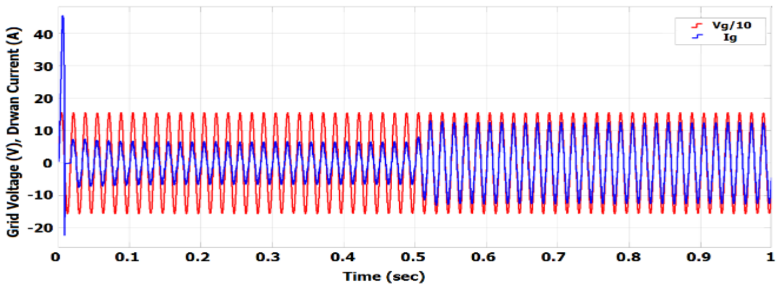
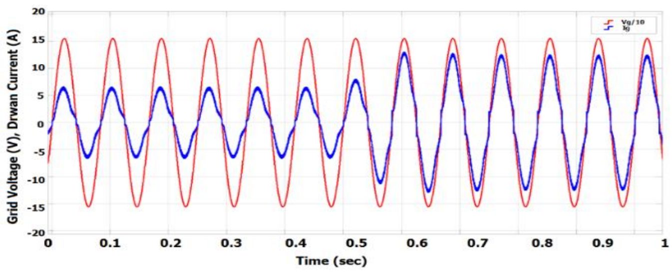


Figure 8. Load voltage during 0 to 0.5 sec at load 150 Ω, and during 0.5 to 1 sec at load 75 Ω.



(a)



(b)

Figure 9. Grid current and the grid voltage using the proposed PFC controller, 0 to 0.5 sec (load=150 Ω), 0.5 to 1 sec (load=75 Ω); (a) Ig, and Vg, (b) Zoom in of Ig, and Vg

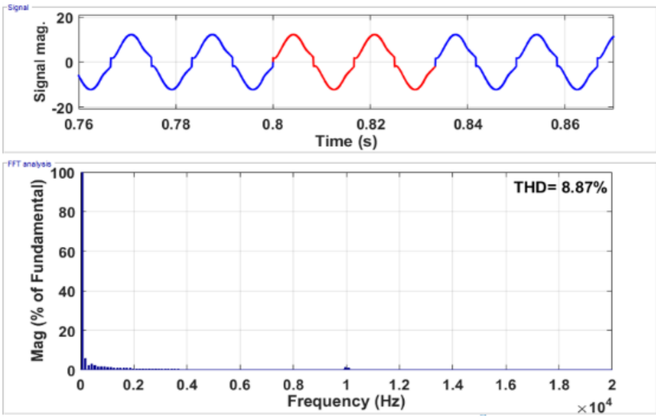


Figure 10. Harmonic spectrum of the dawn current using the proposed PFC controller at load R_L=75 Ω

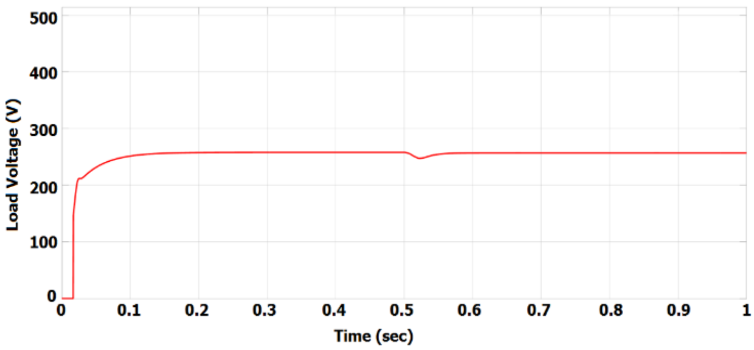


Figure 11. Load voltage using the proposed PFC controller; (0 to 0.5 sec) at load 150 Ω, and (0.5 to 1 sec) at load 75Ω.

Table 2. Load voltage, power factor, and THD records with/without control at 2 different loads

	Load Voltage (V)		**Power Factor**		**THD**	
Load	*D* = 0.6	Controlled *D*	*D* = 0.6	Controlled *D*	*D* = 0.6	Controlled *D*
R_L = 75 Ω	249 V	257 V	0.8314	0.9997	44.76%	8.87%
R_L = 150 Ω	282 V	257 V	0.8124	0.9998	38.91%	12.88%

Table 3. Power factor comparison

	Presented PF controller	**PF controller of [9]**	**PF controller of [10]**	**PF controller of [11]**
Power Factor	0.9997 0.9998	0.984	0.9 →0.93	0.94 → 1

6. Conclusion and Future Work

The study presented an effective power factor correction controller, the proposed controller is designed based on an algorithm of neural network for converter applications. The controller guarantees three aims. The first one is highly improving the power factor of the system. The second aim is enhancing the low order harmonics and level of the grid current THD, whereas the third aim is controlling the load voltage and removing the overshoot of load voltage at starting instants. The collected records showed the increasing PF from less than 0.85 to approximately unity PF at different loads. The enhancing of the THD and low order harmonics of grid current are also gained, as well as stabilizing the load voltage at 257 V compared to the unstable load voltages of 249 V, and 282 V at the load's resistance of 75 Ω, and 150 Ω respectively.

In terms of future work, the function of the neural network algorithm could be extended to include the total controlling objectives involving the voltage controller, in addition to the proposed function of ANN in this study.

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REFERENCES

[1] Saravanan D, Gopinath M, (2016), "A Novel Power Factor Correction Modified Bridge Less-CUK Converter for LED Lamp Applications" IJPEDS, Vol. 7, No. 3, pp. 880-891.
[2] Mallisetti R. K., Duraisamy L., Ch Sai B., (2011), "A Variable Switching Frequency with Boost Power Factor Correction Converter", TELKOMNIKA, Vol. 9, No. 1, pp. 47-54.
[3] R. A. Rani, S. Saat, Y. Yusop, H. Husin, F. K. Abdul Rahman, A. A. Isa, (2016), "The Effects of Total Harmonics Distortion for Power Factor Correction at Non-Linear Load", IJPEDS, Vol. 7, No. 2, pp. 543-550.
[4] Nurul H. I., Muhammad N. Z., Nur A. S., Faizal M. T. T., Aini H. M. S., (2015), "A design of an Automatic Single Phase Power Factor Controller by using Arduino Uno Rev-3", Applied Mechanics and Materials, Vol. 785, pp 419-423.
[5] Kartikesh K. J., Bidyut M., Prem P., Kartick C. J., (2016), "Hardware Implementation of Single Phase Power Factor Correction System using Micro-Controller", IJPEDS, Vol. 7, No. 3, pp. 790-799.
[6] Ahmet G., Ö. Fatih K., Hakan A., Ceyhun Y., Mustafa Ş.i, (2016), "Simulation Study on Power Factor Correction Controlling Excitation Current of Synchronous Motor with Fuzzy Logic Controller", IJISAE, 4(Special Issue), pp. 229–233.
[7] A. Bhakthavachala, S. Tara kalyani, K. Anuradha, Nukala Vengaiah, (2017) "Fuzzy Logic Controller based Unity Power Factor Correction of Boost Converter", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), Volume 12, Issue 6 Ver. II, PP 52-58.
[8] Abdelhalim Kessal, (2014), "Combined Fuzzy and Predictive Controller for Unity Power Factor Converter", International Journal of Electrical and Computer Engineering, Vol:8, No:9, 2014, pp. 1541-1546.
[9] S. Sagiroglu, I. Colak B, R. Bayindir, (2006) "Power factor correction technique based on artificial neural networks", Energy Conversion and Management, Vol. 47, pp. 3204–3215.
[10] Afaf A. A., (2018), "Improved Power Factor of Electrical Generation by using Clustering Neural Network", IJAER, Vol. 13, No. 7, pp. 4633-4636.
[11] Carl John O. Salaan and Noel R. Estoperez, (2011), "An Artificial Neural Network Based Real-time Reactive Power Controller", Proceedings of the World Congress on Engineering and Computer Science, Vol. I, WCECS 2011, October 19-21, 2011, San Francisco, USA.
[12] N. Ramchandra, M. Kalyanchakravarthi, (2012), "Neural Network Based Unified Power Quality Conditioner", International Journal of Modern Engineering Research (IJMER), Vol.2, Issue.1, pp-359-365.
[13] Masashi O., Hirofumi M. (2003), "An AC/DC Converter with High Power Factor", IEEE Trans. on Industrial Electronics, Vol. 50, No. 2, pp. 356–361.
[14] M. Malinowski, M. Jasinski, M.P. Kazmierkowski, (2004) "Simple direct power control of three-phase PWM rectifier using space-vector modulation (DPCSVM)", IEEE Trans. on Industrial Electronics, pp. 447–454.
[15] Hussain A. Attia, (2019), "High performance PV system based on artificial neural network MPPT with PI controller for direct current water pump applications, IJPEDS, Vol. 10, No. 3, pp. 1329-1338.

[16] Hussain Attia, (2019), “Supplying DC Electricity to the Isolated Dwellings through MPP Tracked PV System Based on Artificial Neural Network”, 6th International Conference of Control, Dynamic Systems, and Robotics (CDSR'19), Ottawa, Canada.

[17] Hussain Attia, (2018), “Artificial Neural Networks Based Maximum Power Point Tracking Photovoltaic System for Remote Parks LED Lighting Applications”, International Review on Modelling and Simulations, Vol. 11, Iss. 6, pp. 396-405.

[18] H. A. Attia, T. K. S. Freddy, H. S. Che, W. P. Hew, A. El Khateb, (2017), "Confined Band Variable Switching Frequency Pulse Width Modulation (CB-VSF PWM) for Single-Phase Inverter with LCL Filter," IEEE Trans. on Power Electronics, Vol. 32, No. 11, pp. 8593–8605.

[19] Hussain Attia, (2018), “A Stand-alone Solar PV System with MPPT Based on Fuzzy Logic Control for Direct Current Portable House Applications”, IREMOS, Vol. 11, Iss. 6, pp. 377-385.

[20] Hussain Attia, (2018), “Fuzzy Logic Controller Effectiveness Evaluation through Comparative Memberships for Photovoltaic Maximum Power Point Tracking Function”, IJPEDS, Vol. 9, No. 3, pp. 1147-1156.

[21] Attia Hussain, Del Ama G. F., (2019), “Stand-alone PV System with MPPT Function Based on Fuzzy Logic Control for Remote Building Applications”, IJPEDS, Vol. 10, Iss. 2.

[22] Hussain A Attia, (2017), “Comparative design of fuzzy logic controller for photovoltaic panel maximum power point tracking”, ICECTA2017, Ras Al Khaimah-UAE.

[23] Hussain Attia, Amjad Omar, Maen Takruri, Halah Y. Ali, (2017), "Pulse Width Modulation Based Decentralized Street LED Light," International Journal of Power Electronics and Drive System (IJPEDS), vol. 8(3), pp. 1238-1247.

[24] Hussain A. Attia, Y. I. Al-Mashhadany, Beza N. G., (2014), "Design and Simulation of a High Performance Standalone Photovoltaic System," ICREGA’14 – Renewable Energy: Generation and Applications, Springer Proceedings in Energy 2014.

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