Scientific Research Publishing

Smart Grid and Renewable Energy, 2023, 14, 73-84
https://www.scirp.org/journal/sgre
ISSN Online: 2151-4844
ISSN Print: 2151-481X

Performance of the Boost Chopper, Comparative Study between PI Control and Neural Control to Regulate Its Output Voltage

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How to cite this paper: Gueye, I., Sall, M. and Kebe, A. (2023) Performance of the Boost Chopper, Comparative Study between PI Control and Neural Control to Regulate Its Output Voltage. *Smart Grid and Renewable Energy*, **14**, 73-84.
https://doi.org/10.4236/sgre.2023.145005

Received: February 27, 2023
Accepted: May 16, 2023
Published: May 19, 2023

Abstract

In this study, we investigate the performance of a boost converter regulating its output voltage using two control methods: Proportional-Integral (PI) control and neural control. Both methods are implemented on a simulation platform (Matlab/Simulink) and evaluated in terms of accuracy, response speed, and robustness to disturbances. Indeed, the output voltage of converters exhibits imperfections that require a control method to optimize efficiency when applying a variable load. Results show that neural control offers superior performance in terms of accuracy and response time, with faster and more precise regulation of the output voltage. On the other hand, PI control proves to be more robust against disturbances. These findings can help guide the selection of the appropriate control method for a boost converter based on the specific requirements of each application.

Keywords

Chopper, PI Control, Neural Control

1. Introduction

Thanks to progress in power electronics, the development of DC-DC converters (chopper) is experiencing significant growth in many fields of application. They are widely used in renewable energy, battery backup systems for electrical power, ballasts for high intensity discharge lamps, vehicles and in some medical equipment [1] [2].

The chopper, or DC-DC converter, is a power electronics device that implements one or more electronic switches controlled to allow the value of the (average) voltage of a DC voltage source to be modified with high efficiency [3].

However, the voltage at the output of the chopper has imperfections (response time, overshoot, static error, etc.). Practically the converters have an efficiency of 70% to 95%. Typically, pulse-width modulated control is used to control the open-loop output voltage, but load variations and small supply variations change the magnitude of the output voltage [4] [5]. On the other hand, the most used control techniques for DC-DC converters are PID controllers which tend to give good results. But in most closed-loop applications involving the PID controller as a voltage controller, gain adjustment is cumbersome when the reference value changes with time [6].

However, despite the acceptable results obtained with these correctors, it should be noted that their parameters are determined with the supply voltage of the load, so if this voltage varies, their parameters must also vary. To remedy this drawback, research based on artificial intelligence has been carried out to find adaptive controls: these are fuzzy, neuro fuzzy, neural correctors, etc. [7].

The main objective of this work is to compare the PI control to the neural control for controlling a step-up chopper (resistive load and inductive load) and thus determine the most efficient control with good efficiency.

The work presented in this article is structured as follows: the first part presents the modeling of the chopper, the second part presents the study of the chopper with PI control and neural control and the last part presents the results obtained after a simulation on MATLAB Simulink and discussions.

1.1. Modeling and Dimensioning of the Boost Chopper

Choppers are static DC-DC converters that generate a variable DC voltage source from a fixed DC voltage source. The chopper consists of capacitors, inductors and switches, see **Figure 1**. All these devices in the ideal case do not consume power, this is the reason why choppers have good efficiencies. Generally, the switch is a MOSFET transistor which is a semiconductor device operating in either off or saturated mode [8] [9] [10].

The goal of the analysis of the static converters by the mathematical model is to expose this model by a continuous canonical writing. The model obtained makes it possible to obtain the transfer function [11].

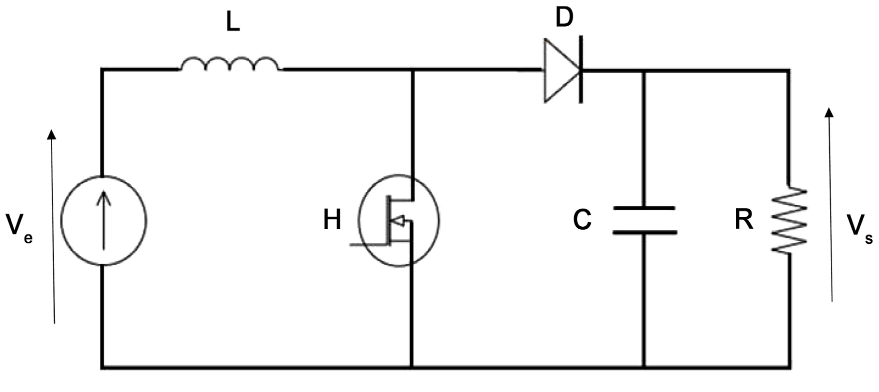

Figure 1. BOOST chopper.

When the switch is closed **Figure 2** we have:

$$\begin{cases} L\dfrac{\mathrm{d}i_L}{\mathrm{d}t} = V_e - V_s \\ C\dfrac{\mathrm{d}V_C}{\mathrm{d}t} = i_L - \dfrac{V_s}{R} \end{cases} \tag{1}$$

When the switch is open **Figure 3** we have:

$$\begin{cases} L\dfrac{\mathrm{d}i_L}{\mathrm{d}t} = -V_s \\ C\dfrac{\mathrm{d}V_C}{\mathrm{d}t} = i_L - \dfrac{V_s}{R} \end{cases} \tag{2}$$

BOOST sizing is summarized in the following **Table 1**.

With ΔV_S = 5% (ripple of the voltage across the capacitor) and ΔI_L = 10% (ripple in the inductor).

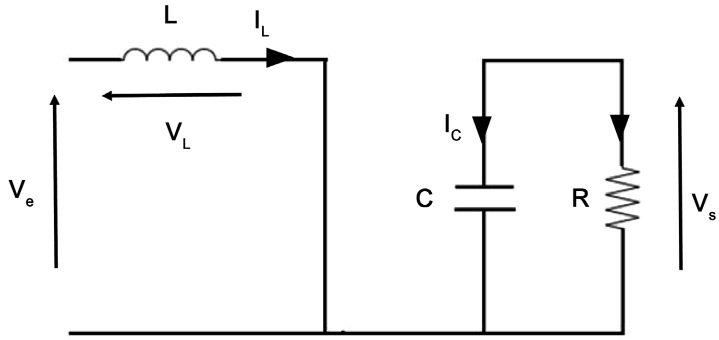

Figure 2. BOOST in closed positio.

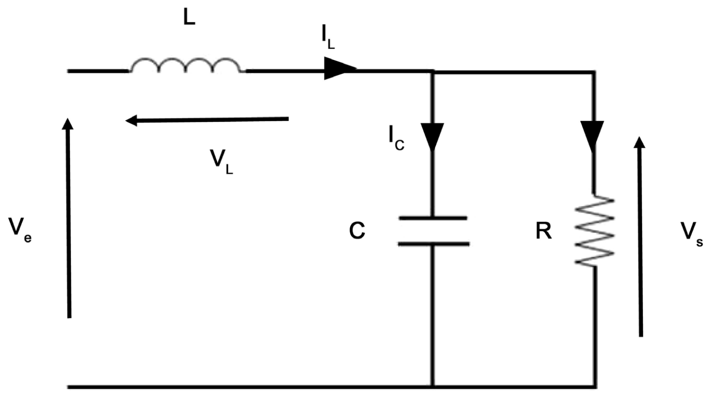

Figure 3. BOOST in open position.

Table 1. Chopper parameters.

Setting	formula	value
Inductance L	$L = \dfrac{V_S}{4f\Delta I_{L\max}}$	3.716 mH
Capacitor C_S	$C_s = \dfrac{I_e}{4f\Delta V_{S\max}}$	100 µF

1.2. Chopper PI Control

In this study, we will synthesize a PI type controller in order to control the output voltage of the BOOST chopper. Figure 4 shows the model of the closed loop PID controller, from this model the Equation (3) below is given.

$$u = K_P e(t) + K_i \int e(t)\mathrm{d}t + K_d \frac{\mathrm{d}e(t)}{\mathrm{d}t} \tag{3}$$

The expression of the PI corrector is given in the Laplace domain by Equation (4):

$$C(S) = K_P + \frac{K_i}{S} \tag{4}$$

Depending on the needs imposed by the system to be regulated, the PI regulator is a combination of several components. A distinction is made between the proportional (P) components which improve speed and the integral (I) which eliminates the static error between the controlled quantity [12] [13].

With the transfer function of the BOOST chopper obtained, a MATLAB script using the Ziegler Nichols method was developed to determine the parameters of the PI controller [14].

This gives $K_p = 0.0012$, $K_i = 12.1098$.

After simulation, with the model given in Figure 5, and by varying the load, the following results are obtained, grouped together in Table 2.

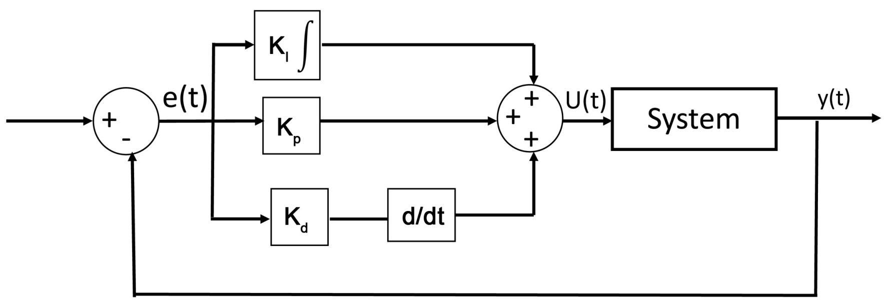

Figure 4. Structure of PID control.

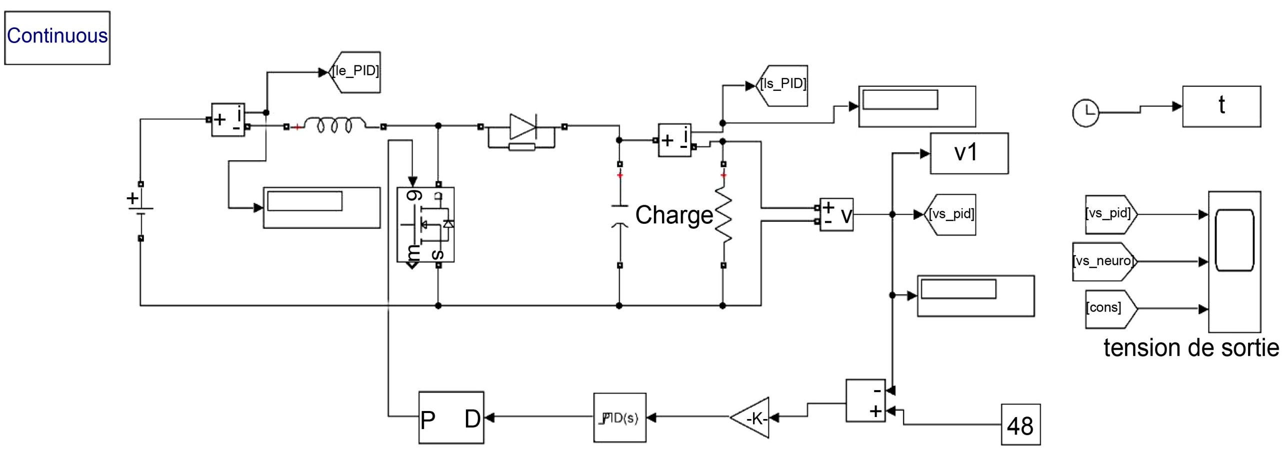

Figure 5. PI control of BOOST chopper.

Table 2. Result of the PI control.

Charge in ohm	Ue (V)	Ie (A)	Pe (w)	Us (V)	Is (A)	Ps (w)	efficiency
10	24	9.8	235.2	48.06	4.8	230.688	98%
20	24	4.92	118.08	48.03	2.4	115.272	96%
40	24	2.48	59.52	48.02	1.2	57.624	96%
60	24	1.66	39.84	48.01	0.8	38.408	96%
80	24	1.26	30.24	48.01	0.6	28.806	95%
100	24	1.02	24.48	48.01	0.48	23.0448	94%

The results obtained **Figure 6** show that the PI control of the BOOST chopper offers a good efficiency of 96%. This remains stable near the nominal load and decreases when the load is doubled.

1.3. Neural Control BOOST Chopper

In 1948, two American researchers, Mac Culloch and Pitts, gave birth to the first mathematical model of a biological neuron, which they called: formal neuron. The formal neuron is a simplified mathematical model of the biological neuron, it has a certain number of inputs, the dendrites, a body processing the inputs according to the all or nothing method, and an axon conveying the response of the neuron. **Figure 7** represents a basic model of a formal neuron [15].

$$y = \varphi(x) \tag{5}$$

$$x = \sum_{i=0}^{n} W_i x_i \tag{6}$$

The activation functions of neurons come in many forms. Most activation functions are continuous and offer an infinite number of possible values in the interval [0, +1] or [−1, +1]) (see **Figure 8**).

The neural network proceeds a high-speed computing time due to its high-speed response time. Therefore, the neural network is very useful for calculating the hash rate of power converters. **Figure 9** shows a schematic diagram of a neural network that has two input layers, four hidden layers, one output layer [16].

The main advantage of these networks lies in their learning capacity. Learning consists of modifying the weight of the connections between neurons. There are several modification rules: Hebb's law, Widrow-Hoff's rule, Grossberg's rule… [17].

In process control, the neural does not need an analytical model of the process to be controlled. This characteristic turns out to be interesting in the case of non-linear models that are difficult to model mathematically. Thus, thanks to its learning and approximation faculties, the neural command reproduce the behavior of the PI controller already developed using the matlab environment and proceeding as follows: [18]

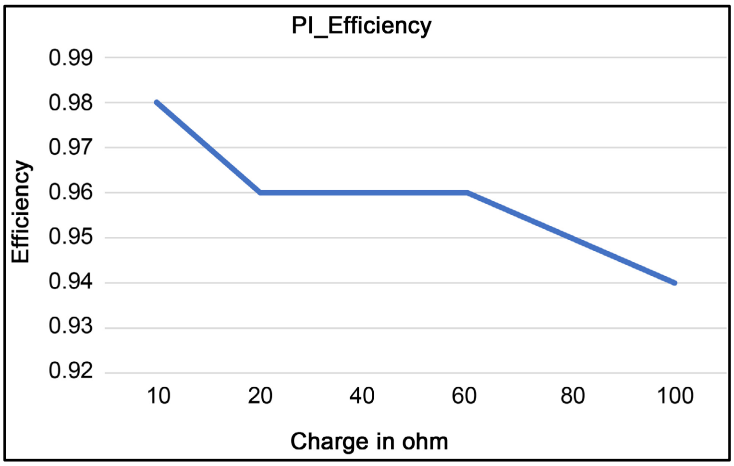

Figure 6. Efficiency versus load curve.

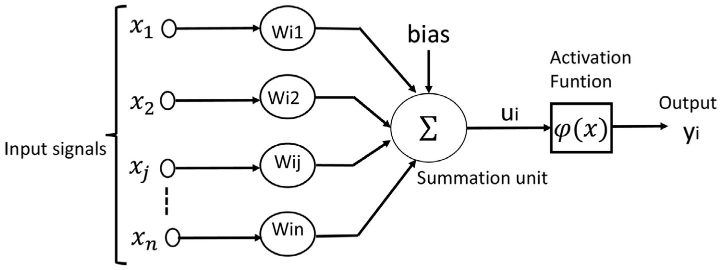

Figure 7. Principle of the artificial neuron.

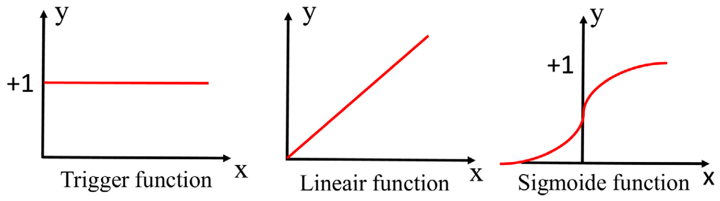

Figure 8. Activation functions.

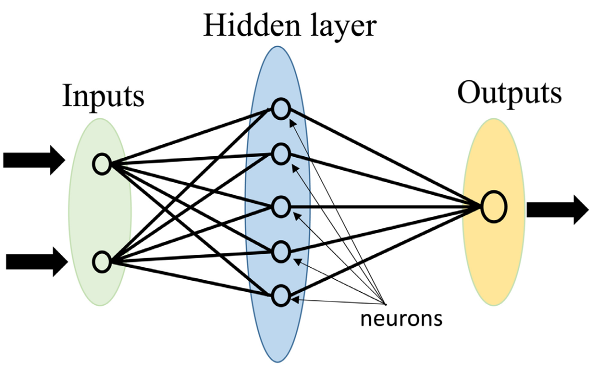

Figure 9. Block diagram of a neural network.

- Step 1: Creating the database;
- Step 2: Choosing the neural network structure;
- Step 3: Training of the neural network (test and validation follow-up);

➢ Step 4: The development and implementation of the neural corrector.

At the end of learning, after five iterations, the results obtained are given by Figure 10 below. We notice that the error which represents the difference between the targets and the outputs obtained is very close to zero (8.55e−6).

Matlab allows us to develop a neural corrector Figure 11 and Figure 12 on Simulink that we will implement in the system to do the simulations.

Simulating the model in Figure 13 by varying the load gives the following results grouped together in Table 3.

The results obtained Figure 14 show that the neural control of the BOOST chopper offers a good efficiency of 97%. This remains stable near the nominal load and decreases when the load is doubled.

1.4. Comparative Study of the PI Control and the Neural Control of the BOOST Chopper

By plotting the data in Table 4, this comparison will be made by superimposing

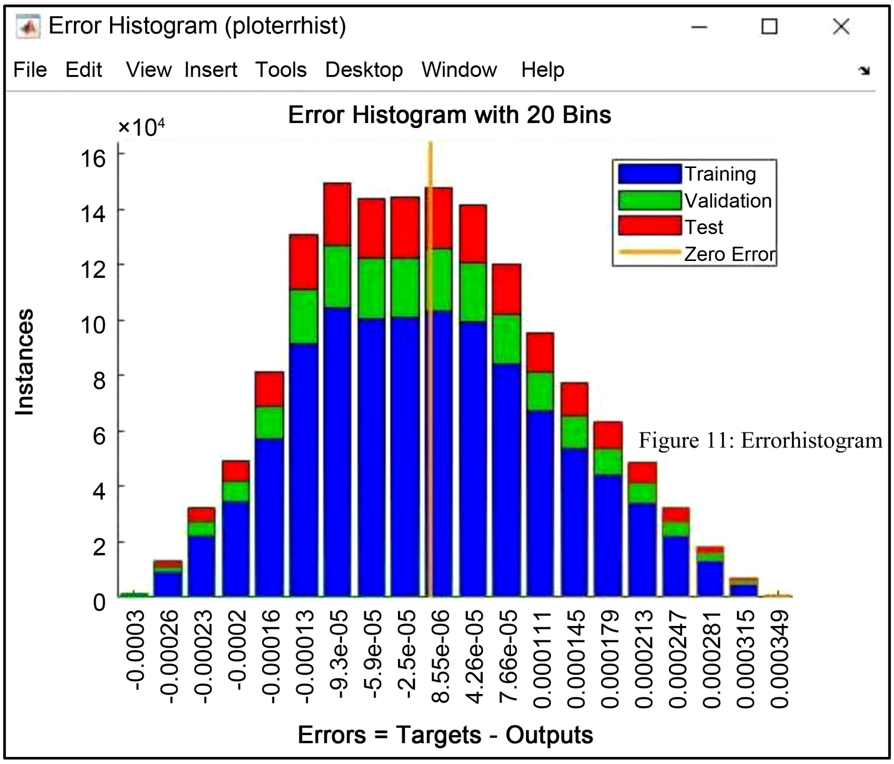

Figure 10. Results of the learning process.

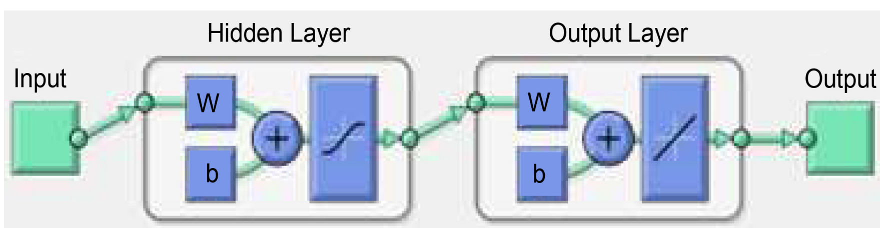

Figure 11. Structure of the created neural network.

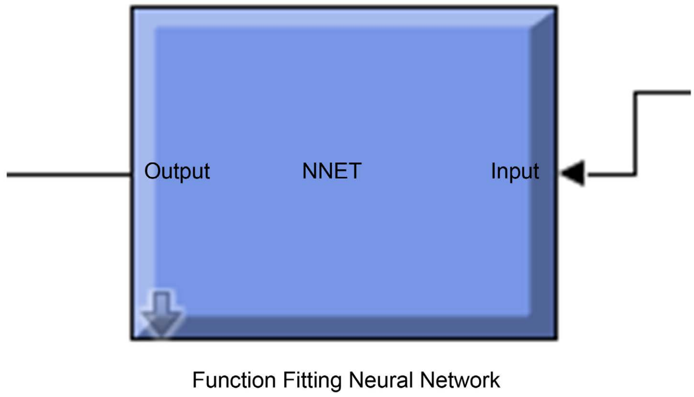

Figure 12. Simulink diagram.

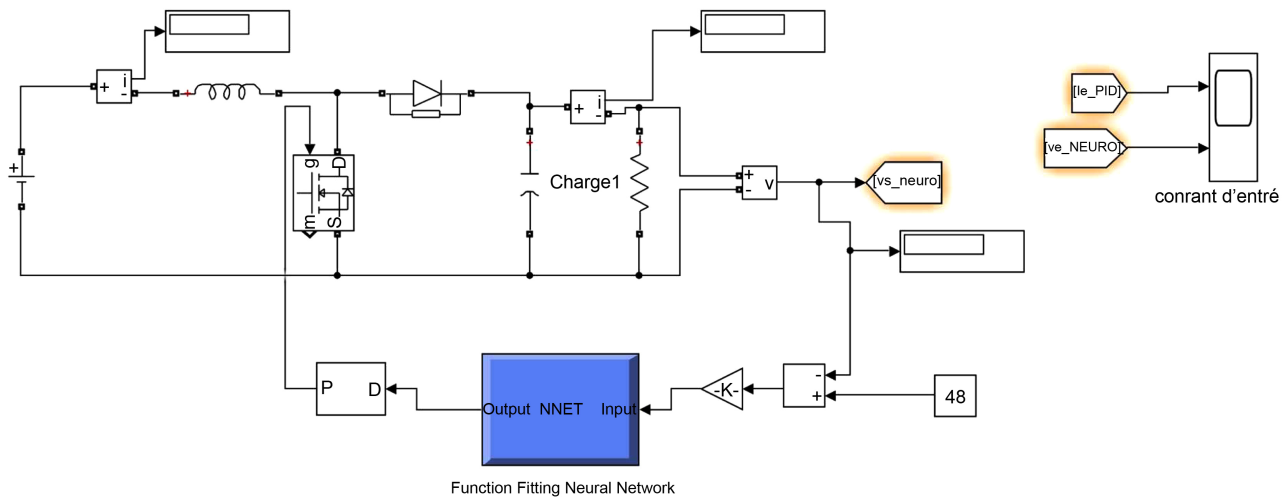

Figure 13. Neural control of the BOOST chopper.

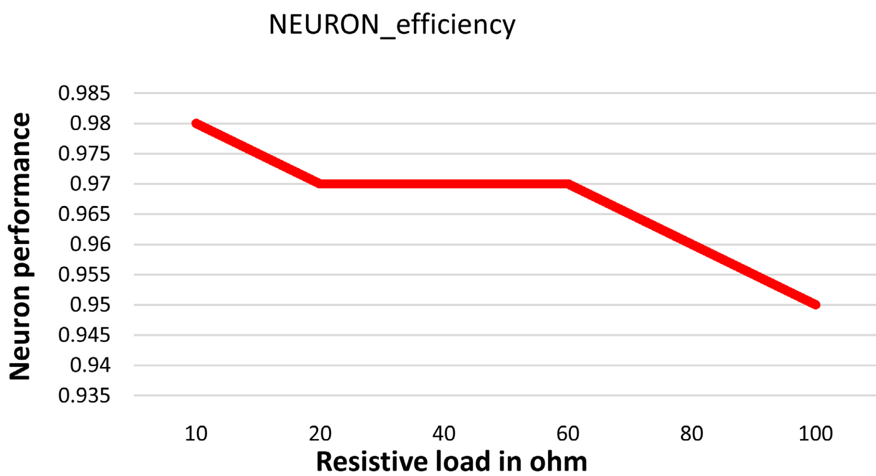

Figure 14. Efficiency versus load curve.

the curves obtained and finally comparing their yield, performance and robustness.

The curves obtained in Figure 15, plotting the results grouped in the table,

Table 3. Neural control results.

Charge in ohm	Ue (V)	Ie (A)	Pe (w)	Us (V)	Is (A)	Ps (w)	efficiency
10	24	9.79	234.96	48.04	4.79	230.1116	98%
20	24	4.92	118.08	48.02	2.4	115.248	97%
40	24	2.48	59.52	48.01	1.2	57.612	97%
60	24	1.66	39.84	48	0.8	38.4	97%
80	24	1.26	30.24	48	0.6	28.8	96%
100	24	1.02	24.48	48	0.48	23.04	95%

Table 4. PI and neuronal performance.

Charge	PI	NEURON
10	98%	98%
20	96%	97%
40	96%	97%
60	96%	97%
80	95%	96%
100	94%	95%

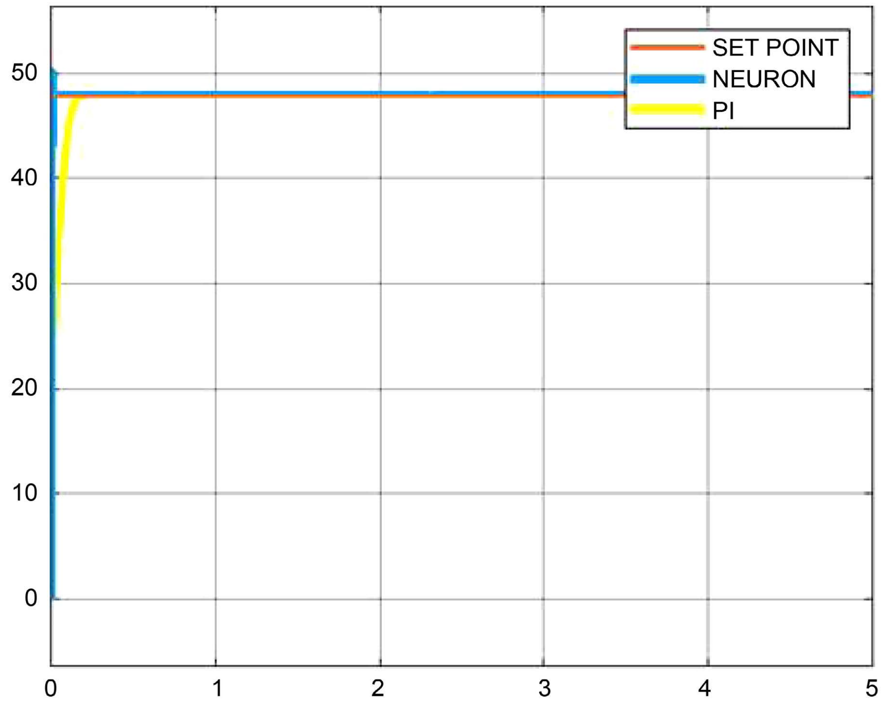

Figure 15. Output voltages of the two controls.

show that both commands offer good performance, but the performance obtained with the neural command is better.

The curves in Figure 15 show that the neural control is much faster and more

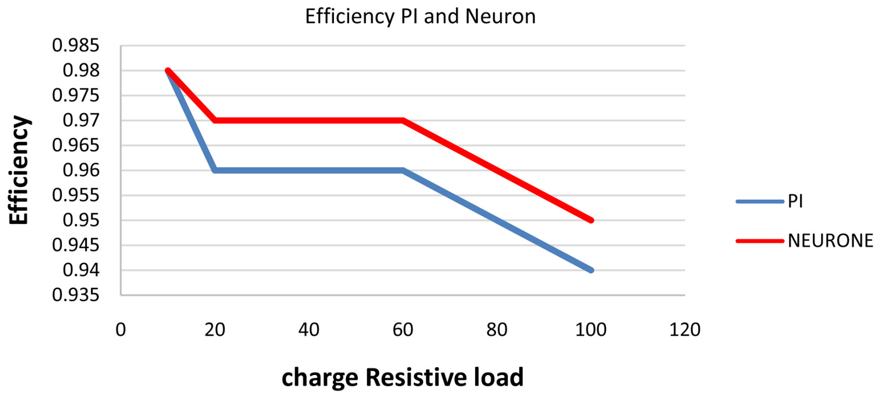

Figure 16. PI and neuron performance.

stable than the PI control, and the efficiency in the neural control is higher in the vicinity of the nominal charge, Figure 16. It goes without saying that the neural controller is much more efficient.

2. Conclusions

Overall, this study examined the performance of a boost converter regulating its output voltage using two control methods: Proportional-Integral (PI) control and neural control. The literature review showed that several works have been carried out to propose new control methods and evaluate their robustness. However, our study distinguishes itself by comparatively evaluating the effectiveness of two popular control methods. The results showed that neural control offers superior performance in terms of accuracy and response time, with faster and more precise regulation of the output voltage.

These results are important as they guide the choice of appropriate control method for a boost converter depending on the specific requirements of each application. They also contribute to research on improving the regulation of the output voltage of converters. In summary, this study demonstrates that neural control is a more effective method for regulating the output voltage of a boost converter than PI control, which can help improve the efficiency and performance of many power systems. Examples include adapting the voltage provided by photovoltaic panels for battery charging, electric vehicles, and lighting systems (using energy-saving lamps).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Zaatri, A. and Belhour, S. (2010) Etude et réalisation d'un hacheur PWM. *Revue des Énergies Renouvelables*, **13**, 187-198.

[2] Lakshmi, M. and Hemamalini, S. (2018) Nonisolated High Gain DC-DC Converter

for DC Microgrids. *IEEE Transactions on Industrial Electronics*, **65**, 1205-1212. https://doi.org/10.1109/TIE.2017.2733463

[3] Ayang, A. (2020) Diagnostic d'un système photovoltaïque à stockage par estimation paramétrique et commandes ADRC, intégré à une centrale autonome de cogénération d'énergie. PhD, Université du Québec à Chicoutimi, Chicoutimi.

[4] Potnuru, D. and Kumar, J.S.V.S. (2017) Design of a Front-End DC-DC Converter for a Permanent Magnet DC Motor Using Fuzzy Gain Scheduling. 2017 *IEEE International Conference on Power*, *Control*, *Signals and Instrumentation Engineering (ICPCSI)*, Chennai, 21-22 September 2017, 1502-1505. https://doi.org/10.1109/ICPCSI.2017.8391962

[5] Jeyasenthil, R., Kobaku, T., Subudhi, B., Sahoo, S. and Dragicevic, T. (2022) Chapter 4. Design and Experimental Validation of Robust PID Control for a Power Converter in a DC Microgrid Application. In: Subudhi, B. and Ray, P.K., Eds., *Microgrid Cyberphysical Systems*, Elsevier, Amsterdam, 89-114. https://doi.org/10.1016/B978-0-323-99910-6.00006-2

[6] Guo, L., Hung, J.Y. and Nelms, R.M. (2009) Evaluation of DSP-Based PID and Fuzzy Controllers for DC-DC Converters. *IEEE Transactions on Industrial Electronics*, **56**, 2237-2248. https://doi.org/10.1109/TIE.2009.2016955

[7] Abdelrahman, A., Eid, M., Ren, J., Wang, Y. and Youssef, M. (2016) Efficient Intelligent Control Techniques for DC-DC Converters: A Comparative Study. 2016 18*th European Conference on Power Electronics and Applications* (*EPE*'16 *ECCE Europe*), Karlsruhe, 5-9 September 2016, 1-5. https://doi.org/10.1109/EPE.2016.7695301

[8] Boujelben, N., Masmoudi, F., Djemel, M. and Derbel, N. (2017) Design and Comparison of Quadratic Boost and Double Cascade Boost Converters with Boost Converter. 2017 14*th International Multi-Conference on Systems*, *Signals & Devices* (*SSD*), Marrakech, 28-31 March 2017, 245-252. https://doi.org/10.1109/SSD.2017.8167022

[9] Forouzesh, M., Siwakoti, Y.P., Gorji, S.A., Blaabjerg, F. and Lehman, B. (2017) Step-Up DC-DC Converters: A Comprehensive Review of Voltage-Boosting Techniques, Topologies, and Applications. *IEEE Transactions on Power Electronics*, **32**, 9143-9178. https://doi.org/10.1109/TPEL.2017.2652318

[10] Ye, H., Jin, G., Fei, W. and Ghadimi, N. (2020) High Step-Up Interleaved DC/DC Converter with High Efficiency. *Energy Sources*, *Part A*: *Recovery*, *Utilization*, *and Environmental Effects*. https://doi.org/10.1080/15567036.2020.1716111

[11] Bahravar, S., Mahery, H.M., Babaei, E. and Sabahi, M. (2012) Mathematical Modeling and Transient Analysis of DC-DC Buck-Boost Converter in CCM. 2012 *IEEE* 5*th India International Conference on Power Electronics* (*IICPE*), Delhi, 6-8 December 2012, 1-6. https://doi.org/10.1109/IICPE.2012.6450404

[12] Valluru, S.K., *et al.* (2018) Design of Multi-Loop L-PID and NL-PID Controllers: An Experimental Validation. 2018 2*nd IEEE International Conference on Power Electronics*, *Intelligent Control and Energy Systems* (*ICPEICES*), Delhi, 22-24 October 2018, 1228-1231. https://doi.org/10.1109/ICPEICES.2018.8897368

[13] Mahmud, M., Motakabber, S.M.A., Zahirul Alam, A.H.M. and Nordin, A.N. (2020) Adaptive PID Controller Using for Speed Control of the BLDC Motor. 2020 *IEEE International Conference on Semiconductor Electronics* (*ICSE*), Kuala Lumpur, 28-29 July 2020, 168-171. https://doi.org/10.1109/ICSE49846.2020.9166883

[14] Rao, V.S., Tapaswi, S. and Kumaravel, S. (2022) Extendable Bidirectional DC-DC Converter with Improved Voltage Transfer Ratio and Reduced Switch Count. *IEEE*

Journal of Emerging and Selected Topics in Industrial Electronics, **4**, 460-470.

[15] Maruta, H., Mitsutake, D. and Kurokawa, F. (2014) Transient Characteristics of DC-DC Converter with PID Parameters Selection and Neural Network Control. 2014 13*th International Conference on Machine Learning and Applications*, Detroit, 3-6 December 2014, 447-452. https://doi.org/10.1109/ICMLA.2014.78

[16] Ko, J.-S., Jung, B.-J., Park, K.-T., Choi, C.-H. and Chung, D.-H. (2008) Maximum Power Point Tracking Control of PV System for DC Motors Drive with Neural Network. 2008 *International Conference on Smart Manufacturing Application*, Goyang-Si, 9-11 April 2008, 514-519.

[17] Khan, H.S., Mohamed, I.S., Kauhaniemi, K. and Liu, L. (2021) Artificial Neural Network-Based Voltage Control of DC/DC Converter for DC Microgrid Applications. 2021 6*th IEEE Workshop on the Electronic Grid* (*eGRID*), New Orleans, 8-10 November 2021, 1-6. https://doi.org/10.1109/eGRID52793.2021.9662132

[18] Liu, J., *et al.* (2021) A Backpropagation Neural Network Controller Trained Using PID for Digitally-Controlled DC-DC Switching Converters. 2021 *IEEE* 16*th Conference on Industrial Electronics and Applications* (*ICIEA*), Chengdu, 1-4 August 2021, 946-951. https://doi.org/10.1109/ICIEA51954.2021.9516423