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Step-up DC-DC Boost Converter Control with PID Controller and Artificial Neural Network

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Abstract:
These days, energy markets are witnessing a shift to renewable and sustainable energy sources, which increases demand for power electronic devices, especially DC-DC boost converters. This letter examines the problem of the voltage of the output adjustment of a DC-DC boost converter connecting with a resistive load. This study introduces a comparison between two techniques, namely artificial neural network (ANN) and PID controller to adjust the voltage of the output of the DC-DC boost converter. The simulation outcomes display that the ANN control technique gives a better dynamic response than the PID controller.

Keywords: Energy Markets, Power Electronics Devices, Boost Converter, Artificial Neural Network, PID Controller.

الملخص
تشهد أسواق الطاقة هذه الأيام تحولاً نحو مصادر الطاقة المتجددة والمستدامة، مما يزيد الطلب على الأجهزة الإلكترونية القوية، وخاصة محولات تعزيز التيار المستمر إلى التيار المستمر. تبحث هذه الورقة في مشكلة ضبط جهد الخرج لمحول تعزيز التيار المستمر إلى التيار المستمر المتصل بحمل مقاوم. تقدم هذه الدراسة مقارنة بين تقنيتين، وهما الشبكة العصبية الاصطناعية (ANN) ووحدة التحكم PID لضبط جهد الخرج لمحول تعزيز التيار المستمر إلى التيار المستمر. تظهر نتائج المحاكاة أن تقنية التحكم ANN تعطي استجابة ديناميكية أفضل من وحدة التحكم PID.

الكلمات المفتاحية: أسواق الطاقة، أجهزة الكترونات القدرة، محول التعزيز، الشبكة العصبية الاصطناعية، وحدة تحكم PID

Introduction

A step-up DC-DC converter is utilized in several industrial fields like PV modules, storage devices (charging of batteries), communication systems, power supplies, and some electronic devices. In general, the purpose of a DC-DC boost converter is to provide a suitable output voltage greater than the input voltage despite disturbances in the parameters of the converter and the load. DC-DC boost converter has nonlinear characteristics. Therefore, many techniques have been introduced by researchers to adjust the voltage of the output of DC-DC boost converters [1].

The classical control ways like the proportional-integral (PI) and the proportional-integral-derivative (PID) have linear characteristics and simple designs [2]. The PI and PID controllers are usually utilized to control the on/off switching of the converter to get a stable output voltage [3]. Yet, if the controlled element is variable and intricate, the selection of suitable parameters for the PI and PID is difficult, and the performance under different operations is not satisfactory.

Lately, artificial intelligence technologies (AI) such as genetic algorithms, fuzzy logic control, and artificial neural networks are used to solve optimization problems like uncertainty issues, and design errors, particularly in the control of power electronic devices [4]. The authors in [5] used the technology of fuzzy logic control technique to decrease the ripples of the output voltage of the DC-DC boost converter and enhance its output performance.

Paper [6] submits a genetic algorithm method to calculate the optimum values of the parameters of the boost converter. To enhance the startup response of the DC-DC boost converter, Particle Swarm Optimization (PSO) control has been used [7]. It was found that PSO control is superior to conventional control methods [7]. Our paper aims to make a comparison between PID controller and artificial neural network (ANN) in terms of their capability to stabilize and improve the characteristics of the dynamic response of DC-DC boost converter.

DC-DC Boost Converter Design

Figure 1 displays the basic structure of a DC-DC boost converter. There are two operation modes of the boost converter. Mode 1 starts when the switch S_w is closed. In this case, the power diode D becomes an open circuit, and the energy stored in the capacitor has been discharged into the resistance R. Mode 2 starts when the switch S_w is open. In this case, the power diode becomes short circuit, and the current i_L flows through the resistance R and the capacitor C [8].

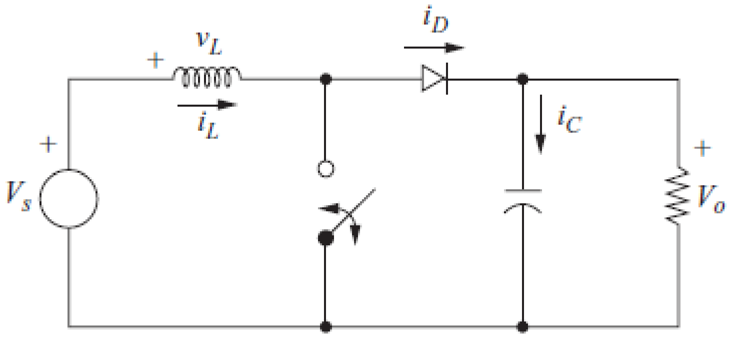

Figure 1: Circuit of the boost converter.

Figure 2 displays the Mode1 circuit when the switch S_w is closed.

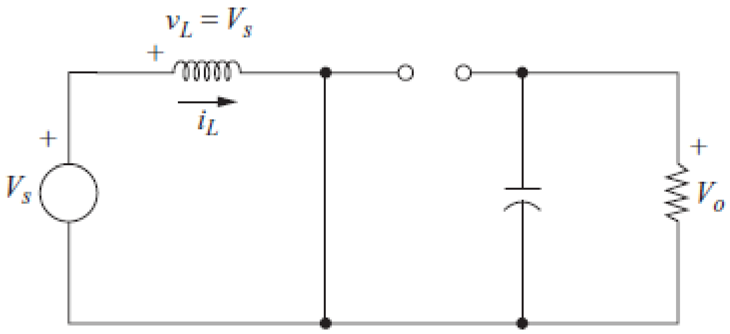

Figure 2: Mode 1 circuit.

By applying the KVL's around the first closed path in the circuit we will get this equation

$$v_L = v_s = \frac{Ldi_L}{dt} \rightarrow \frac{v_s}{L} = \frac{di_L}{dt} \quad (1)$$

The voltage source is a DC voltage source, so the current change rate is constant and the current will be increased linearly during the S_w is closed.

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{v_s}{L} \quad (2)$$

$$(\Delta i_L)_{closed} = \frac{v_s DT}{L} \quad (3)$$

Figure 3 shows the circuit of Mode 2 when the switch S_w is open

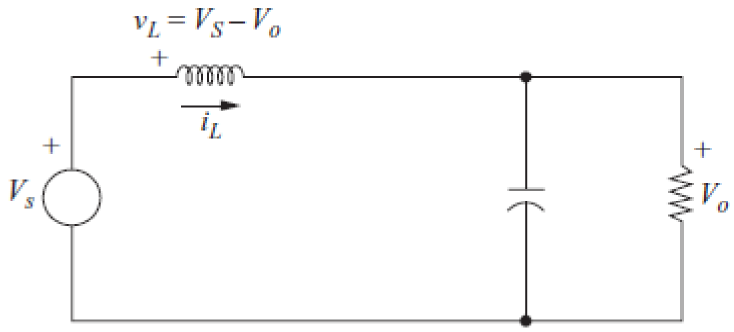

Figure 3: Mode 2 circuit.

In this case, the S_w is opened, so the inductor voltage is

$$v_L = v_s - v_o = \frac{Ldi_L}{dt} \tag{4}$$

$$\frac{di_L}{dt} = \frac{v_s - v_o}{L} \tag{5}$$

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{v_s - v_o}{L} \tag{6}$$

$$(\Delta i_L)_{open} = \frac{(v_s - v_o)(1-D)T}{L} \tag{7}$$

Concerning the operation of a steady state, the change in the current of the inductor equals zero, by using Eqs.3 and 6.

$$(\Delta i_L)_{closed} + (\Delta i_L)_{open} = 0 \tag{8}$$

$$\frac{v_s DT}{L} + \frac{(v_s - v_0)(1-D)T}{L} == 0 \tag{9}$$

$$v_s(D + 1 - D) - v_o(1-D) = 0 \tag{10}$$

$$v_o = \frac{v_s}{1-D} \tag{11}$$

The following figures illustrate the waveforms of the step-up DC-DC boost converter:

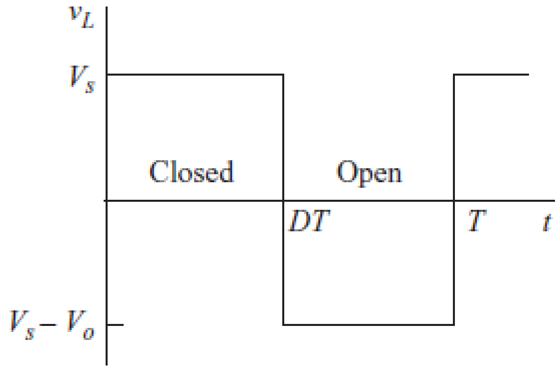

Figure 4: The inductor voltage of the step-up DC-DC boost converter**.**

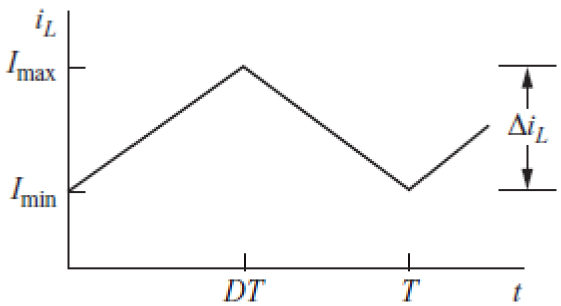

Figure 5: The inductor current of the step-up DC-DC boost converter.

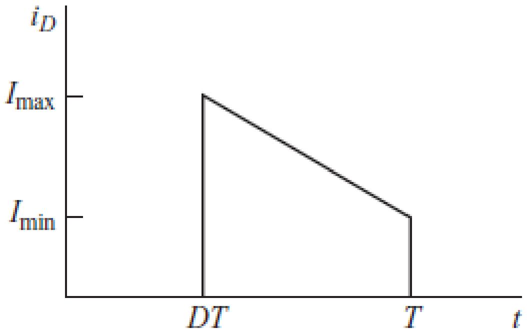

Figure 6: The diode current of the step-up DC-DC boost converter.

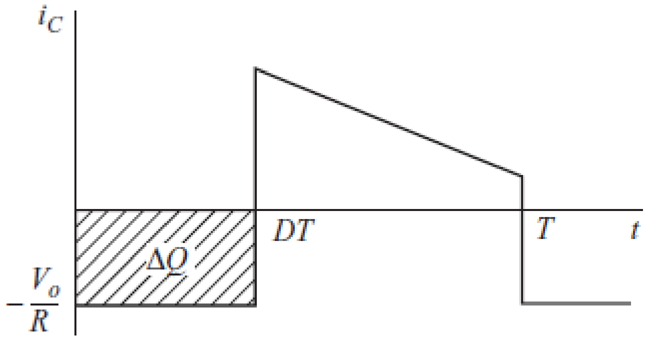

Figure 7: The capacitor current of the step-up DC-DC boost converter.

The boost converter parameters have been chosen depending on the following equations:

$$D = 1 - \frac{v_s}{v_o} \tag{12}$$

$$L_{min} = \frac{D(1-D)^2(R)}{2f} \tag{13}$$

$$L = 1.25L_{min} \tag{14}$$

$$C = \frac{D}{R\left(\Delta v_o / v_o\right) f} \tag{15}$$

$$\Delta v_o = \frac{v_o DT}{RC} = \frac{v_o D}{RCf} \tag{16}$$

Table 1 shows the parameters of the converter of this study.

Table 1: Boost converter parameters.

Parameter	Rated value
The voltage of the input (v_s)	12 V
The voltage of the output (v_o)	30 V
D	0.6
Inductor (L)	120 μH
Capacitor (C)	48 μF
Load (R)	50 Ω
The frequency of the switching (f)	25 kHZ
The output voltage ripple $\left(\Delta v_o / v_o\right)$	0.01

PID Controller

The PID controller can be classified as one of the classical controllers that are used to drive many systems. Figure 8 displays the loop of the PID controller. As we see it consists of three terms: integral (I), proportional (P), and derivative (D) parameters. The PID controller represents a closed-loop control system that aims to calculate and correct the error to get the setpoint depending on tuning the parameters of the PID controller [9].

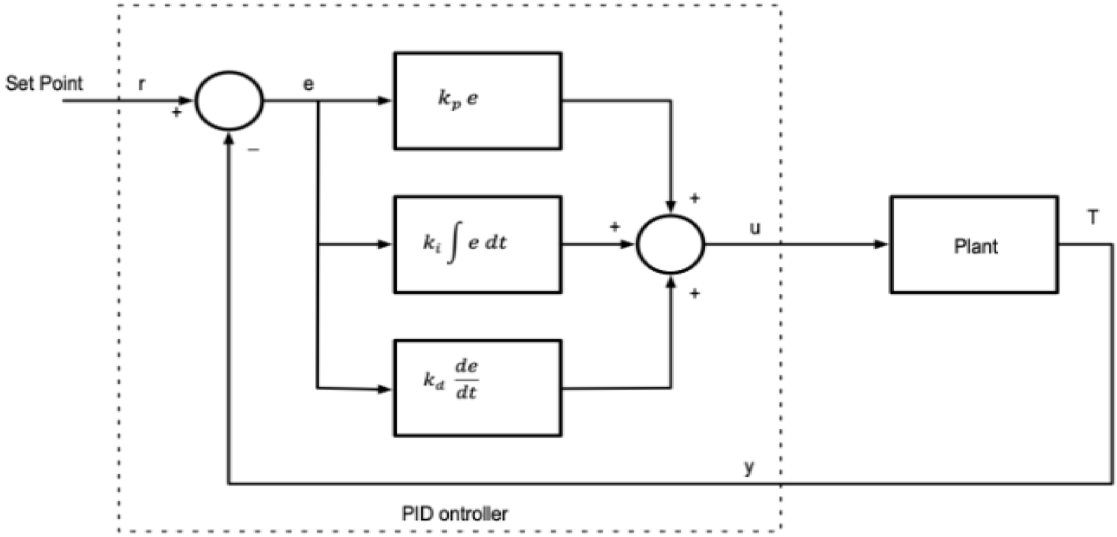

Figure 8: PID controller structure.

Artificial Neural Network

The ANN is a calculation model consisting of an enormous number of processors recognized as neurons. The idea of an ANN is inspired by the human brain's neurons. This type of technology uses artificial intelligence based on machine learning to make predictions and identify patterns based on input data [10].

Three fundamental types of layers compose a neural network:

- Input layer: Neurons in this layer represent the features of the input data.
- Hidden layers: One or more hidden layers may exist between the input layer and the output layer. The hidden layers carry out complicated calculations on the input data and pass the outcome through an activation function.
- Output layer: This layer makes the ultimate forecast or outcome. The type of issue determines how many neurons are in this layer.

Figure 9 shows the artificial neural network suggested.

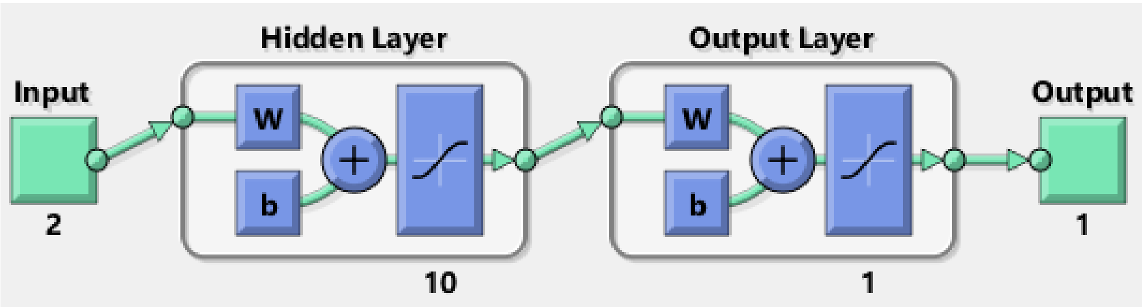

Figure 9: The artificial neural network suggested

The following flowchart denotes how the neural network works depending on the training process:

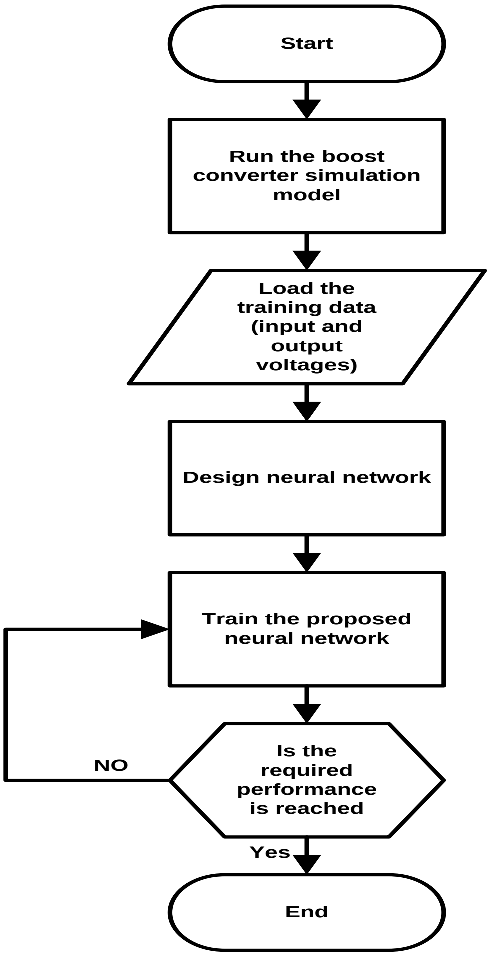

Figure 10: The flowchart of the ANN with boost converter.

Results

In this study, we have used two Matlab/Simulink models to compare the step-up DC-DC boost converter performance when operating with the PID controller and ANN. Figure 11 displays the operation of the step-up DC-DC boost converter with the PID controller.

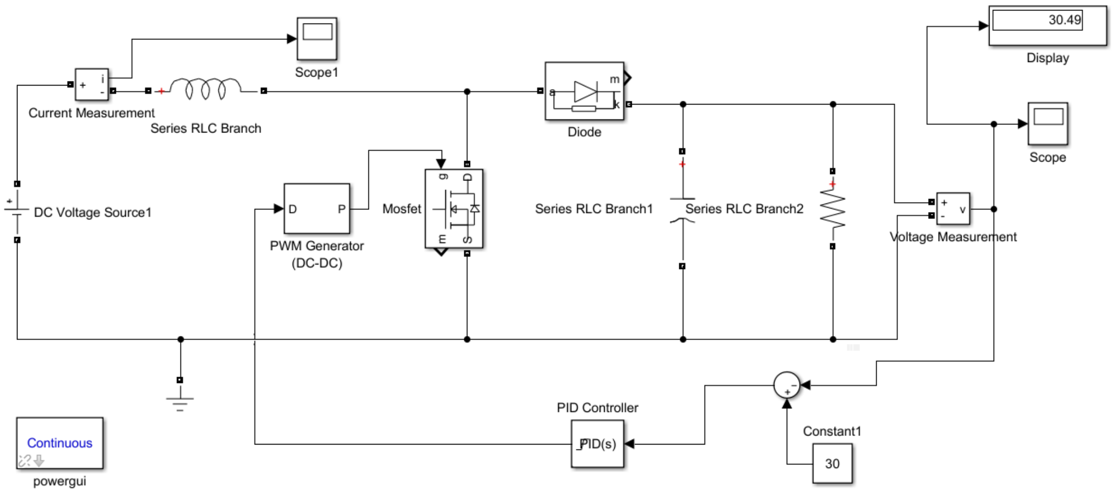

Figure 11: The step-up DC-DC boost converter control with the PID controller.

Figure 12 shows the output voltage of the step-up DC-DC boost converter with the PID controller. In this figure, we can see the overshoot reaches 190 v also the transient period and settling time are too long.

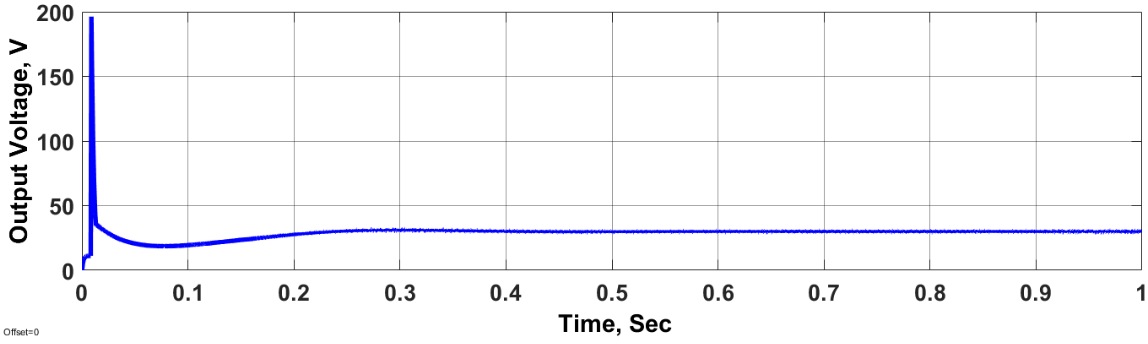

Figure 12: The step-up DC-DC boost converter output voltage with the PID controller.

Figure 13 shows the Matlab/Simulink circuit of the step-up DC-DC boost converter with ANN.

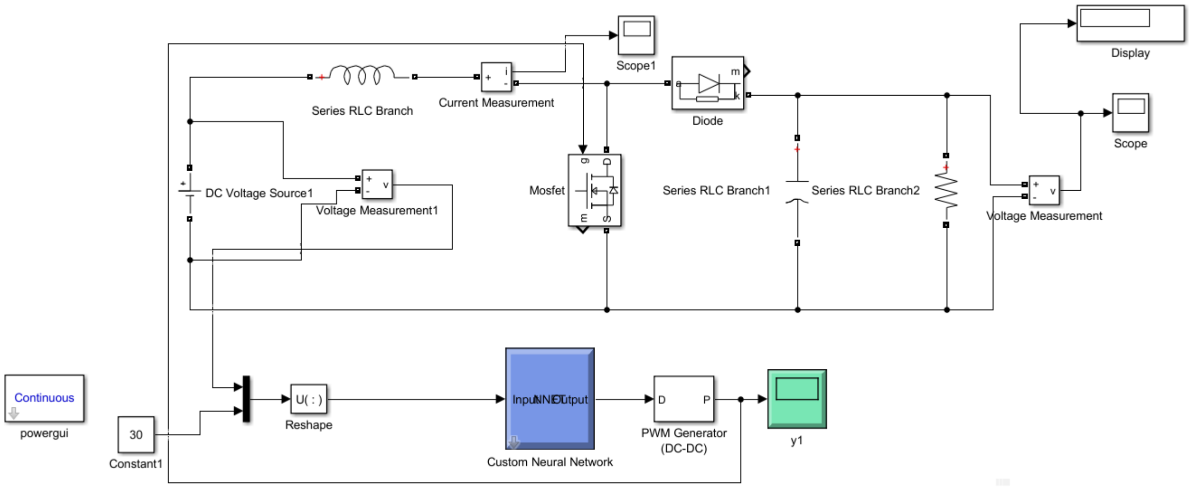

Figure 13: The step-up DC-DC boost converter control with the ANN.

Figure 14 shows the voltage of the output of the step-up DC-DC boost converter with the ANN. In this figure, we can see the overshoot reaches 50 v also the transient period and settling time are too short.

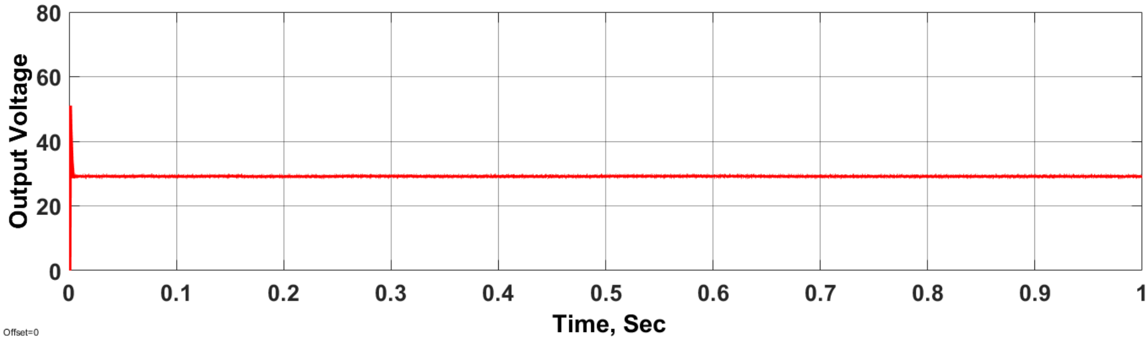

Figure 14: The voltage of the output of the step-up DC-DC boost converter with the ANN.

Figure 15 displays a comparison between the two models.

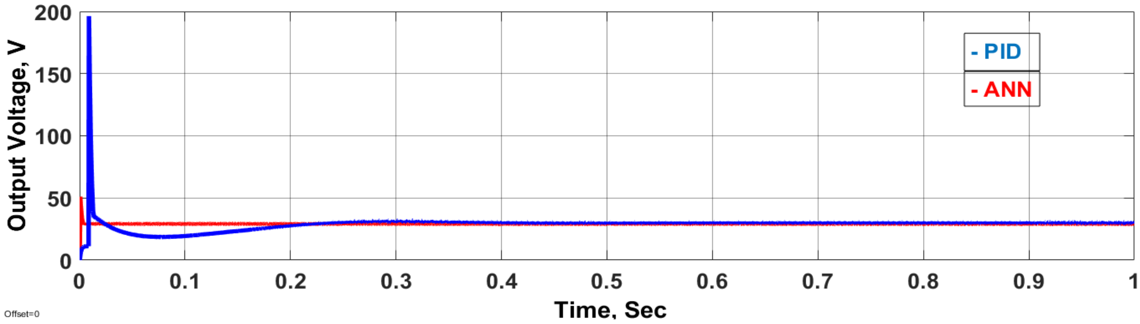

Figure 15: A comparison between control of the output voltage of the step-up DC-DC boost converter with the ANN and PID controller.

We can summarize the comparison in the following table :

Table 2: A comparison between PID controller and ANN.

Dynamic response	PID controller	ANN
Overshoot	High	Low
Time settling	Long	Short
Transient period	Long	Short
Output voltage	Stable	More stable
Start-up	Not smooth	Smooth
Feedback system	Not fast response	Fast response

The outcomes display that the step-up DC-DC boost converter control based on ANN gives a higher performance than the step-up DC-DC boost converter control based on the PID controller.

Conclusion

The present comparative study shows how an intelligent control (ANN) can outperform classical control (PID controller) in improving the characteristics of the dynamic response of the boost converter. The simulation outcomes have shown that the control of the boost converter with the artificial neural network has better transient response specifications (time settling, transient period, overshoot, feedback, start-up) than the control of the boost converter with the PID controller.

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