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Backpropagation neural network for DC-DC boost converter control using arduino microcontroller

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ABSTRACT

One kind of power converter that is frequently found in devices that employ a DC voltage source to produce a voltage output higher than the input voltage is the boost converter. The boost converter output voltage converter must be adjusted in order to produce the desired voltage output. This research suggests utilizing an Arduino Mega 2560 microcontroller implemented backpropagation-type artificial neural network to manage the boost converter output voltage. The highest output voltage of the boost converter is 24 volts, and its input voltage is 12 volts. Laboratory tests using different reference voltages and loads are used to validate the boost converter voltage control system based on a backpropagation neural network. Experiments conducted under a variety of test conditions demonstrate that the backpropagation neural network-based boost converter output voltage control system used in this study has effectively controlled the boost converter output voltage in accordance with the reference output voltage value, both when the load and the reference voltage are varied.

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1. INTRODUCTION

A variety of electrical devices, including electronic devices and DC electric motors, rely on DC voltage sources for their energy. A variety of sources, including batteries, DC generators, solar panels, fuel cells, and more, can provide this DC voltage source [1]-[2]. This DC voltage-generating apparatus generates voltage in a range of standards or values, including 1.5, 3, 6, and so forth [3]. However, different voltage values are also needed for equipment that employs DC voltage sources. Numerous DC-DC converters that may generate output voltage in accordance with requirements have been developed in order to acquire DC voltage as needed. Depending on the requirements, a different form of power converter is designed, such as a boost converter, which produces an output voltage higher than the input [4]-[11], or a buck converter, which produces an output voltage lower than the input voltage [12]-[15]. This study develops a boost converter to produce a dc voltage higher than its input voltage. Utilizing power semiconductors like MOSFET or IGBT, this boost converter operates [16]-[17]. An input voltage of 12 volts and an output voltage that can fluctuate up to 24 volts are the specifications for the boost converter.

The boost converter output voltage setting can be done by setting the modulation pulse of the semiconductor switch used in the converter. The modulation pulse setting of this converter switch can be done using the Pulse Width Modulation (PWM) method [18]-[19]. In this method, the converter output voltage setting is done by setting the PWM pulse width, where the pulse width is determined by the duty cycle value. In other words, the boost converter output voltage setting can be done by setting the PWM duty cycle for the switch converter. Several control methods have been applied for this setting, such as proportional integral (PI) controller [6],[20], sliding mode control [21] and artificial intelligence-based control systems, such as fuzzy logic controller [22]-[23] and artificial neural networks (ANN) [24]-[28].

These days, ANNs are being used in control systems at an accelerating rate. One type of machine learning or artificial intelligence algorithm that functions similarly to human neural networks is called an ANN. Data classification, pattern identification, control systems, predictions, and other applications are all possible with this ANN [29]. Adaptive learning capabilities, which allow the ANN to perform tasks based on initial experience or data provided during training, are among its benefits. Additionally, the ANN can generate or construct its own structure or organization based on information or experience gained or received during training [30]. Based on these advantages, in this study, ANN was chosen to be applied in controlling the PWM duty cycle for controlling the output voltage of the boost converter. There are several types of ANN that have been developed, such as recurrent neural networks [31], backpropagation neural networks [32], convolutional neural networks [33], and so on. In this study, the type of ANN used is backpropagation ANN, because it is simpler to apply. This backpropagation ANN will be used to determine the value of the change in duty cycle based on the output voltage error of the boost converter. With this concept, it is expected that the boost converter can produce voltage according to its reference value. This JST backpropagation-based boost voltage control is implemented using an Arduino Mega 2560 programmed with Simulink Matlab.

2. METHOD

The research on the application of JST backpropagation for boost converter voltage control was conducted in the form of experiments, starting from design, manufacture, testing, and analysis. The block diagram of the boost converter voltage control based on JST backpropagation is shown in Figure 1.

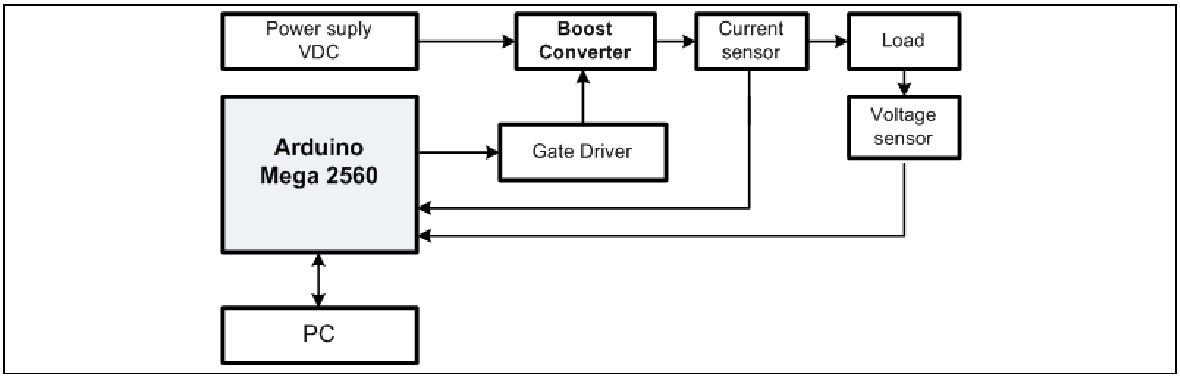

Figure 1. Diagram block of proposed system

Figure 1 shows that the boost converter voltage control based on JST backpropagation consists of a boost converter with a 12-volt input and a maximum output of 24 volts, current and voltage sensors to obtain voltage and current data from the boost converter. The voltage signal from this sensor will also be used as feedback for controlling the converter output voltage..

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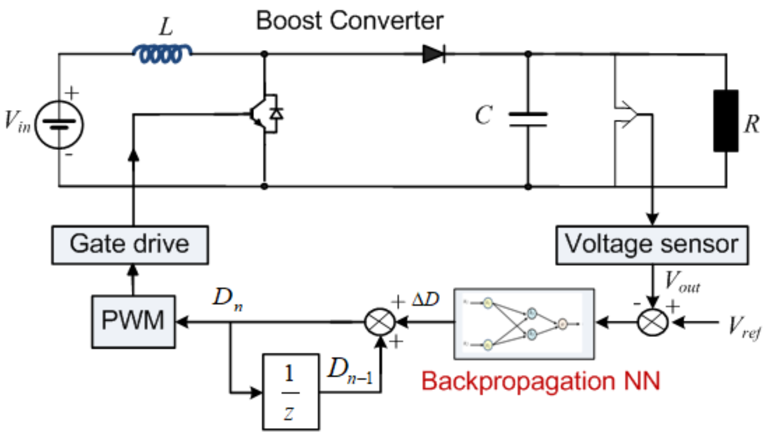


Figure 2. Scheme of Bacpropagation neural network control for boost converter

This JST-based boost converter voltage control system is implemented with Arduino Mega 2560 to generate PWM pulses for modulating the converter switch. The PWM pulses from the Arduino PWM pin will be amplified by the gate drive circuit so that it will produce a voltage according to the voltage level required to activate the converter switch. Figure 2 shows the JST backpropagation-based boost converter output voltage control scheme output. Figure 2 shows that the backpropagation ANN is used to determine the value of the change in duty cycle ΔD based on the output voltage error of the boost converter, where the voltage error is determined by the comparison between the desired reference voltage and the feedback voltage obtained from the sensor. This backpropagation ANN is a multi-layer ANN consisting of an input layer, a hidden layer and an output layer, as shown in Figure 3. Backpropagation ANN uses a training data method in the form of supervised learning. To achieve the desired output target, the backpropagation ANN algorithm has two propagations, namely forward propagation and backward propagation. To obtain a Backpropagation ANN model that can produce the desired output, the ANN training is first carried out by preparing the input data and target output data.

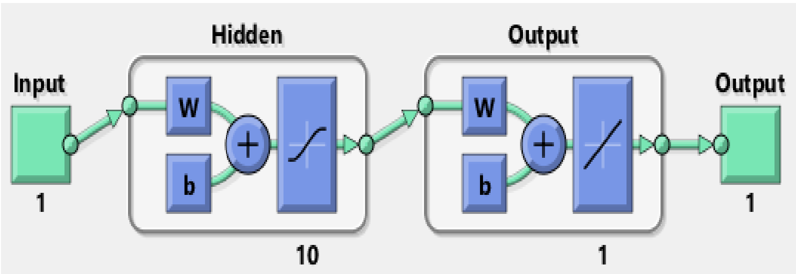


Figure 3. Structure of Bacpropagation neural network

3. RESULTS AND DISCUSSION

After assembling the circuit, the first step is to create a backpropagation neural network model that will be used for boost converter voltage control. The backpropagation neural network model is created using the JST toolbox in matlab. The backpropagation backpropagation neural network model is created with one input, namely voltage error, and one output, namely duty cycle changes. The backpropagation neural network model is created with 10 hidden layers, as shown in Figure 3. Figure 4 shows the training results of creating an ANN model using the ANN toolbox in Matlab. Figure 4(a) shows a graph of input, output and target data at training and testing times. Figure 4(a) shows that the output data and target data are almost the same. This shows that the trained ANN model has provided output values according to the target, where the resulting MSE error reaches 0.000001 at epoch 11 training time and 0.01 testing time, as shown in Figure 4(b).

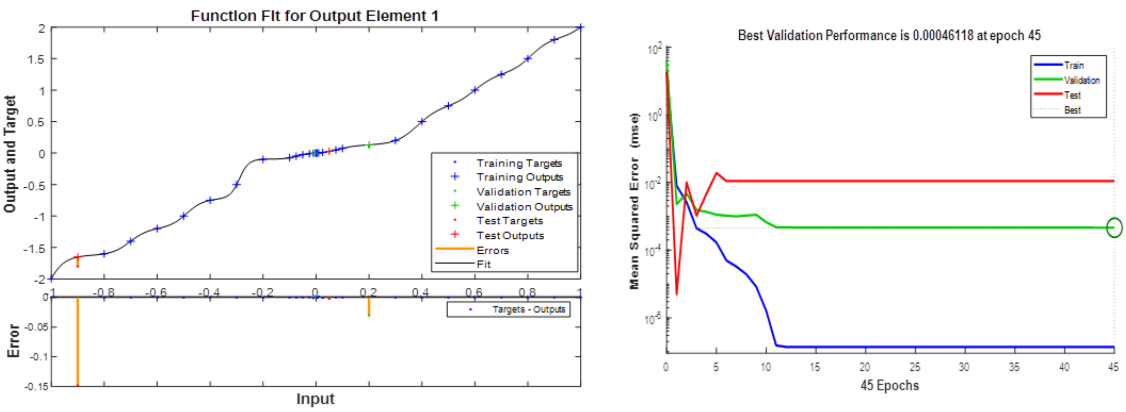


Figure 4. Training results of Bacpropagation neural network

After the JST model is considered valid for the boost converter output voltage control, the JST model is then entered into the boost converter output voltage control program created in Simulink matlab. Figure 5 shows the form of the boost converter output voltage control program based on JST created in Simulink. In this model, there are three analog input pins of Arduino used, namely for the input current sensor, output current and output voltage. Meanwhile, the PWM pulse is issued on the PWM digital pin with a switching frequency of 31372 Hz, as shown in Figure 5. Each input signal is added with a lowpass filter to obtain real voltage and current data. This voltage and current data will be displayed in graphical form using the scope block in Simulink matlab.

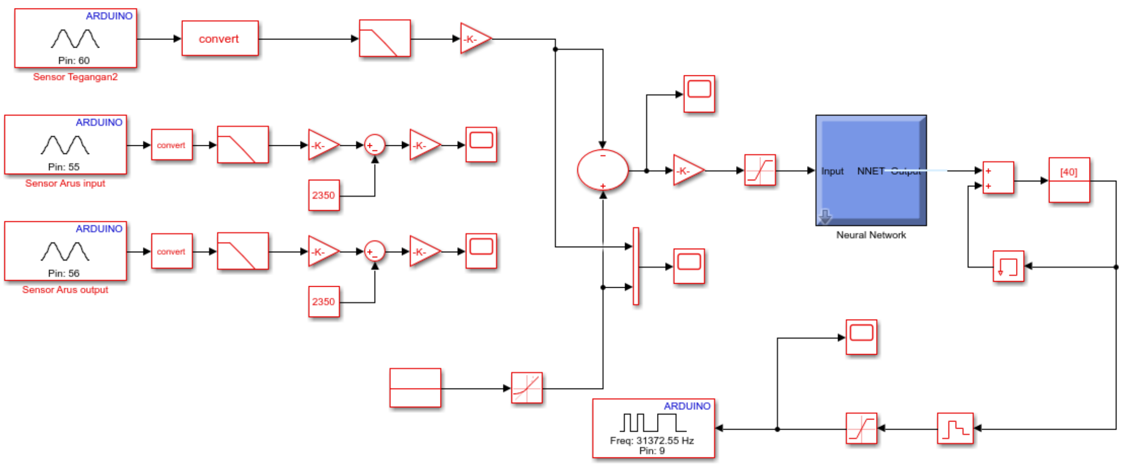


Figure 5. Control block using Bacpropagation neural network in Matlab simulink

Next, validation of the backpropagation neural network based boost converter output voltage control system program created in Simulink Matlab using hardware is carried out. Figure 6 shows the hardware circuit for testing the backpropagation neural network based boost converter output voltage control system using Arduino Mega 2560. In this test, the boost converter is given an input voltage of 12 Volts and a load in the form of a variable resistor load.

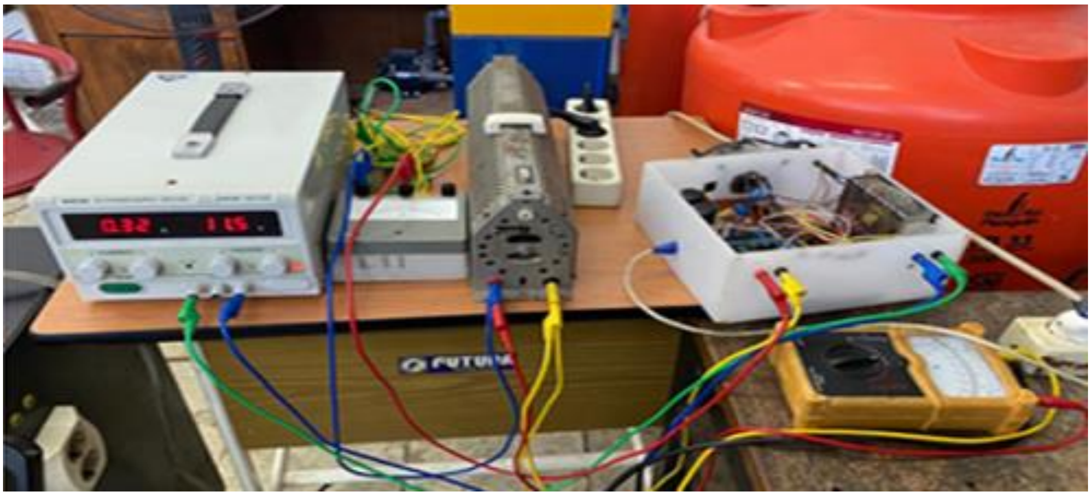
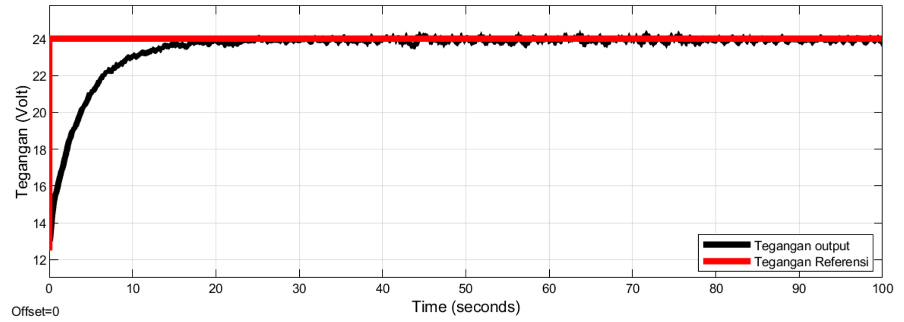
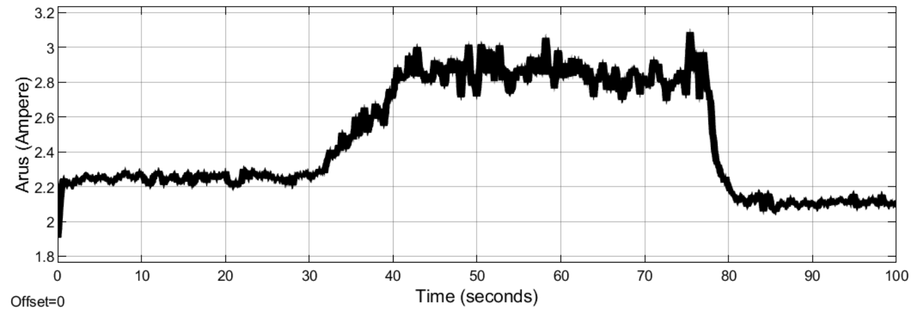


Figure 6. Experimental setup

Hardware testing was conducted in several experiments. The first experiment was to create a constant reference voltage of 24 Volts with a varying load starting from 2.2 Ampere then increased to 2.8 Ampere and then decreased to 2.1 Ampere. In uncontrolled conditions, if the load is increased, the load current will increase and this will cause the output voltage to decrease. With the addition of a control system, it is expected that the voltage will remain in accordance with the reference value even though the load is changed. The results of the first experiment are shown in Figure 7. The voltage graph in Figure 7(a) shows that the output voltage of the boost converter remains constant at 24 Volts according to the reference value, even though the load is varied. This shows that the design of the boost converter output voltage control system based on JST backpropagation has successfully controlled the output voltage according to its reference value even though the load changes, as shown in the graph in Figure 7(b).



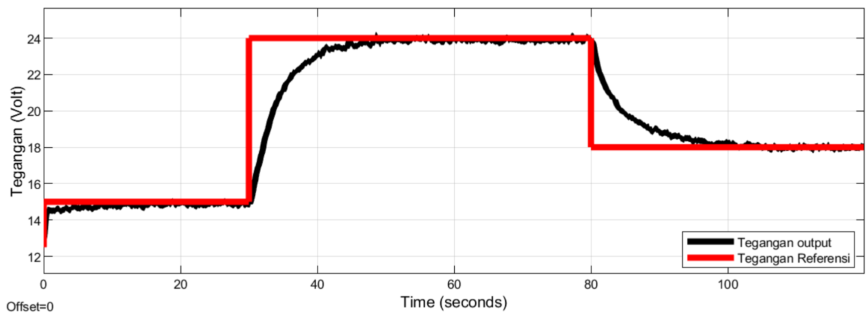
(a)



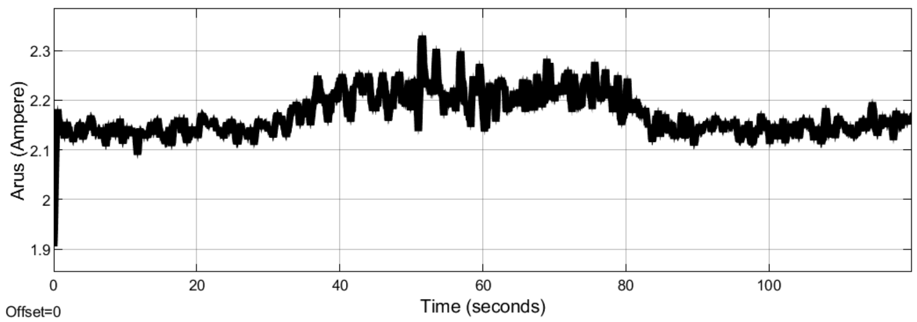
(b)

Figure 7. First experimental results with variable load, (a) Voltage, (b) Current

The second experiment was conducted by making a constant load of 2 Ampere, while the output reference voltage was varied starting from 15 Volts in the initial condition, then increased to 24 Volts at 30 seconds and then decreased to 18 Volts at 80 seconds, as shown in Figure 8. The voltage graph in Figure 8 shows that the converter output voltage can follow the reference voltage at each variation of its value. These results indicate that the boost converter voltage control design with JST backpropagation has successfully controlled the output voltage in various variations of values. These results indicate that the JST-based converter control system can control the output voltage as desired. Figure 8 also shows that even though the load is made constant, if the reference voltage is increased, the converter current will also increase



(a)



(b)

Figure 8. Second experimental results with variable voltage and constant load, (a) Voltage, (b) Current

4. CONCLUSION

The boost converter voltage control system based on backpropagation neural network is designed for boost converter with input voltage of 12 Volt and maximum output voltage of 24 Volt. The control system is implemented using Arduino Mega 2560. The backpropagation neural network model created for this control gives mse 0.000001 during training and 0.01 during testing. The boost converter voltage control system based on backpropagation neural network is tested with various experiments. The results of all experiments show that the backpropagation neural network implemented for boost control has successfully controlled the output voltage of the boost converter according to the reference value in various experiments.

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