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Control of Buck Converter Using Artificial Neural Network

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ABSTRACT

Electrical energy has an important role in various aspects of life. Electrical energy is used in the form of alternating current (AC) voltage and direct current (DC) voltage. To produce a direct voltage (DC) that varies and as needed, a power converter is needed that is equipped with a control system so that the resulting voltage remains stable and does not experience overvoltage or undervoltage. In this research, the converter used is a buck converter. Because the buck converter is a nonlinear system, it requires a control system with a dynamic response rate. So it is necessary to design a buck converter by applying a control system that can maintain the stability of the buck converter output voltage efficiently and adaptively such as the Artificial Neural Network (ANN) method. The control proposed system will be implemented using an Arduino ATMega2560 programmed through Simulink Matlab. To test the effectiveness of this control system, several experiments will be conducted with an input voltage of 24 Volts and outputs worth 9 and 12 Volts. From this test, a voltage error of 0.1 Volt was obtained in the experiment with constant voltage and constant load criteria, proving that the control has successfully controlled the buck converter output voltage according to the reference voltage.

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1. INTRODUCTION

Electrical energy plays an important role in various aspects of life. Dependence on electrical energy has become one of the main foundations of modern life and affects almost all aspects of human life. Electrical energy also became the main force in the second industrial revolution in the late 19th and early 20th centuries [1]. In addition, electrical energy provides significant advantages in mass production and automation. Starting from mass production of vehicles, household appliances, and various other consumer products. The electrical energy that is generally used is in the form of alternating current (AC) voltage and direct current (DC) voltage [2]. To obtain DC voltage, it is usually obtained from the rectification of alternating voltage (AC) by semiconductor components such as diodes, MOSFETs and thyristors [3]. To produce varying direct voltage (DC) and according to needs, a power converter can be used that is adjusted to the input voltage source to be supplied [4]. If the source voltage obtained is direct voltage (DC), then the converter used is a DC Chopper or DC-DC converter [5]. One type of DC-DC converter is a buck converter. Buck converter is a type of DC-DC converter that produces a lower output voltage than the input voltage or is commonly called a step-down converter[6]. Buck Converter according to its dynamic performance is divided into two modes, namely Continuous Conductor Mode (CCM) and Discontionus Conductor Mode (DCM) [7]. The buck converter system is a type of DC chopper that has the function of stabilizing the voltage by lowering the voltage where the output voltage is lower than the input voltage without having to remove relatively large power from the converter[8].

The construction of this buck converter circuit consists of an active switch in the form of a MOSFET/transistor, one passive switch in the form of a diode and there are inductors and capacitors as filter components for its output [9]. The buck converter voltage is usually regulated using the PWM (Pulse Width Modulation) duty cycle as a switching control [10]. PWM is a modulation technique that changes the pulse width with a fixed frequency and amplitude value [11]. The time-on and time-off conditions of the active switch in the form of a MOSFET or transistor will be regulated in such a way as to obtain varying DC voltages. The stability of the resulting voltage must also be considered so that overvoltage and undervoltage do not occur [12]. Therefore, it is necessary to design a buck converter by implementing a control system that can maintain the stability of the buck converter output voltage efficiently and adaptively such as the Artificial Neural Network (ANN) method. Previously, various methods of controlling the output voltage of the buck converter have been reviewed by previous researchers, including the use of PI control methods [13], fuzzy logic [14], PID [15] and others which have their own advantages and disadvantages. However, because the buck converter is a nonlinear system, it requires a control system with a higher level of dynamic response, one of which is the artificial neural network (ANN) method.

In this study, the designed buck converter will implement a control system with the ANN method to regulate the output voltage that varies and is in accordance with needs. The output voltage is regulated by adjusting the buck converter duty cycle value. The ANN method has the ability to adapt instantly to changes in external conditions and internal variations in the converter. This study is expected to contribute to the development of a more adaptive and intelligent power control system.

2. METHOD

The method used to regulate the output voltage of the buck converter uses Simulink Matlab based on Artificial Neural Networks (ANN) with a controller in the form of Arduino ATmega2560. The buck converter will change the input voltage value to be lower as its output [16]. Where the input voltage on the designed buck converter is 24 VDC and will be lowered to produce a maximum output voltage of 12 VDC. The working principle of the buck converter uses a semiconductor switch with 2 switch modes, namely On and Off [17]. The On and Off time of a semiconductor in PWM is determined by the duty cycle, which is the ratio of the switch on time to the period [18]. The design of the buck converter output voltage control based on ANN can be represented in Figure 1, the following system block diagram..

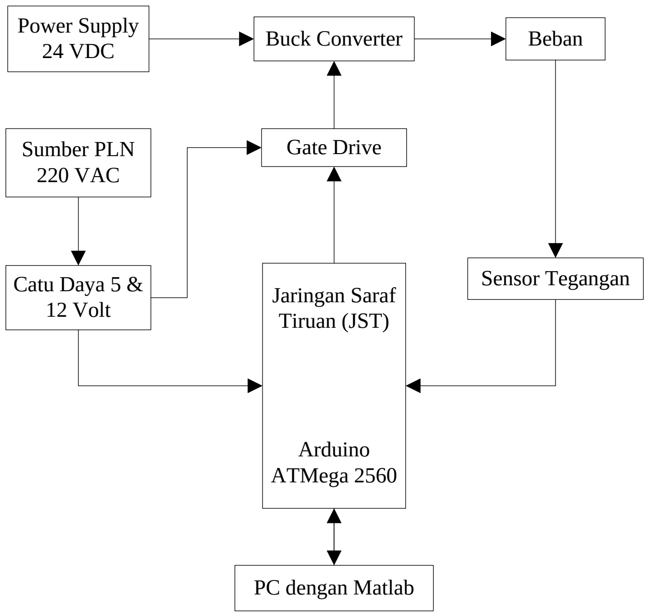

Figure 1. Diagram block of proposed system

Based on Figure 1, it can be seen that this system uses a 220 VAC PLN source which is reduced to 12 VAC through a CT Step Down transformer to enter the power supply. The power supply then converts this voltage to 12 VDC and 5 VDC using a diode bridge and regulator IC (LM7812 and LM7805). The 12 VDC voltage is used for the gate drive, while the 5 VDC is used for the Arduino and sensors. The gate drive circuit will be used as a connector between the buck converter circuit and the Arduino ATMega2560. Furthermore, the Arduino ATMega2560 processes the signal from the voltage sensor and adjusts the proportional (Kp) and integral (Ki) control parameters to regulate the output voltage of the buck converter.

The buck converter that has been given a voltage of 24 VDC will reduce the voltage to a lower level, with the gate drive circuit (IC IR2184S) to control the MOSFET switching based on the PWM signal from the Arduino. The voltage sensor provides output data as system feedback. A PC and Matlab software are used for programming the Arduino with a ANN-based control system created using the toolbox in Simulink Matlab. The working principle of the buck converter output voltage control based on Artificial Neural Networks (ANN) can be seen in Figure 2 below.

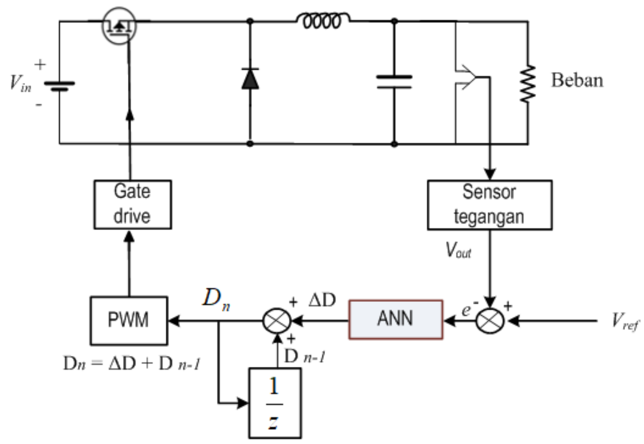

Figure 2. Scheme of buck converter control based on ANN

Artificial neural networks (ANN) are information processing systems that have characteristics like biological neural networks [19]. In another article it is stated that Artificial neural networks (ANN) are networks consisting of a group of small processing units modeled based on human neural networks [20]. Modern neural networks are non-linear statistical data modeling tools. This network is usually used to model complex relationships between input and output or to find patterns in data. In human neural networks there are dendrites and axons as places for input and output signals while in ANNs they are analogous to ANN input and output [21]. In human neural networks there are synapses while ANNs have weights. Human neural networks have potential and impulse signals while ANNs have activation functions and weights. Based on Figure 3, the following elements are found in artificial neural networks: input unit (x), hidden unit (s), output unit (o), weight (w), bias (b), and activation function [22].

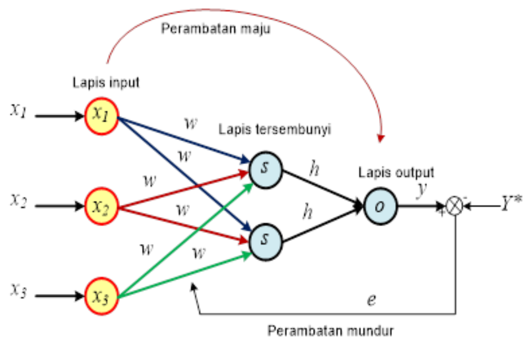

Figure 3. Structure of Backpropagation Neural Network

ANN is formed as a generalization of the mathematical model of biological neural networks with the assumptions that information processing occurs in many simple elements (neurons), signals are sent between neurons through connectors, connectors between neurons have weights that will strengthen or weaken the signal, and to determine the output of each neuron an activation function will be used [23]. In previous studies, ANN control has been applied to several systems such as induction motor speed control [24], perceptron algorithm buck converter [25], and others. From several studies, ANN control has proven its effectiveness by producing fast responses and high levels of accuracy.

The working principle of controlling the output voltage of the buck converter based on ANN is done by adjusting the modulation of the switch pulses used in the buck converter. The ANN applied in this study will regulate the PWM pulse value in the buck converter circuit. The input to the ANN is the voltage error, where this voltage error is the difference between the voltage produced and the programmed reference voltage. The resulting voltage is obtained from the voltage sensor installed on the output side of the buck converter. Meanwhile, the output of the ANN is in the form of a duty cycle change value, where the duty cycle for the PWM pulse will increase or decrease according to the voltage error. This duty cycle produces a PWM pulse on the Arduino, which is then increased in voltage through the gate drive circuit to match the voltage required to activate the MOSFET. Thus, the buck converter can produce a voltage that matches the reference voltage value. The flow chart diagram in this study can be seen in Figure 4.

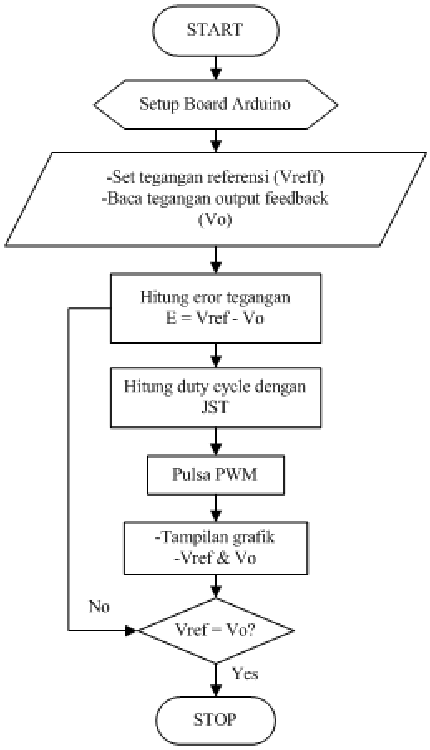

Figure 4. Flowchart of Buck converter control based on ANN

3. RESULTS AND DISCUSSION

In this research, the ANN-based buck converter output voltage control that will be designed will be tested with several test models. This test aims to analyze the working response of the ANN control method to the buck converter output. If the output voltage produced by the system has reached the regulated reference voltage, then the designed ANN control system can be said to be successful.

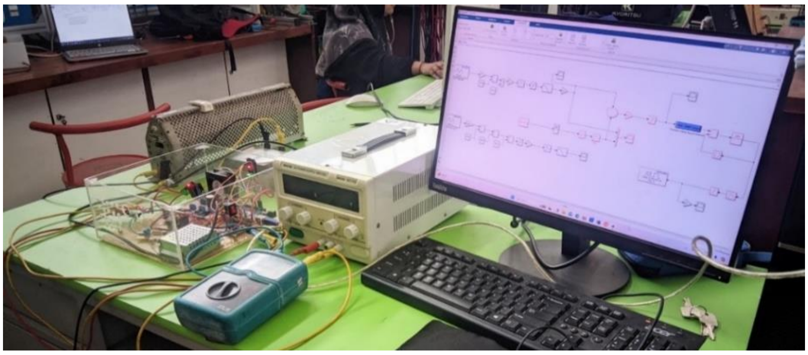

Figure 5. Hardware setup for experimental

Figure 5 is a circuit that will be used for testing the buck converter using the ANN control system. As seen in the figure, this test will use a buck converter connected to a PC integrated with Matlab software, voltmeter, ammeter, DC power supply, and variable resistor. Previously, the buck converter will be tested without using a control system, then the buck converter will be tested using the ANN control system that has been designed. Then in testing the buck converter using the ANN control system, several more test models will be carried out, namely testing constant reference voltage with varying loads and testing varying reference voltage with constant loads.

When testing, data is needed to be trained on the ANN control system using the neural network toolbox in Matlab. The data to be trained has different values but is linear and the format is represented in the form of the number of rows. The input data in this study represents the voltage error value which amounts to 25 data with a range of 24 to -24. While the output data is a presentation of the change in duty cycle which amounts to 25 data with a range of 10 to -10. The pattern of input and output data in this study is that the greater the voltage error value, the greater the change in duty cycle value. Then the input data value will be greater than the output data value, with a constant difference between the data. In this study, the difference in input data is 2 while the difference in output data is 0.75. The data will be entered into the ANN model with the number of hidden layers used amounting to 10 and the training data used is 90%. The results of training data on the ANN model can be seen in Figure 6 below. Figure 6 is a graph of the fit plot and regression plot. The graph consists of two main parts, namely the upper fit plot and the lower error plot. The fit plot graph shows that the model output follows the target quite well during training, validation, and testing, as seen from how the points (output) approach the blue line (target). While the error plot graph shows the error for each input. Most errors are close to zero, indicating that the model has a small error for most inputs. However, there are some larger error values, especially for some points on the left side of the graph.

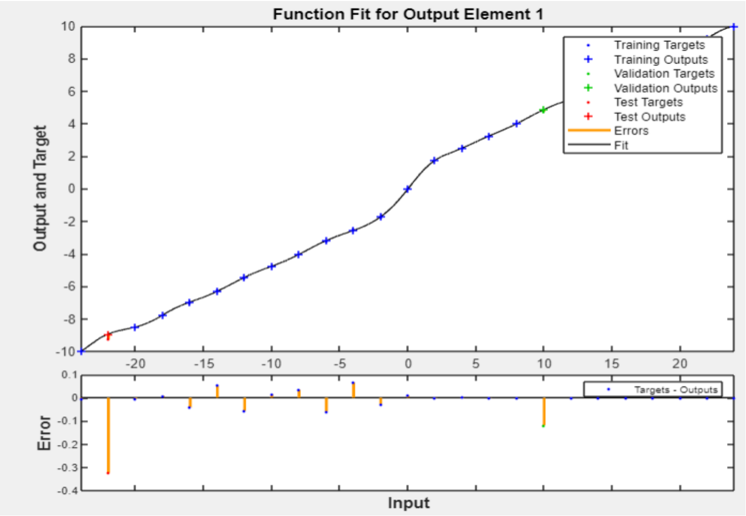

Figure 6. Training results of ANN

After the ANN model is validated, the next step is to integrate the ANN model into the buck converter control system program that has been developed using the Simulink Matlab software. The program that has been designed in Simulink is then uploaded to the Arduino Atmega2560 board, which functions as the control center in this study. The following is a ANN-based buck converter output voltage control program that has been created in Simulink Matlab. Figure 7 shows the ANN-based buck converter output voltage control system program that has been designed in Simulink Matlab.

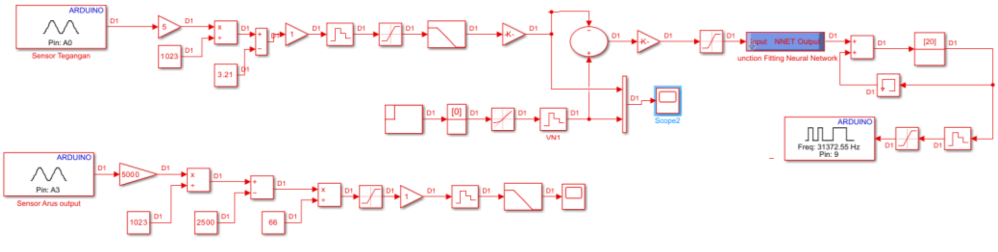

Figure 7. Program in Simulink Matlab

The first test conducted was the uncontrolled buck converter test. The results of the uncontrolled buck converter test can be seen in Figure 8. In Figure 8, it can be seen that when the load is increased, the current will increase and the voltage value will decrease. This is because when the load on the buck converter increases, the current flowing through the circuit also increases. In this scenario, if the input voltage remains constant, the output voltage tends to decrease because the higher load draws more current, causing a voltage drop across the inductive and resistive components in the circuit. Conversely, when the load is reduced, the current decreases and the voltage increases. This proves that the buck converter circuit is functioning properly and in accordance with its working principle, where the higher the current, the voltage value will decrease, and the lower the current, the voltage value will increase. Further testing is carried out using ANN control.

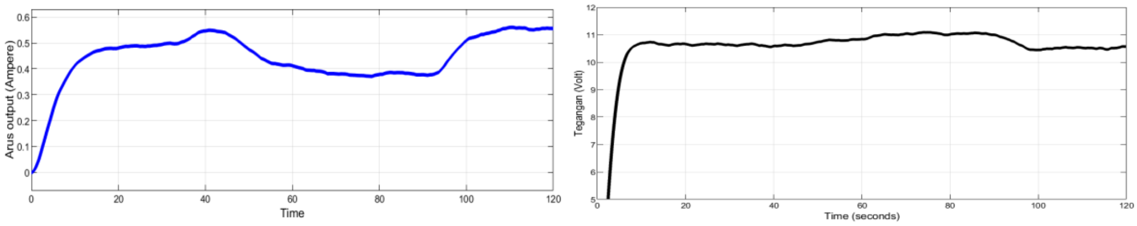

Figure 8. Uncontrolled buck converter test results

Next, testing is carried out with constant voltage treatment and varying loads. Figure 9 shows the test results with a constant reference voltage criterion of 12 Volts, while the current starts from 0.3 A, then is increased to 0.4 A, decreased to 0.3 A and increased again to 0.5 A. At 15 seconds the output voltage has reached the reference voltage value with a duty cycle value reaching 58%.

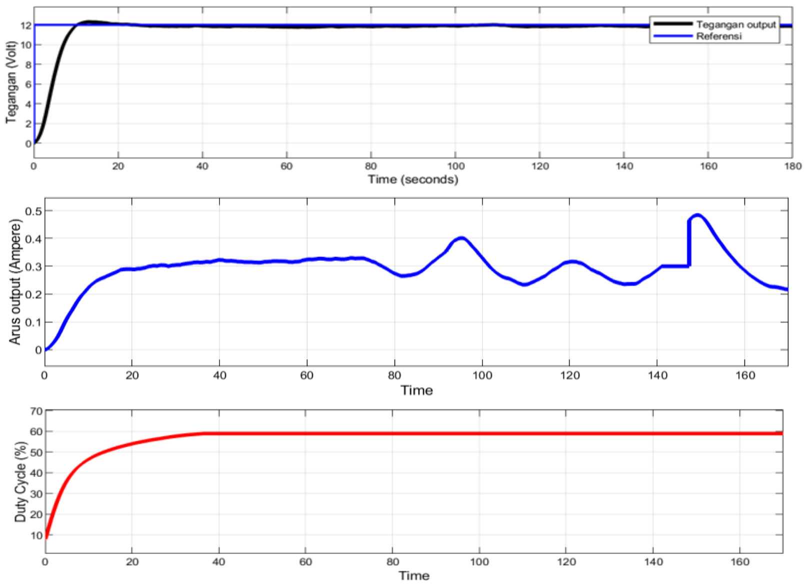

Figure 9. Test results of constant reference voltage and varying load.

Next, constant load testing is carried out with varying reference voltages. Figure 10 shows the results of testing the buck converter output voltage when the reference voltage is varied and the load is constant. The reference voltage is varied starting from 9 Volts then increased at 40 seconds to 12 Volts, and decreased to 9 Volts at 90 seconds and increased again to 12 Volts at 140 seconds. Figure (a) above shows that the buck converter output voltage can follow the varying reference voltage even though there is still ripple. In this test, the current value reaches 0.3 A and the duty cycle value changes according to the voltage value, as seen in figure (c) that when the reference voltage is 9 V the duty cycle value is at 27% while when the reference voltage value is 12 V the duty cycle value is 50%. Several tests that have been carried out have proven that the ANN control has good performance and has succeeded in controlling the buck converter output according to the desired reference voltage.

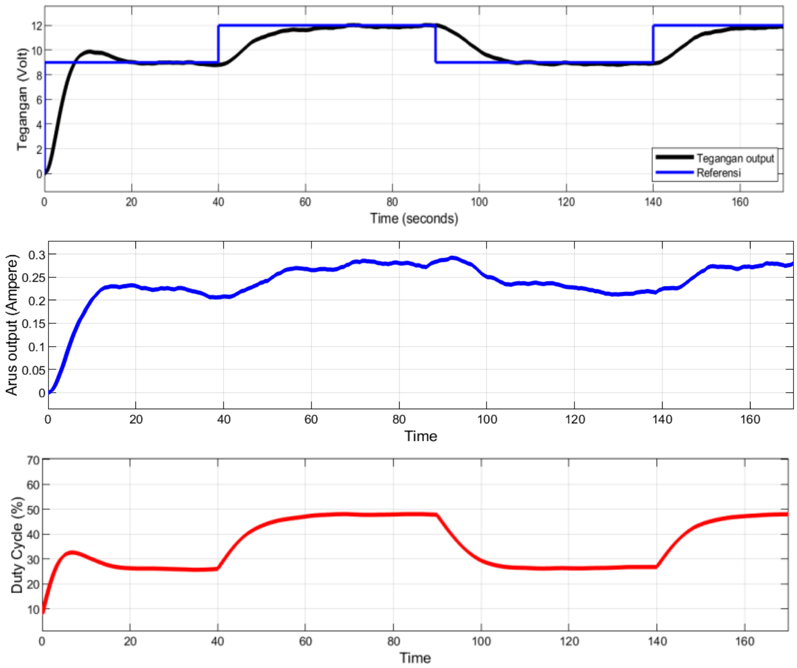

Figure 10. Test results with varying reference voltage criteria and constant load.

4. CONCLUSION

In this study, a control system based on Artificial Neural Network (ANN) is proposed for controlling the output voltage system of the buck converter which will be validated through several tests such as testing with constant load and constant reference voltage, testing with constant load but varying reference voltage, and testing with varied load but constant reference voltage. From this test, a voltage error of 0.1 Volt was obtained in the test with constant voltage and constant load criteria, proving that the ANN control has succeeded in controlling the output voltage of the buck converter according to the reference voltage. Based on these tests, it can be concluded that this study has succeeded in designing and implementing a buck converter output voltage control system using the Artificial Neural Network (ANN) method, with a platform in the form of Arduino ATMega2560 programmed via Simulink Matlab.

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