Journal of Industrial Automation and Electrical Engineering
Vol. 01, No. 02, December 2024, pp. 78~85
ISSN: 3089-1159

Control of buck boost converter with Mamdani Fuzzy inference system using Microcontroller Arduino

Rahmat Alwafi[1], Muldi Yuhendri[1], Citra Dewi[1], Ayu Hendra[1]
[1]Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Padang, Padang, Indonesia

Article Info

Article history:

Received Ocotber 14, 2024
Revised Ocotber 28, 2024
Accepted November 20, 2024

Keywords:

Buck boost converter
Fuzzy Mamdani
Voltage control
Arduino

ABSTRACT

Various electrical equipment utilizes direct voltage (DC) as a power source. Examples of this equipment include various electronic devices as well as DC motors and others. The direct voltage used usually has various ratings, ranging from 1.5 volts to 12 volts, and other numbers. To ensure that the direct voltage is in accordance with the tool's needs, it is necessary to control this voltage. This control is generally carried out using a power converter. In this research, buck-boost converter output voltage control will be implemented using the Fuzzy Mamdani method with an Arduino Atmega 2560. The control system developed will be tested through experiments in the input voltage range between 12 to 24 Volts, with a maximum output of 18 Volts. The experimental results show that the Fuzzy Mamdani based buck-boost converter output voltage control system successfully regulates the output voltage according to the desired reference value.

Corresponding Author:

Rahmat Alwafi
Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Padang
Kampus UNP Pusat, Jl. Prof. Hamka, Air Tawar, Padang 25131, Indonesia
Email: rahmatalwafi17@gmail.com

1. INTRODUCTION

One energy source that people utilize frequently is electricity. Electrical energy is the primary energy source for a variety of electrical and electronic devices. Electrical criteria set by the load must be met by power plants that generate electricity. In electrical energy, voltage and frequency are the standards that need to be taken into account [1]-[5]. Alternating voltage (AC) and direct voltage (DC) are the two categories of voltage used for voltage standards [6]. Direct voltage (DC) is used as the power source for a variety of electrical devices, including electronic devices and DC motors. Batteries, solar panels, fuel cells, thermogenerators, and other electrical devices can all produce DC voltage. Repaired AC voltage is another source of DC voltage [7]-[10.

In this study, a DC-DC converter of the buck-boost converter type will be used. Buck-boost converter is a DC-DC converter that functions to increase and decrease DC voltage [11]-[13], this converter is used to obtain a DC output voltage that is greater and smaller than the source voltage. Buck-boost converter is composed of MOSFET (active switch) and diode (passive switch) [14]. To obtain an output voltage that is in accordance with the needs of the equipment, the buck boost converter needs to be controlled. Various methods of controlling the output voltage of the buck boost converter have been discussed by previous researchers, such as the use of the PI controller method [15], PID controller [16], Fuzzy logic [17], and others. Each control method has its own advantages and disadvantages. The PI controller is easy to implement but less reliable in dealing with the dynamics of load changes [9]. In this study, the control of the output voltage of the buck-boost converter was controlled using an artificial intelligence method, namely Fuzzy Logic Type Mamdani. Fuzzy Mamdani is a fuzzy logic system used for rule-based decision making [18]-[25]. Fuzzy logic is a way to describe input into an output [26]. By using the hybrid learning procedure, Fuzzy Mamdani can build an input-output mapping based on human knowledge (in the form of fuzzy if-then rules) with the right membership function. The selection of Fuzzy Mamdani control for controlling the output voltage of the buck-boost converter is expected to produce a more valid output voltage compared to other methods.

Buck-boost converter is designed with input voltage of 12-24 volts and maximum output voltage of 18 volts. Control of output voltage of buck-boost converter in this research is implemented using Arduino Atmega 2560. For programming Fuzzy Mamdani control will be done using simulink matlab software. Testing of output voltage control system of buck-boost converter will be done in two ways, namely testing of varying load with constant reference voltage and testing of constant load with varying reference voltage. The use of Fuzzy Mamdani control in this buck-boost converter is expected to produce better output voltage response compared to other control methods.

2. METHOD

This research was conducted in the form of an experiment, using Fuzzy Mamdani control to control the output voltage of the buck-boost converter. In this study, the buck-boost converter with an input voltage of 12 to 24 volts will be reduced in voltage to produce a maximum output voltage of 18 volts. This buck-boost converter works with the process of switching on and off on the MOSFET based on the duty cycle value [27]. The on and off time of a semiconductor in PWM is determined by the duty cycle, which is the comparison of the switch on time with the period [28]-[33]. The design of the buck-boost converter output voltage control system based on Fuzzy Mamdani is implemented with Arduino Atmega 2560 which functions as the main working processor in the circuit. In this study, there is a gate drive circuit as a connector between the buck-boost converter circuit and the Arduino Atmega 2560. This buck-boost converter circuit is also equipped with a voltage sensor on the buck-boost converter output side to obtain buck-boost converter output voltage data which will later function as feedback for Fuzzy Mamdani control. The design of the buck-boost converter output voltage control based on Fuzzy Mamdani can be presented with a block diagram shown in Figure 1.

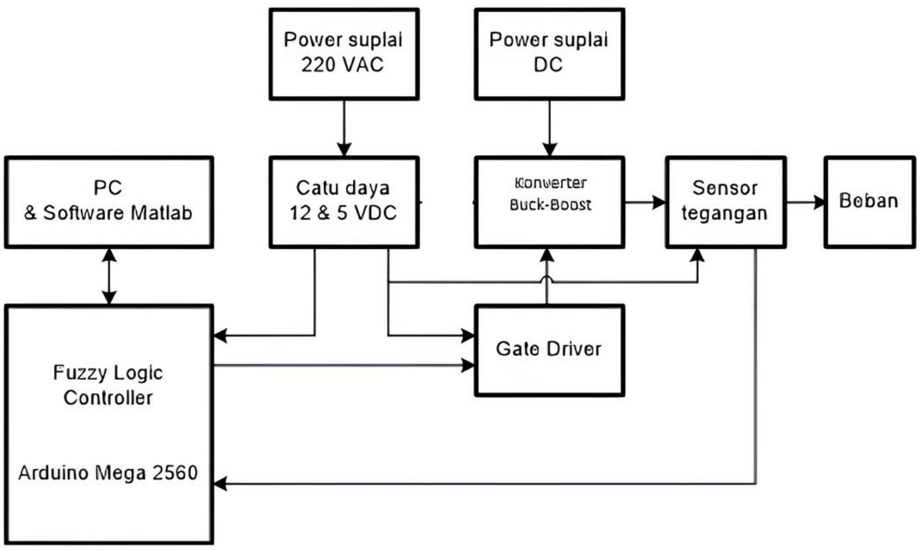

Figure 1. Block diagram of the buck boost converter control system with Fuzzy Mamdani inference system

Figure 1 shows a block diagram of the output voltage control system of the Fuzzy Mamdani-based buck-boost converter. The working principle of the Fuzzy Mamdani-based buck-boost converter output voltage control is done by adjusting the PWM pulse of the semiconductor switch in the buck-boost converter, as shown in Figure 2 below. The Fuzzy Mamdani input is a voltage error, this voltage error is the difference between the reference voltage and the output voltage feedback. The output voltage feedback is obtained from a voltage sensor installed on the output side of the buck-boost converter. The Fuzzy Mamdani output is in the form of a duty cycle change value, the duty cycle value for the PWM pulse will increase and decrease according to the voltage error. The duty cycle will produce a PWM pulse on the Arduino, the resulting PWM pulse will be increased in voltage through the gate drive circuit according to the voltage required to activate the MOSFET. That way the buck-boost converter will produce a voltage value that matches the reference voltage value.

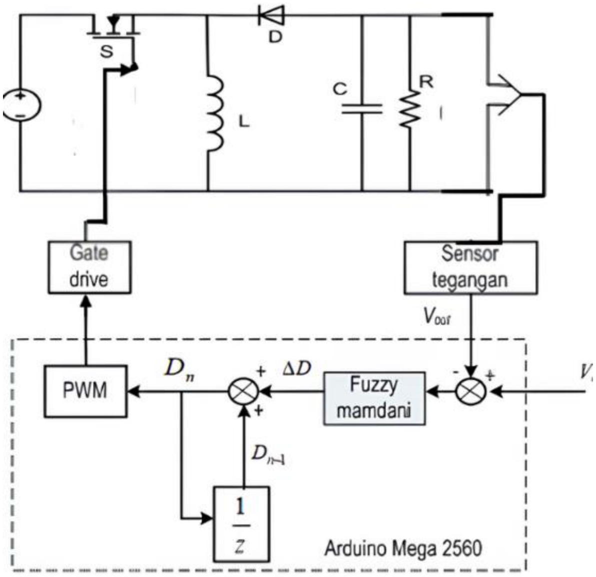

Figure 2. Schematic of the output voltage control system of the buck-boost converter with Fuzzy Mamdani

The flowchart of the buck-boost converter output voltage control system based on Fuzzy Mamdani can be seen in Figure 3.

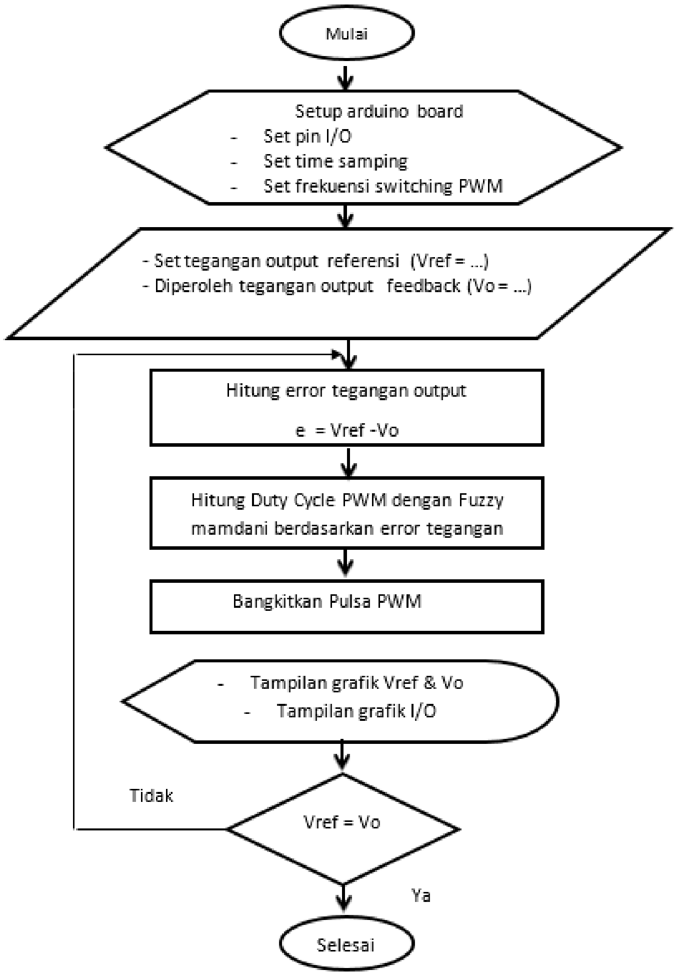

Figure 3. Flowchart of the buck-boost converter output voltage control system based on Fuzzy Mamdani

Figure 3 is a flowchart of the buck-boost converter output voltage control system based on Fuzzy Mamdani. This study uses Fuzzy Mandani control to regulate the PWM pulse in the buck-boost converter circuit. Fuzzy Mamdani is one of the methods in fuzzy logic used to build a fuzzy inference system, especially in the context of decision making or automatic control. Fuzzy Mamdani consists of Fuzzification, inference system, rule base and defuzzification. In Fuzzification, the process of converting numeric input data into linguistic language is carried out using Fuzzy membership functions. One of the characteristics of Fuzzy Mamdani is that its input and output are presented with Fuzzy membership functions. In this paper. Fuzzy input is a voltage error, while the output is a change in Duty cycle, as shown in Figure 4.

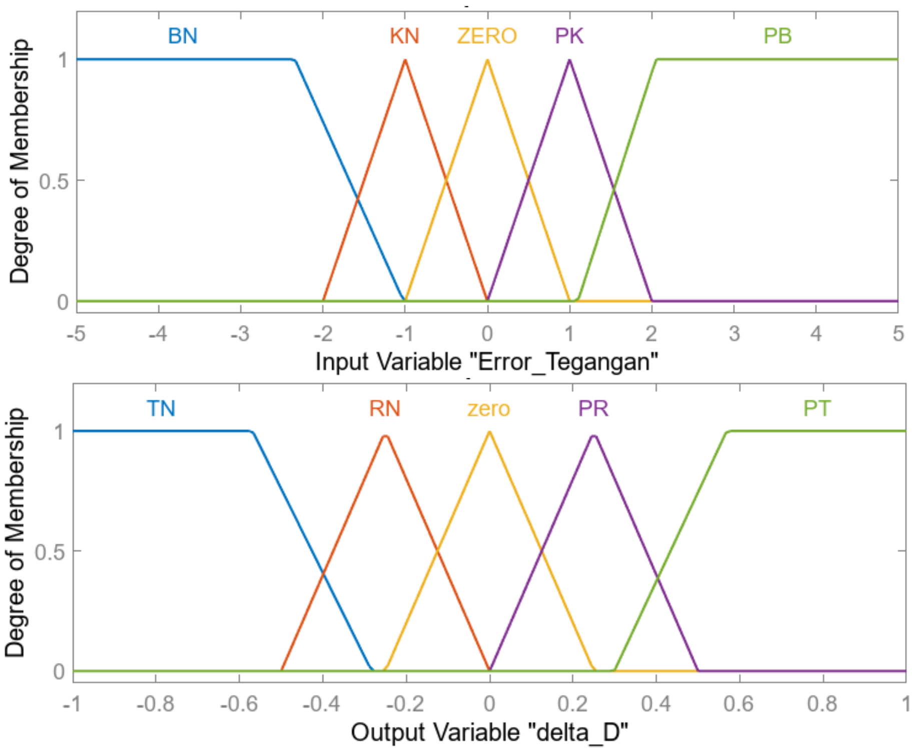

Figure 4. Input and output membership functions of the proposed Mamdani Fuzzy

The relation between Fuzzy input and output is presented with a rule base. Based on the number of input and output membership functions, there are five rules in this paper, as shown in Figure 5. Figure 5 is a rule base. In this section, fuzzy logic rules in the form of IF-THEN are applied. Each rule describes the relationship between input and output in a more abstract form. These rules relate input variables to the desired output.

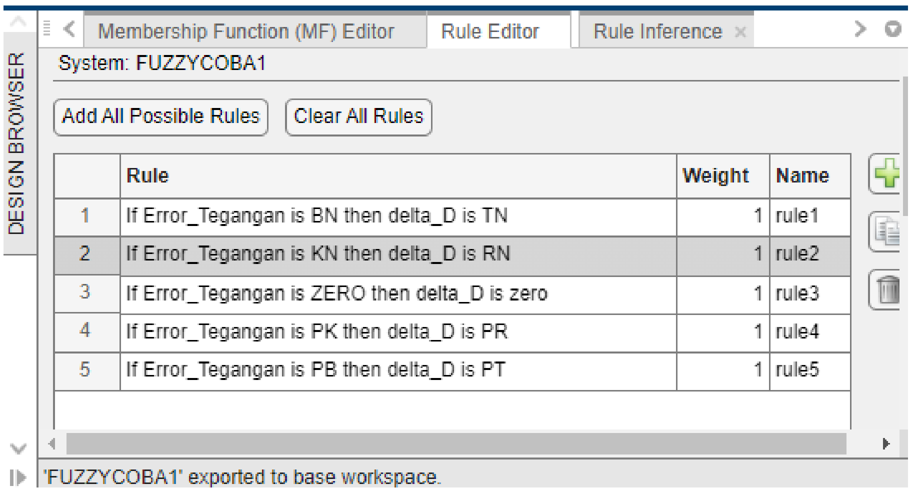

Figure 5. Fuzzy Mamdani rule base

3. RESULTS AND DISCUSSION (10 PT)

After the design of the output voltage control system is complete, the next step is testing. Testing is done using a buck-boost converter circuit, which has been connected to several components such as a PC (Simulink Matlab), volt meter, ampere meter, DC power supply, and variable resistor. The test circuit can be seen in Figure 6.

Figure 6. Installation of buck-boost converter testing hardware

Figure 6 is a series of tools for testing the output voltage on the buck-boost converter. The test was carried out using the Fuzzy Mamdani method that has been programmed in the Matlab Simulink software. In this test, the input voltage on the buck-boost converter is 12 volts. The test was carried out with several experiments, namely testing a constant reference voltage with a varied load and testing a constant load with a varied reference voltage. In this test, the Fuzzy Mamdani control system is said to be valid if the output voltage produced is in accordance with the reference voltage. Figure 7 is a program for the Fuzzy Mamdani-based buck-boost converter output voltage control system that has been created in Matlab Simulink.

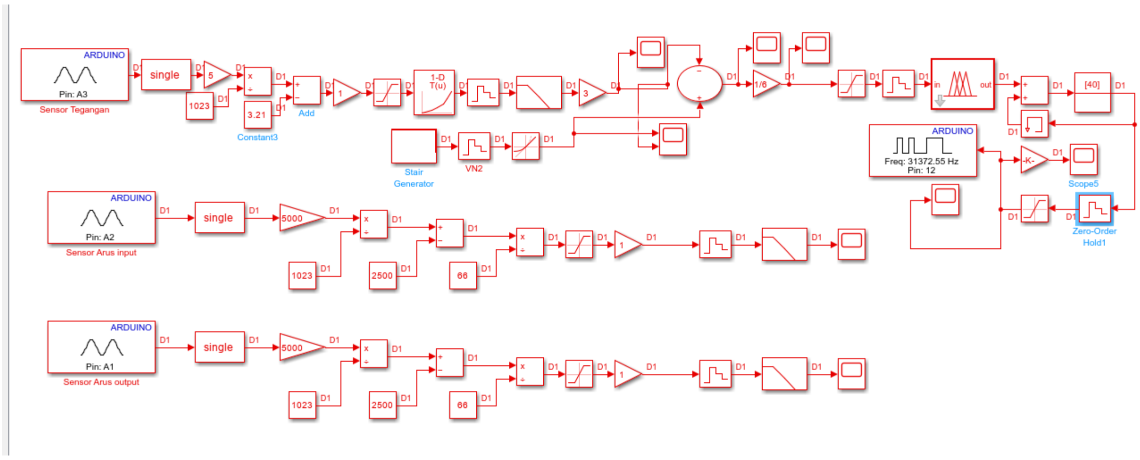

Figure 7. Fuzzy Mamdani based buck-boost converter voltage control system program

The first test was conducted with a constant reference voltage and varying load. Figure 8 shows the results of the buck-boost converter test when the voltage is constant and the load is varied. The figure above shows that the Fuzzy Mamdani-based buck-boost converter output voltage control has succeeded in controlling the buck-boost converter output voltage, this is evidenced by the output voltage graph which remains constant at 9 V even though the load value is varied from 0.2 A, increased to 1.4A and decreased again to 0.3 A. Furthermore, the Fuzzy Mamdani-based buck-boost converter voltage control system will be tested with a varied reference voltage and a constant load.

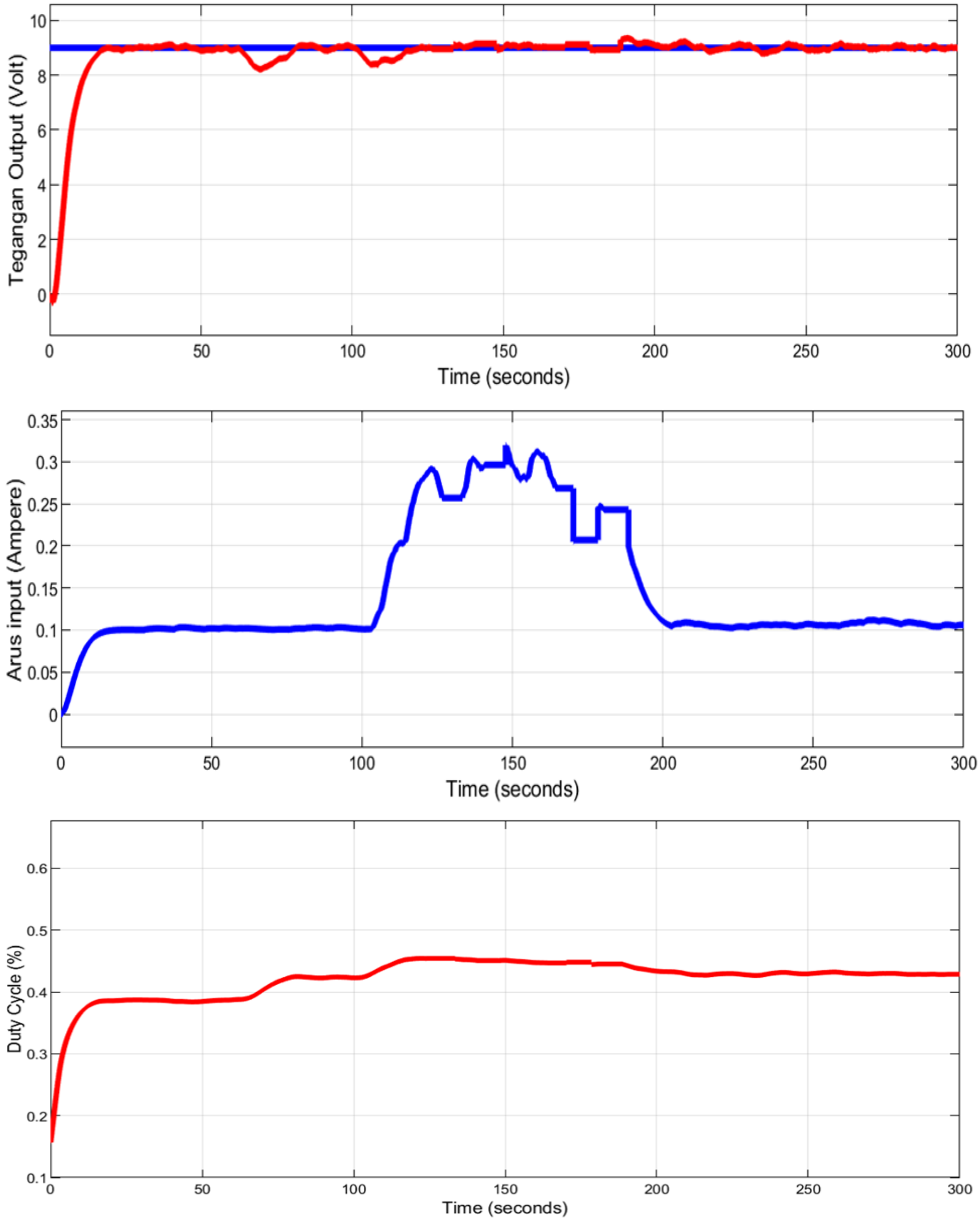

Figure 8. Varied load testing

The second test was conducted with a varying reference voltage and constant load experiment. Figure 9 shows the results of the buck-boost converter output voltage test when the reference voltage is varied and the load is constant. The reference voltage is varied starting from 6 V then increased at 120 seconds to 15 V and decreased at 240 seconds to 9 V. The figure above shows that the buck-boost converter output voltage can follow the varying reference voltage. The duty cycle value has also been successfully adjusted based on the reference voltage value. The results of this test indicate that the buck-boost converter output voltage control system based on Fuzzy Mamdani has successfully controlled the buck-boost converter output voltage according to its reference voltage value.

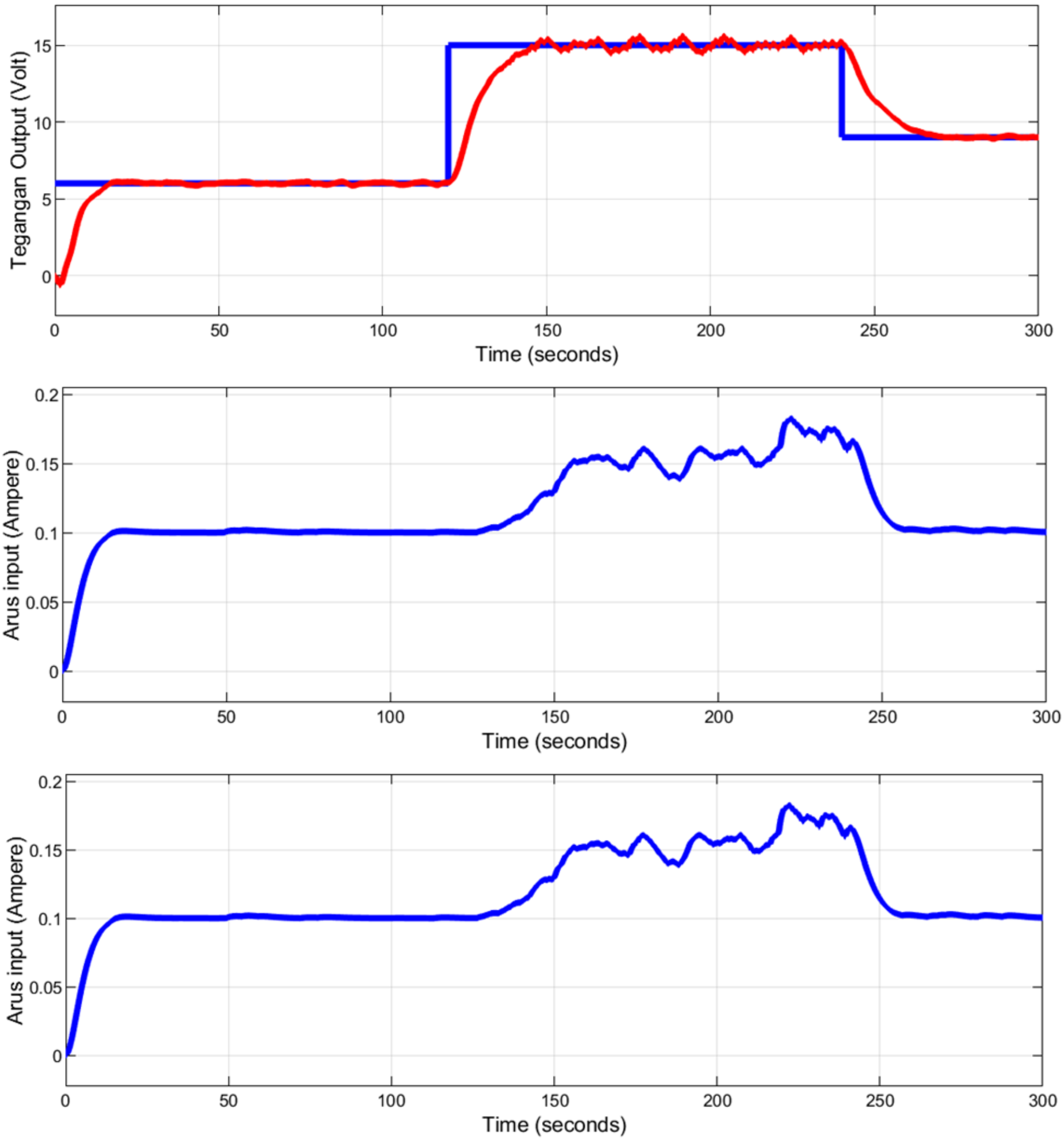

Figure 9. Results of varying voltage tests

4. CONCLUSION

Arduino Atmega 2560 is used to construct a fuzzy Mamdani-based buck-boost converter output voltage control system. The highest output voltage of this control system's 24 volt buck-boost converter is 18 volts. Numerous tests have been conducted to test the control system, including testing constant loads with variable reference voltages and varying loads with constant reference voltages. The test results demonstrate that the buck-boost converter output voltage management system based on fuzzy mamdani has effectively managed the converter voltage under both load and voltage variations.

REFERENCES

[1] E. D. Aranda, S. P. Litrán and M. B. F. Prieto, "Combination of interleaved single-input multiple-output DC-DC converters," in *CSEE Journal of Power and Energy Systems*, vol. 8, no. 1, pp. 132-142, Jan. 2022, doi: 10.17775/CSEEJPES.2020.00300.

[2] M. N. Gitau, G. P. Adam, L. Masike and M. W. K. Mbukani, "Unified Approach for Synthesis and Analysis of Non-Isolated DC-DC Converters," *IEEE Access*, vol. 9, pp. 120088-120109, 2021, doi: 10.1109/ACCESS.2021.3108191.

[3] M. Yuhendri and R. Setiawan, “Implementasi DC-DC Boost Converter Menggunakan Arduino Berbasis Simulink Matlab,” *JTEIN J. Tek. Elektro Indones*., vol. 1, no. 2, pp. 144–149, 2020, doi: 10.24036/jtein.v1i2.64.

[4] C. Rani, CH Hussain Basha and Sarah Odofin, "A Review on Non-isolated Inductor Coupled DC-DC Converter for Photovoltaic

Grid-Connected Applications", *International Journal of Renewable Energy Research*, vol. 7, no. 4, pp. 1570-1585, December 2017.
[5] M. Forouzesh, Y. P. Siwakoti, S. A. Gorji, F. Blaabjerg and B. Lehman, "Step-up DC–DC converters: A comprehensive review of voltage-boosting techniques topologies and applications", *IEEE Trans. Power Electron.*, vol. 32, no. 12, pp. 9143-9178, Dec. 2017.
[6] A. Anggawan and M. Yuhendri, "Kendali Tegangan Output Buck Converter Menggunakan Arduino Berbasis Simulink Matlab," *JTEIN J. Tek. Elektro Indones*., vol. 2, no. 1, pp. 34–39, 2021, doi: 10.24036/jtein.v2i1.110.
[7] I. Alhurayyis, A. Elkhateb and J. Morrow, "Isolated and Nonisolated DC-to-DC Converters for Medium-Voltage DC Networks: A Review," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 9, no. 6, pp. 7486-7500, Dec. 2021, doi: 10.1109/JESTPE.2020.3028057.
[8] R. Suryadevara and L. Parsa, "Full-bridge ZCS-converter-based high-gain modular DC-DC converter for PV integration with medium-voltage DC grids", *IEEE Trans. Energy Convers.*, vol. 34, no. 1, pp. 302-312, Mar. 2019.
[9] P. Prabhakaran and V. Agarwal, "Novel Boost-SEPIC Type Interleaved DC–DC Converter for Mitigation of Voltage Imbalance in a Low-Voltage Bipolar DC Microgrid," *IEEE Transactions on Industrial Electronics*, vol. 67, no. 8, pp. 6494-6504, Aug. 2020, doi: 10.1109/TIE.2019.2939991.
[10] M. Yuhendri, I. Z. Candra, and C. Dewi, "Kendali Boost converter Berbasis Fuzzy sugeno," *JTEIN J. Tek. Elektro Indones.*, vol. 4, no. 1, pp. 50–59, 2023
[11] S. N. Soheli, G. Sarowar, M. A. Hoque and M. S. Hasan, "Design and Analysis of a DC -DC Buck Boost Converter to Achieve High Efficiency and Low Voltage Gain by using Buck Boost Topology into Buck Topology," *2018 International Conference on Advancement in Electrical and Electronic Engineering (ICAEEE)*, Gazipur, Bangladesh, 2018, pp. 1-4, doi: 10.1109/ICAEEE.2018.8643001.
[12] S. Palanidoss and T. V. S. Vishnu, "Experimental analysis of conventional buck and boost converter with integrated dual output converter," *2017 International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques (ICEECCOT)*, Mysuru, India, 2017, pp. 323-329, doi: 10.1109/ICEECCOT.2017.8284521.
[13] P. Azer and A. Emadi, "Generalized State Space Average Model for Multi-Phase Interleaved Buck, Boost and Buck-Boost DC-DC Converters: Transient, Steady-State and Switching Dynamics," in *IEEE Access*, vol. 8, pp. 77735-77745, 2020, doi: 10.1109/ACCESS.2020.2987277.
[14] A. Alfaris and M. Yuhendri, "Sistem Kendali dan Monitoring Boost Converter Berbasis GUI (graphical user interface) Matlab Menggunakan Arduino," *JTEIN J. Tek. Elektro Indones.*, vol. 1, no. 2, pp. 266–272, 2020, doi: 10.24036/jtein.v1i2.83.
[15] N. Rana, S. Banerjee, S. K. Giri, A. Trivedi and S. S. Williamson, "Modeling, Analysis and Implementation of an Improved Interleaved Buck-Boost Converter," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 68, no. 7, pp. 2588-2592, July 2021, doi: 10.1109/TCSII.2021.3056478.
[16] M. Veerachary and M. R. Khuntia, "Design and Analysis of Two-Switch-Based Enhanced Gain Buck–Boost Converters," *IEEE Transactions on Industrial Electronics*, vol. 69, no. 4, pp. 3577-3587, April 2022, doi: 10.1109/TIE.2021.3071696.
[17] M. R. Banaei, H. Ardi and A. Farakhor, "Analysis and implementation of a new single switch buck-boost converter", *IET Power Electron.*, vol. 7, no. 2, pp. 1906-1914, Feb. 2014.
[18] M. Syafitri and M. Yuhendri, "Control of DC-DC Buck Converter Based on Adaptive Neuro Fuzzy Inference System (ANFIS)," *JTEIN J. Tek. Elektro Indones.*, vol. 5, no. 2, pp. 476–486, 2024.
[19] N. Rana, S. Sonar and S. Banerjee, "Performance Investigation of Closed-Loop Dual Phase Interleaved Buck-Boost Converter With Dragonfly Optimized Type-III Controller," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 69, no. 3, pp. 1472-1476, March 2022, doi: 10.1109/TCSII.2021.3131567.
[20] M. Veerachary and V. Khubchandani, "Analysis, Design, and Control of Switching Capacitor Based Buck–Boost Converter," *IEEE Transactions on Industry Applications*, vol. 55, no. 3, pp. 2845-2857, May-June 2019, doi: 10.1109/TIA.2018.2889848.
[21] P. Ulandari and M. Yuhendri, "Kendali Tegangan Output Buck Converter Berbasis Fuzzy Mamdani," *JTEIN J. Tek. Elektro Indones.*, vol. 5, no. 2, pp. 411–420, 2024.
[22] K. Akhilesh and N. Lakshminarasamma, "Dead-Zone Free Control Scheme for H-Bridge Buck–Boost Converter," *IEEE Transactions on Industry Applications*, vol. 56, no. 6, pp. 6619-6629, Nov.-Dec. 2020, doi: 10.1109/TIA.2020.3018423.
[23] V. Khubchandani and M. Veerachary, "Extended Switching-Capacitor-Based Buck–Boost Converter," *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*, vol. 4, no. 2, pp. 471-481, April 2023, doi: 10.1109/JESTIE.2022.3224882.
[24] H. F. Ahmed, O. Alzaabi, M. S. El Moursi and K. Al Hosani, "Highly Efficient Dual-Buck Structured Buck–Boost AC–AC Converter With Versatile Identical Inverting/Noninverting Operations," *IEEE Transactions on Industrial Informatics*, vol. 19, no. 12, pp. 11403-11417, Dec. 2023, doi: 10.1109/TII.2023.3246531.
[25] S. Miao and J. Gao, "A Family of Inverting Buck-Boost Converters With Extended Conversion Ratios," *IEEE Access*, vol. 7, pp. 130197-130205, 2019, doi: 10.1109/ACCESS.2019.2940235
[26] Y. Zhou, J. Li, X. Liu, Y. Zheng and K. N. Leung, "Bidirectional Buck–Boost Converter With Reduced Power Loss and No Right-Half-Plane Zero," *IEEE Transactions on Power Electronics*, vol. 38, no. 2, pp. 2127-2142, Feb. 2023, doi: 10.1109/TPEL.2022.3210296.
[27] Y. Zheng, J. Guo and K. N. Leung, "A Single-Inductor Multiple-Output Buck/Boost DC–DC Converter With Duty-Cycle and Control-Current Predictor," *IEEE Transactions on Power Electronics*, vol. 35, no. 11, pp. 12022-12039, Nov. 2020, doi: 10.1109/TPEL.2020.2988940.
[28] C. Bhuvaneswari, N. Sathyaprakash, W. A. Memala and M. Pushpavalli, "Analysis of Modified Buck Boost Converter fed DC Motor drive," *2023 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES)*, Chennai, India, 2023, pp. 1-4, doi: 10.1109/ICSES60034.2023.10465535.
[29] V. Aishwarya and K. GnanaSheela, "Performance analysis of Buck-Boost and Cuk converter-fed brushless DC motor drives", *Materials Today: Proceedings*, vol. 24, pp. 1865-1873, 2020.
[30] M. Z. Fikri and M. Yuhendri, "Kendali Tegangan Boost Converter Berbasis Adaptive Neuro Fuzzy Inference System (ANFIS)," *JTEIN J. Tek. Elektro Indones.*, vol. 4, no. 1, pp. 416–427, 2023.
[31] S. Siouane, S. Jovanovic and P Poure, "Service continuity of PV synchronous Buck/Buck-Boost converter with energy storage", *Energies*, pp. 1369, 2018.
[32] V. F. Pires, A. Cordeiro, D. Foito and J. F. Silva, "A DC-DC Buck-Boost Converter with High Voltage Gain, Bipolar Output and Continuous Input Current," *2023 12th International Conference on Renewable Energy Research and Applications (ICRERA)*, Oshawa, ON, Canada, 2023, pp. 46-51, doi: 10.1109/ICRERA59003.2023.10269402.
[33] M. E. Şahin and H. İ. Okumuş, "Comparison of Different Controllers and Stability Analysis for Photovoltaic Powered Buck-Boost DC-DC Converter", *Electric Power Components and Systems*, vol. 46, no. 2, pp. 149-161, April 2018.