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Real time control of buck converter with Sugeno Fuzzy Inference System using Arduino

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ABSTRACT

As time progresses, technology for electrical and electronic equipment also develops very rapidly, generally these electronic devices use electrical energy as a source, energy sources also vary from high voltage for industry and low voltage for household appliances. There are two types of voltage, namely direct and alternating. This direct voltage can be obtained from a DC generator, battery, or AC voltage that is directed to DC. In general, a buck converter has the meaning of reducing DC to DC voltage which has two types of storage, namely capacitor and inductor, thus producing a small ripple value. To be able to get the appropriate voltage value, the output value needs to be set via the Simulink Matlab program, namely Sugeno Fuzzy Inference System. Buck converters that have been set using different settings are different from those that have not been set using fuzzy. Buck converter circuits that do not use a control system only reduce the voltage according to the existing results and if you want to change the output results then we have to change the duty cycle value manually of course this will not be effective in the long term or using the tool periodically whereas if you use a fuzzy control system We can set the output value of the buck converter according to what we need.

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1. INTRODUCTION

As time goes by, the technology of electrical and electronic equipment has also developed very rapidly. Various electrical and electronic equipment has been produced to meet various human needs. Generally, this electrical and electronic equipment uses electrical energy as its main energy source. The source of electrical energy needed also varies from a large scale that can be used for industry to a small scale that is used for household needs. Power plants must of course pay attention to the electrical standards needed, the standards that must be considered include voltage and frequency, for voltage standards there are two types of voltage, namely alternating voltage and direct voltage [1]-[3].

DC voltage is commonly used in electronic equipment. Various DC voltage ratings are used in equipment, starting from 1.5 Volts, 3 Volts, 6 Volts, 9 Volts, 12 Volts and so on. This DC voltage source can be obtained from DC power generators, such as DC generators, solar panels, fuel cells, thermo generators and so on. It can also be obtained from a rectified AC voltage source. In addition, this DC voltage source can also be obtained from batteries. If a DC voltage generator is used, such as a solar panel or DC generator, then to obtain a voltage that matches the voltage rating required by the equipment, a DC to DC power converter is needed that can regulate the voltage according to needs. There are several types of DC-DC converters, namely voltage reduction (buck converter), voltage increase (boost converter), voltage increase and decrease (buck-boost converter) [4]-[15]. If the source voltage is greater than the required voltage, then the type of converter that can be used is a buck converter.

Buck converter works by processing switching on and off using mosfet then setting the duty cycle [16]. Buck converter has two types of energy storage, namely capacitor and inductor, so that the circuit can produce a small ripple voltage. To get the desired output voltage, the buck converter needs to be controlled. Several control system methods have been applied to obtain better buck converter performance, such as the use of the PI controller [17]-[20], inteligent control such as Mamdani type Fuzzy logic and Neural Network [21]-[25] and so on. Each method has advantages and disadvantages. The fuzzy method can provide a better response than the PID method. Therefore, this paper proposes a buck converter output voltage control system using the Fuzzy Logic Controller (FLC). Fuzzy logic is very suitable to be implemented in the system because it has a problem-solving system ranging from small, simple, multi-channel systems or based on data acquisition and control systems. Fuzzy decision-making (inference) systems can generally be grouped into Mamdani, Sugeno and so on inference systems. Basically, the reasoning of the Sugeno method is not much different from Mamdani, except that the output is not in the form of a fuzzy set but a constant or linear equation. In this study, a fuzzy inference system for controlling the buck converter output voltage is designed using Sugeno inference. The advantage of fuzzy Sugeno lies in its ability to produce numeric output based on a linear combination of inputs. It is expected that this method can produce a better output voltage response. The buck converter output voltage control system is designed using Arduino Mega 2560. The buck converter is designed for a maximum input of up to 48 Volts with a maximum power of 300 Watts.

2. METHOD

The research of this buck converter circuit was conducted in the form of an experiment using fuzzy logic sugeno to control the output voltage and current values of the buck converter so that the power distribution is in accordance with the specified values [8]. The buck converter will receive 24 volt input and a maximum output of 18 volts. The fuzzy logic sugeno control system will be implemented using the Arduino mega 2560 which is the control center and data processing, there is a gate drive circuit as an interface between the buck converter circuit and the Arduino mega 2560. The creation of the fuzzy logic sugeno controller uses the fuzzy toolbox in the matlab application using Simulink. Simulink is a module that is often used to simulate dynamic systems through graphical block diagrams. By using the fuzzy toolbox available in matlab, in addition to being a tool for creating a Simulink control system, matlab can also be used to display and process data, for example data from voltage sensors. Measuring instrument and oscilloscope are already available in the library so that they can be used directly in data collection, then Simulink can also be used on hardware devices, of course this allows us to test a tool and operate it.

Buck converter is a direct current converter used to lower DC voltage or in other words the output voltage is lower than the input voltage. This occurs due to the switching pattern generated by the PWM pulse by Arduino. Arduino PWM pulses have a working principle of regulating the switch used in the converter so that changing the size of the output voltage pulse from the converter will be determined by the duty cycle value entered in the PWM pin. To obtain an output voltage value that matches the reference, the buck output voltage is controlled by fuzzy sugeno. Output voltage control is done by adjusting the duty cycle value, as shown in Figure 1 below.

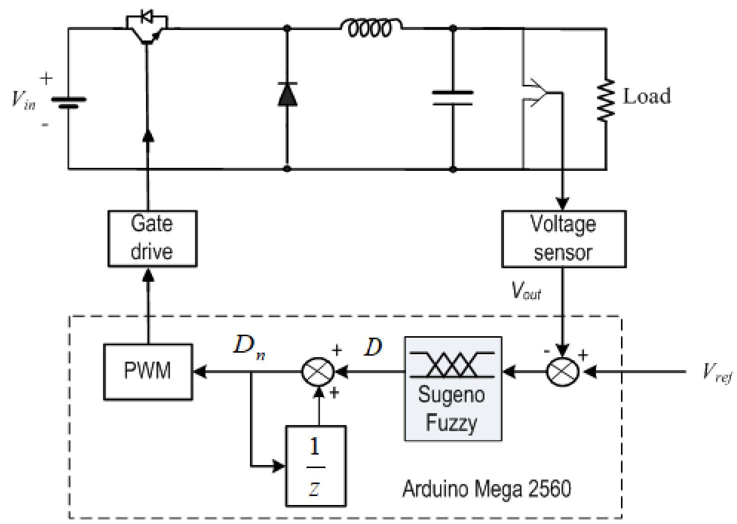


Figure 1. Buck converter voltage control scheme with fuzzy sugeno

Figure 1 shows that the fuzzy input is an output voltage error obtained from the difference between the reference voltage and the output voltage feedback, where this output voltage feedback is obtained from the voltage sensor installed on the buck converter output. Fuzzy sugeno will produce a duty cycle change value based on the voltage error. In accordance with the relationship between the duty cycle and the buck converter output voltage which is directly proportional, the duty cycle (D) needs to be added when the voltage error is positive. This positive voltage error occurs when the output voltage is smaller than the reference voltage. In this condition, fuzzy sugeno will produce a positive duty cycle output value. Conversely, when the voltage error is negative, fuzzy will produce a negative duty cycle value. With this concept, the duty cycle value for the PWM pulse will increase and decrease according to the voltage error. This duty that is produced will produce a PWM pulse on the Arduino PWM pin according to the PWM pulse needed to get the output voltage according to the set point. The PWM pulse generated by the Arduino pin will have its voltage increased through the gate driver according to the voltage needed to activate the MOSFET. The PWM signal has the function of controlling the power related to the power supply and regulating the movement of electronic devices. With this concept, the buck converter will produce a voltage according to the reference value. Figure 2 shows the flowchart of the buck converter output voltage control system with the proposed Fuzzy Sugeno.

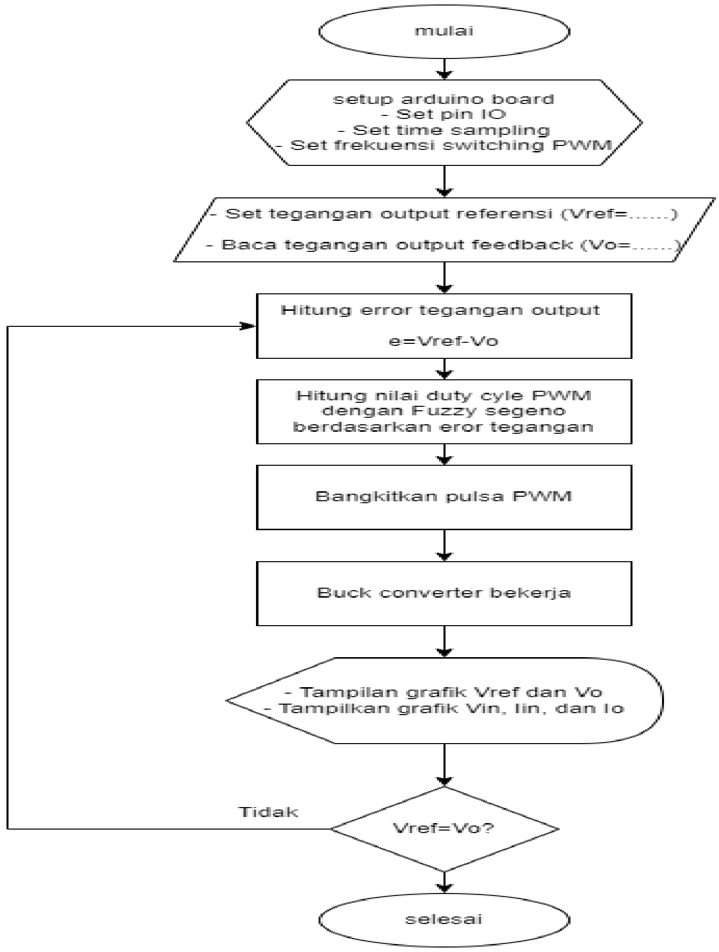


Figure 2. Flowchart of the Sugeno fuzzy based buck converter control system

Buck converter output voltage control can be done as the flow diagram in Figure 2. The buck converter will be connected to the Simulink program to be able to regulate its output voltage through the Sugeno fuzzy logic program and duty cycle settings. However, before that you need to pay attention to the IO pin set, sampling time set, and PWM set in order to get the desired output according to the flow diagram. The voltage sensor functions to determine the amount of voltage from the buck converter that comes out which will be used as a reference to regulate the MOSFET switching to be able to control the PWM pulse width so that the output voltage on the buck converter remains according to the reference. For the voltage sensor circuit that will be connected to the Arduino Mega 2560, the value of the resistor is determined so that we can get the output according to our needs. The resistor functions as a divider of the ADC input voltage on the microcontroller and is connected in series to have a large resistance value. Figure 3 shows the voltage sensor circuit schematic used in this study.

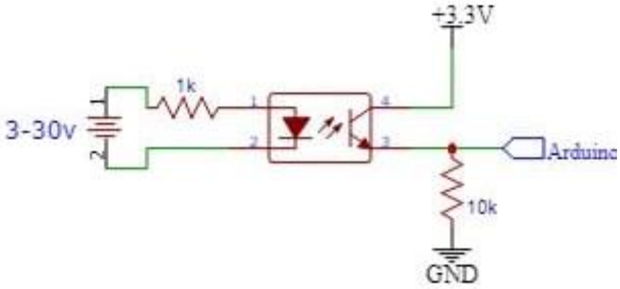


Figure 3. Voltage sensor circuit schematic

The output voltage of the buck converter is proposed using Fuzzy Logic Sugeno. Figure 4 shows the structure of Fuzzy Sugeno, which consists of fuzzifiction (a process of changing a solid number into a fuzzy number), rule basis, fuzzy reasoning system, and the last is defuzification which is a process of changing a fuzzy number into a solid number.

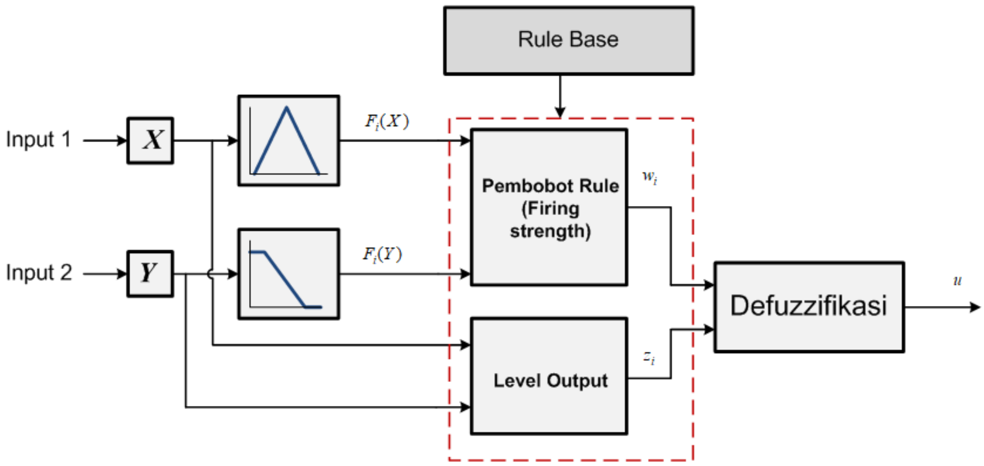


Figure 4. Sugeno fuzzy structure

Figure 5 and Table 1 show the membership functions of the input and output of the Sugeno Fuzzy used in this study. The fuzzy input is the voltage error, while the output is the change in duty cycle. The input is presented with nine membership functions consisting of 2 in the form of trapezium and 7 in the form of triangle.

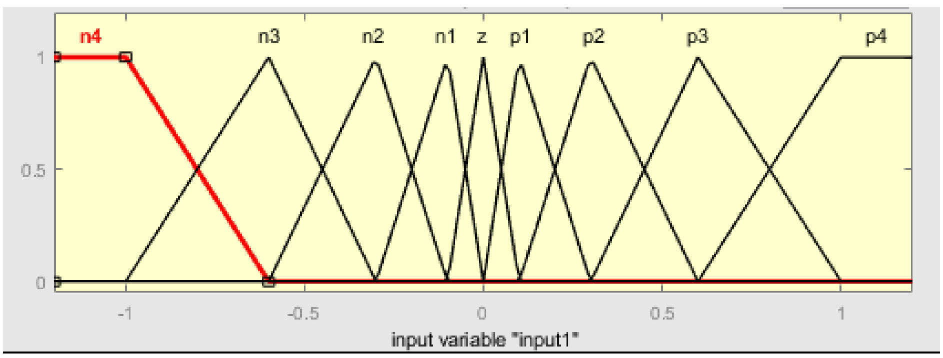


Figure 5. Sugeno fuzzy input membership function

Table 1. Output membership functions

Variable	Symbol	Value
Output 1	O1	-5
Output 2	O2	-1
Output 3	O3	-0.5
Output 4	O4	-0.05
Output 5	O5	0
Output 6	O6	0.05
Output 7	O7	0.5
Output 8	O8	1
Output 9	O9	5

The output of the fuzzy sugeno program is the duty cycle value for the PWM switch buck converter, in table 1 it can be seen that the fuzzy sugeno output is in the form of a single tone, in this study nine single tones are used to present the duty cycle value which is presented with linguistic variables at certain values, the table above shows that linguistic variables 01 to 09 have a value range of -5 to 5. The relationship between input and output is connected by the if then rule. Table 2 describes the Fuzzy sugeno rule base applied in this study.

Table 2. Rule Base

Input	Output
N4	O1
N3	O2
N2	O3
N1	O4
Z	O5
P1	O6
P2	O7
P3	O8
P4	O9

The next stage after the inference process is the defuzzification stage, namely the process of changing the output value in linguistic form into numeric data for the duty cycle value, the rules in the rule base will determine the output value in fuzzy sugeno, after the process of converting the value for pwm, the duty cycle value will be converted into a PWM pulse via the PWM pin on the Arduino Mega 2560 with the switching frequency as needed to modulate the buck converter switch.

3. RESULTS AND DISCUSSION

After the design of the tool is complete, the next step is testing the tool. The buck converter circuit will be assembled with several components, namely PC (MATLAB), variable resistor, power supply, volt meter, ampere meter, buck converter. Figure 6 is a series of tools to test the output voltage of the buck converter using the sugeno fuzzy logic control system, the input voltage that will be used by the researcher this time is 24 volts. This test will be carried out in two ways, namely without control and using variable voltage load control, but before that it is necessary to set the IO pin, set the pwm, and validate the data in the Simulink program by comparing the voltage and current read by the measuring instrument and that read by Simulink. If there is a difference, a match is made by changing some changes in value, after all is complete, the test of the fuzzy sugeno-based buck converter output voltage control system can be started.

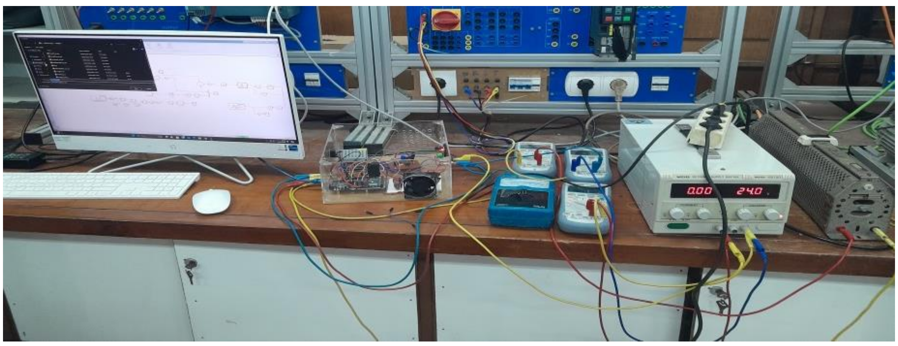


Figure 6. Complete Hardware Series

Figure 7 is a Simulink display of the fuzzy logic sugeno program where the Arduino Mega 2560 will be used as the controller center in this data processing, the voltage read on the measuring instrument will be re-validated in the circuit so that there is no difference between the value on the measuring instrument and the value on Simulink. In order to get a precise voltage value, a low pass filter is needed in the Simulink circuit to get a more precise signal and current voltage to get the reference voltage value. The first step we do is add a constant block to the Simulink circuit, the reference voltage value this time is then compared from the output voltage of the buck converter, the error obtained is entered into Sugeno to be input, the output of this fuzzy Sugeno is PWM. The new duty cycle value is obtained from the sum of the duty cycle values obtained with the previous duty cycle value, and the next step is that the duty cycle will be used as input for the PWM pin which will later have an output in the form of a PWM signal. The performance of the converter in Simulink is that the output voltage and the reference voltage will adjust to each other.

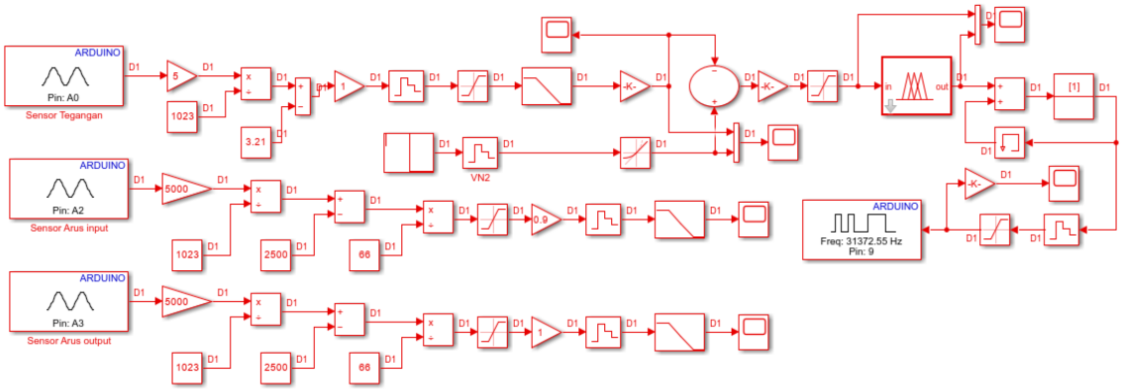
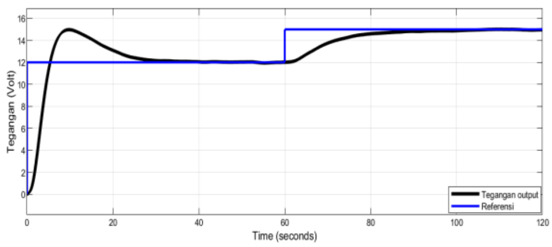
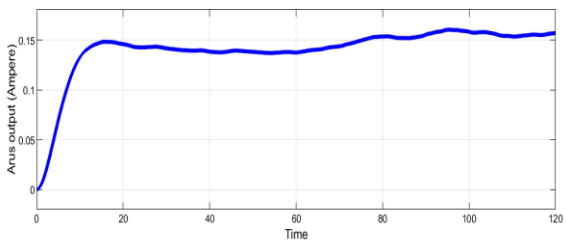


Figure 7. Fuzzy Sugeno-based buck converter voltage control system program

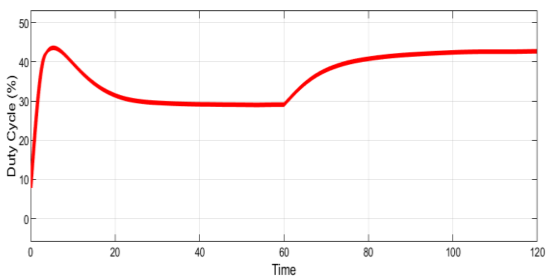
The experimental results are shown in Figure 8. The figure shows that with an input voltage of 24v and its reference value set at 12 and 15, the output voltage successfully adjusts the value according to the reference value that has been determined based on the graph in the figure. Initially, the output voltage immediately rises to 15 but slowly follows at a value of 12 volts, then at 60 seconds when the reference voltage is 15, the output voltage, which had previously dropped to 12 volts at 80 seconds also reaches a value of 15 volts and that is in accordance with the reference voltage. The duty cycle value also adjusts based on the reference voltage where the duty cycle if it experiences an increase and decrease in value and one of the factors that makes this program run is a stable pwm value and experiences very little noise.



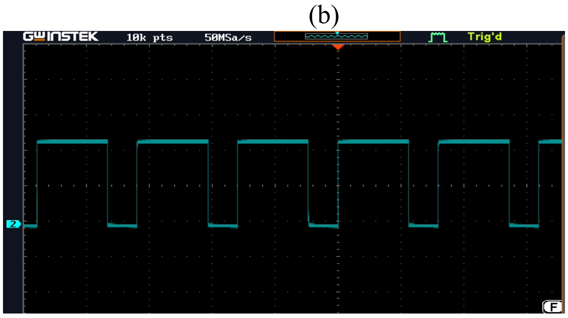
(a)



(b)



(d)



(d)

Figure 8. Test results. a) Output Voltage, b) output current, c) Duty Cycle, d) PWM

4. CONCLUSION

The output voltage control of the fuzzy logic sugeno buck converter in this study using Arduino Mega and Simulink as the brain of this control system gets results when the output voltage rises, the output current will fall, and vice versa when the output voltage falls, the output current will rise. The buck converter circuit when given a fuzzy logic sugeno control system, the output voltage can be determined according to the reference voltage that we have determined in the Simulink program.

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