Journal of Physics: Conference Series **1444** (2020) 012018 doi:10.1088/1742-6596/1444/1/012018

Comparison of Different Rule Base Matrix in Fuzzy Logic Controller

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Abstract. The development of power electronics technology has been widely applied in various fields. Converters have been widely used in renewable energy and several industrial applications. Many control that used to operate the converter, one of these is Fuzzy Logic Controller (FLC). FLC is used because it has advantages such as fast response and good performance. FLC is a rule-based control system, so the basic rules are made to operate this system by input processing. Fuzzy variable 3x3 matrix rule base is less responsive in achieving steady state conditions. Therefore, a 5x5 matrix rule base fuzzy variable is modified, so that it gets smoother response and faster system to achieve steady state. In this paper, the response of the output voltage to changes in the fuzzy variable 3x3 matrix rule base will be compared to the 5x5 matrix rule base.

1. Introduction

Renewable energy is being developed such as wind energy and hydro energy as alternatives to limit the use of conventional energy. Converters have been widely used in renewable energy and several industrial applications to raise a low voltage to a high voltage [1]. Many control that used to operate the converter, one of these is Fuzzy Logic Controller (FLC) [2]. FLC is widely used because it has advantages such as fast response and good performance. This controller offers interesting features such as gives a robust performance under parameter variations, supply and load disturbances [3]. With this type of controller certainly requires mathematical modeling to get an accurate result in more complex circuits [4].

The development of FLC concern is in getting the control circuit as desired [5]. This control does not require an accurate mathematical modeling system and can work in conditions with less precise input [6]. The function of implementation FLC in each range is to show the membership function when the variable is set in fuzzy [7].

This method expresses the relationship between input and output variables [8]. For two fuzzy inputs, if each input has 3 fuzzy sets, there are a total of 9 (3x3) rule bases [9]. The response of fuzzy variable 3x3 matrix rule base voltage output is very slow in reaching steady state [10]. To get a more constant output voltage response, it can be done by modifying fuzzy variable [11]. Fuzzy variable 3x3 matrix rule base is modified to fuzzy variable 5x5 matrix rule base. With a modified fuzzy variable will provide a more constant response and better performance [12]. Then a comparison is made between fuzzy variable 3x3 matrix rule base and fuzzy variable 5x5 matrix rule base to see the output voltage response in achieving steady state [13].

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In this paper, the response of the output voltage to changes in the fuzzy variable 3x3 matrix rule base will be compared to the 5x5 matrix rule base. The response time of a control system consisting of "transient" and "steady state" then compared to the output current. This method was developed with simulation using PSIM software to be implemented on the dsPIC30F4012 microcontroller. The output signal result from this method is provided in this paper.

2. Method

2.1. Fuzzy Logic Controller

Fuzzy Logic Controller (FLC) is a nonlinear and adaptive controller that uses rule-based systems that provide strong performance under parameters variation and load disturbances. Basically, FLC consist of four basic components: fuzzification, defuzzification, inference engine, and rule base. The most important specification of the fuzzy logic control method is their fuzzy logical ability in the perception of quality dynamics of the system and the application of these quality ideas simultaneously to the desired control system. A simple block diagram of a fuzzy logic system is shown in figure 1.

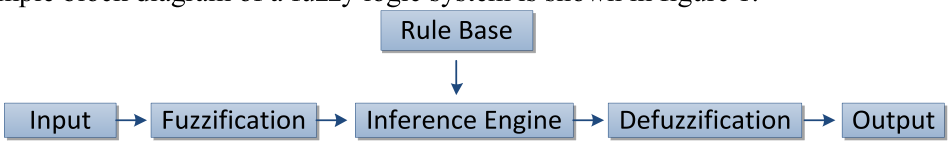


Figure 1. Structure of Fuzzy Logic Controller

The result obtained by fuzzy logic depends on fuzzy inference rules and fuzzy implication operators. The knowledgebase provides the information needed for linguistic control rules and information for fuzzification and deffuzification. In the defuzzification relationship, an actual control action is obtained from the fuzzy inference engine. The input signal in the FLC block is an error signal (the difference between the reference voltage and the actual output voltage). Input signal that is used in measurement are using hard or crisp set method, some of measurement results are converted to fuzzy values for fuzzy input sets with fuzzyfication blocks.

2.2. Fuzzification

Variable input in this system is voltage error and voltage error-dot. The fuzzification process will change the magnitude in the crip set (numerical magnitude of the error and derivative error values) to the magnitude in the fuzzy set (the value of error and derivative error as elements of the fuzzy variable is negative (A), zero (B), and positive (C)).

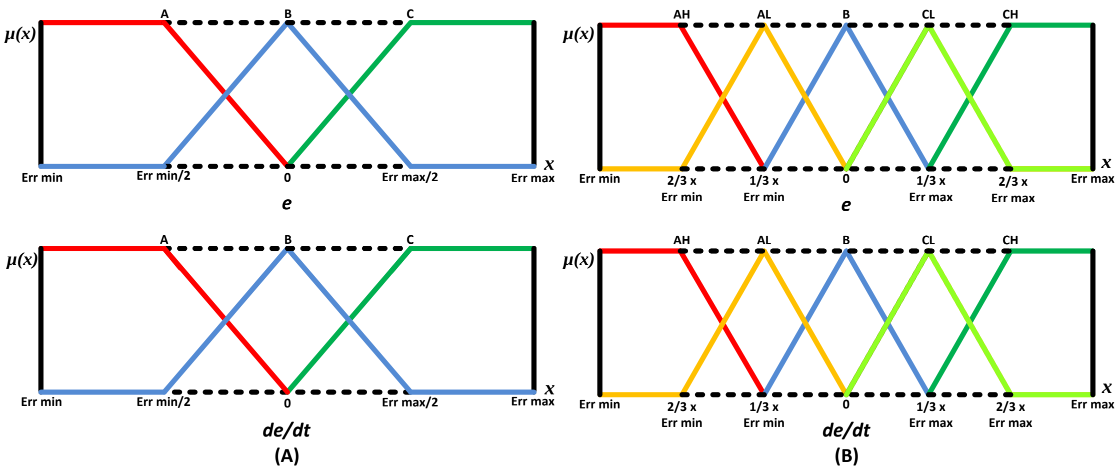


Figure 2. Membership function (A) fuzzy variable 3x3 (B) fuzzy variable 5x5 required.

The comparison of the 3x3 and 5x5 fuzzy variable membership function in a symmetrical state shows in figure 2. To get the result of a better control system then modify fuzzy variable is needed. As in the figure 2 (B), the fuzzy variable is expanded to negative big (AH), negative small (AL), zero (B), positive small (CL), and positive big (CH), and a membership function for better error and derivative error position will be generated. Thus the matrix rule base will be obtained from one of the rules as in figure 3.

2.3. Rule Base

FLC is a rule-based control system, so the basic rules are made to operate this system by input processing. On the reference fuzzy variables for error and derivative error are three, there are negative (A), zero (B), and positive (C), then the number of rules (IF-THEN) is nine. For the fuzzy variable modification for error and derivative error five pieces, there are negative big (AH), negative small (AL), zero (B), positive small (CL), and positive big (CH), then the number of rules (IF-THEN) is 25 [14]. From the 3x3 fuzzy variable rules, there are three kinds of conditions (A, B, and C) then the output voltage condition is connected to actualization. If the predetermined rules are displayed in the form of a matrix, then it will be a matrix that has orders 3x3 and 5x5 as shown in figure 3.

de/dt \ e	A	B	C
A	A K1	C K2	C K3
B	A K4	B K5	C K6
C	A K7	A K8	C K9

(A)

de/dt \ e	AH	AL	B	CL	CH
AH	AH K1	AH K2	CL K3	CL K4	CL K5
AL	AH K6	AL K7	CL K8	CL K9	CL K10
B	AL K11	AL K12	B K13	CL K14	CL K15
CL	AL K16	AL K17	AL K18	CL K19	CH K20
CH	AL K21	AL K22	AL K23	CH K24	CH K25

(B)

Figure 3. Matrix rule base structure (A) fuzzy variable 3x3 (B) fuzzy variable 5x5.

2.4. Inference Engine and Defuzzifier

In this inference process, each output which has the same weight will be determined. The process is done by squaring the matrix rule base and adding up the same properties and then determining the roots. By looking at the rule base in figure 3 (A), it can be determined from the 3x3 fuzzy variable that negative (A), zero (B), and positive (C) output is achieved. After going through the inference process, the result of value in fuzzy quantities will be produced. For the application of these quantities in the real system, it must be changed in crisp quantities through the defuzzifier process as to be seen in equation 1 [15].

$$O = \frac{100(Z) - 100(X)}{Z + X + Y} \tag{1}$$

Equation 1 show where O is output total, X is output negative, Y is output zero and Z is output positive.

Likewise with 5x5 fuzzy variables can be determined that the output of negative big (AH), negative small (AL), zero (B), positive small (CL), and positive big (CH) achieved based on figure 3 (B). After going through the inference process, it will get the result of value in fuzzy quantities. By going through the fuzzy centroid process, it will be obtained as to be seen in equation 2 [15].

$$O = \frac{100(ZH) + 50(ZL) - 50(XL) - 100(XH)}{ZH + ZL + XL + XH + Y} \tag{2}$$

Equation 2 show where O is output total, XH is output negative big, XL is output negative small, Y is output zero, ZL is positive small, and ZH is positive big. Then O will be converted into a duty cycle to turn on and off the switch on the control system in detail.

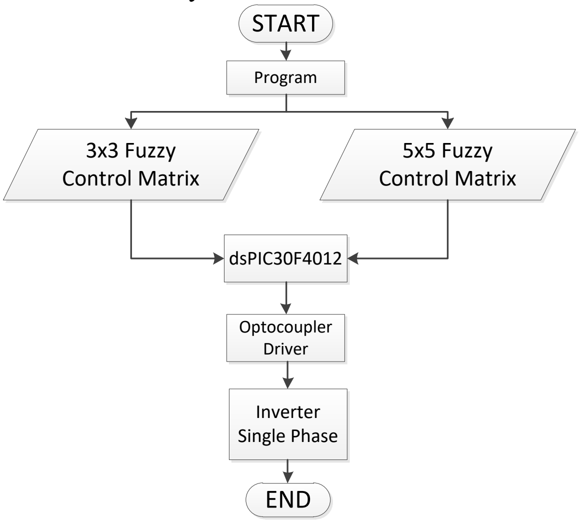
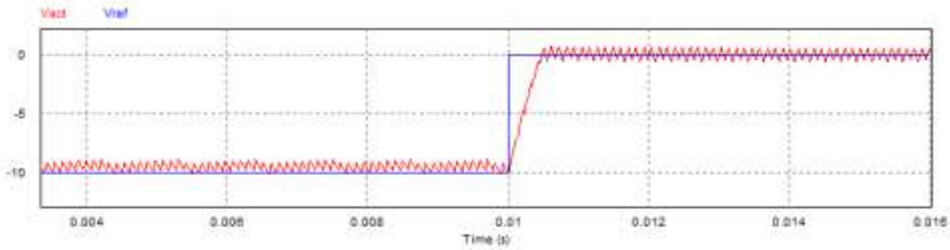


Figure 4. The diagram functional of signal processing to compare the output of fuzzy variable 3x3 and 5x5.

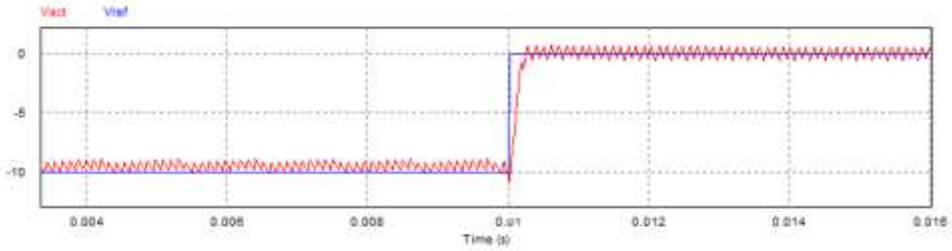
Process diagram of the output signal waveform is shown in figure 4. The FLC program compiled by input the program into the microcontroller dsPIC30F4012. The output signal that has been compiled, is going to the optocoupler driver to be processed into IC IR2132. The output signal from the IC IR2132 was controlled by IGBT to apply the fuzzy controller. The output of the signal can be seen on oscilloscope, by using AFG (Audio Function Generator) as a reference signal. The output signal from the IGBT is given the voltage from power supply to track the signal reference from AFG.

3. Result And Discussion

Before this analysis applied to the control circuit, a simulation is needed. Testing of FLC-based control design is done by simulation using PSIM software. The simulation circuit consists of C Block as a microcontroller with input and actual signal input, and PWM as a duty cycle regulator of the C Block output. DC 100V source for the voltage in a single-phase inverter circuit that has a current sensor. The simulation has been programmed in C Block which is implemented on the dsPIC30F4012 microcontroller. The following of the result of taking output voltage data based on changes in rule base.



(A)



(B)

Figure 5. Response of output voltage to changes in fuzzy (A) 3x3 matrix rule base (B) 5x5 matrix rule base.

Simulation result in figure 5 shows that the transient position can be seen that the respond of output fuzzy variable voltage 5x5 is faster when approaching the reference signal than the output of fuzzy variable voltage 3x3. Red signal as the actual voltage and blue signal as the reference voltage. With the same parameters, using a modified fuzzy variable will show better work results.

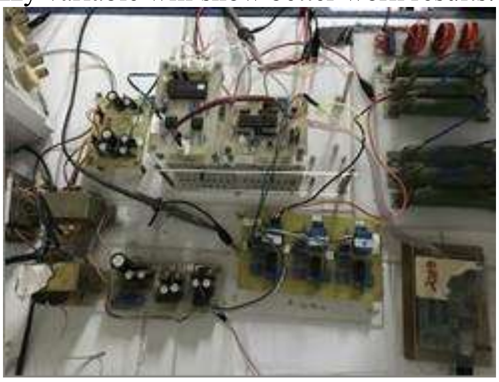


Figure 6. Prototype for testing

Table 1. Parameter of fuzzy variable 3x3

Fuzzy variable 3x3	
Error	Derivative error
Err max = 4	Derr max = 8
Err min = -4	Derr min = -8

Table 2. Parameter of fuzzy variable 5x5

Fuzzy variable 5x5	
Error	Derivative error
Err max = 4	Derr max = 8
Err min = -4	Derr min = -8

After the simulation result, then continue with testing on the prototype. Parameters used in experimental works are despicted in table 1 and table 2. In this test, fuzzy variable output voltage is generated from hardware that contains dsPIC30F4012 microcontroller, single phase inverter with IGBT, current sensor, 6 *mH* inductor, and 11.2ΩJ load resistor. The control system consists of a driver which has an IC IR 2132 optocoupler with a 12V input power supply. All hardware used in this test can be seen in figure 6. After testing the prototype, data retrieval is performed by using an oscilloscope with a reference signal using AFG. The result obtained in the form of a comparison of the output voltage fuzzy variable 3x3 and 5x5.

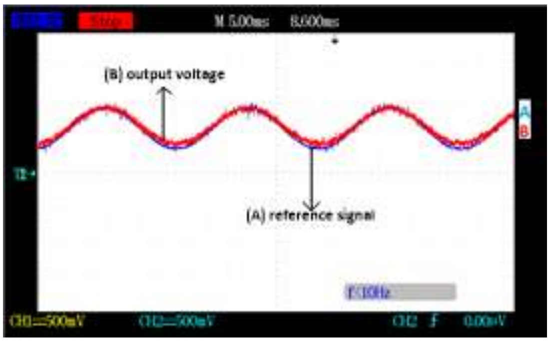


Figure 7. Experimental result (A) output voltage to 3x3 matrix changes fuzzy variable rule base (B) sine reference signal.

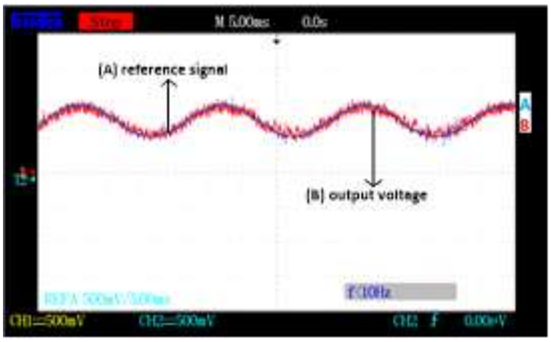


Figure 8. Experimental result (A) sine reference signal (B) output voltage to fuzzy variable 5x5 matrix rule base.

Fuzzy variable output voltage signal 3x3 can be seen in figure 7, while the fuzzy variable voltage output signal 5x5 can be seen in figure 8. Signal A as a reference generated from AFG and signal B as the fuzzy variable output voltage. The output voltage signal follows the reference signal with a steady state. In symmetrical conditions with the same error and derivative error parameters, the matrix rule base output 5x5 is better when following a reference signal.

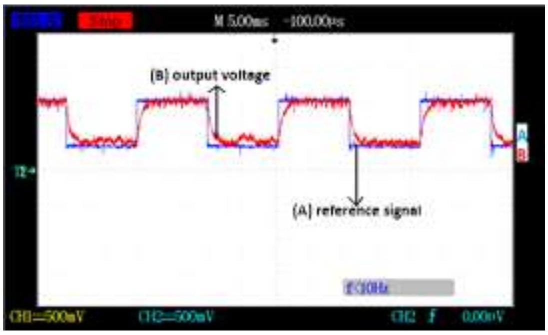


Figure 9. Experimental result (A) box signal reference (B) output voltage to fuzzy variable changes 3x3 matrix rule base.

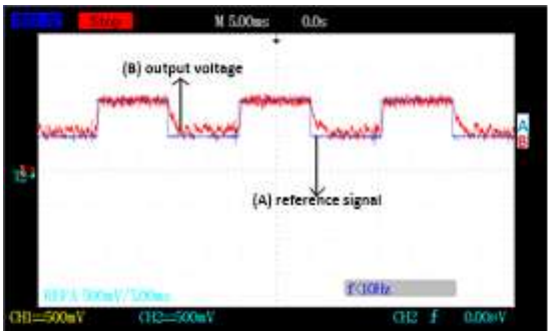


Figure 10. Experimental result (A) box signal reference (B) output voltage to 5x5 fuzzy variable change matrix rule base

By using a box signal reference, the ratio of the output voltage will be more visible by going to the transient position. Signal A as a reference generated from AFG and signal B as the fuzzy variable output voltage. figure 9 shows the 3x3 matrix rule base voltage output is not constant when following the reference signal, so the transient position is greater. Whereas in figure 10 shows the 5x5 matrix rule base output voltage has a faster response to the reference signal, so the transient response is faster toward steady state. figure 10 shows that the level of accuracy that produced is higher.

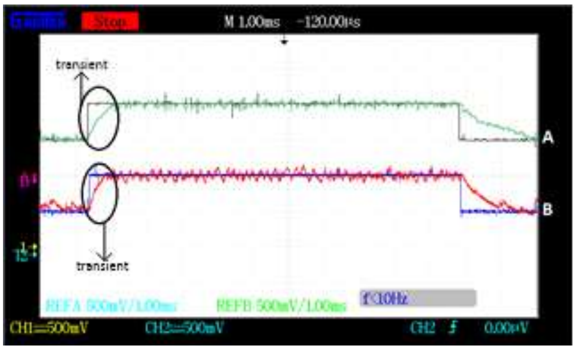


Figure 11. Experimental result (A) output voltage to changes in fuzzy variable 3x3 matrix rule base (B) output voltage to changes in fuzzy variable 5x5 matrix rule base.

Comparison of 3x3 fuzzy variable voltage output and 5x5 matrix rule base can be seen in figure 11. Signal A as fuzzy variable output 3x3 rule base matrix and signal B as output fuzzy variable 5x5 rule base matrix. In the experimental results it can be seen that the output voltage of signal A has a weakness that is the slow response in reaching steady state. Signal output voltage B has a faster response when it reaches steady state, so it works better than signal output A. The experiments show that the fuzzy variable 3x3 matrix rule base output voltage is less responsive to the reference signal compared to the 5x5 fuzzy variable matrix rule base output voltage.

4. Conclusion

This paper shows the comparison of the fuzzy variable 3x3 matrix rule base and the fuzzy variable 5x5 matrix rule base. Based on retrieval data in result and discussion section, fuzzy logic control with 5x5 matrix rule base gives a better response than 3x3 matrix rule base. With the same parameters, it can be concluded that using a modified fuzzy variable will show better work result. An increasing number of rule base makes the result more accurate and the system faster in achieving steady state conditions. To get a maximum response, modifications are needed by adding a higher order.

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Acknowledgment

This work was supported by Directorate of Research and Community Service, Directorate General of Research Strengthening and Development, The Ministry of Research, Technology and Higher Education, Republic of Indonesia 2019.