Implementation of Fuzzy Logic Controller with Different Membership Function Curves

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Abstract. Generally, the applications of power electronic are widely applied in the industrial, household, renewable energy fields, etc. Fuzzy Logic Controller is considered as an effective support control in the application because this implementation is very useful. Fuzzy Logic Controller is more reliable when compared to conventional control systems. This paper provides a Fuzzy Logic Controller based control method to identify the transformation of the membership function curve by using the dsPIC30F4012 microcontroller. In the implementation, the different membership function curves are adopted to obtain the maximum power output. The fuzzification process is needed to convert numerical numbers into fuzzy numbers. The other process is also required to convert the result of fuzzification process, it is called defuzzification process. To obtain the control system performance, the rule is defined in the rule base matrix. The experimental results were done to verify the analysis of Fuzzy Logic Controller.

1. Introduction

The digital control that based on power electronics dominates the application of modern technology and renewable energy. There are many applications that use this control, involves Uninterruptible Power Supply (UPS), motor speed controller, solar panel, fuel cell, and others. However, in real practice most application produces DC voltage source. Therefore, a control series to convert DC voltage into AC voltage in converter is needed. Commonly, several controllers often used such as Proportional-Integral (PI) and Proportional-Integral-Differential (PID). The controller requires a precise and accurate mathematic model [1][2]. But now, many researches combine these controllers with Fuzzy Logic Controller to get the better result.

It becomes the reason that the development of fuzzy logic thfieory was important to get the expected control. The implementation of Fuzzy Logic Controller has many advantages, this control could give fast responses, good performances [3], simple execution, more reliable than conventional control system, and overcome the nonlinearity [4][5][6]. Therefore, the developers use this controller as a system stabilizer [7][8] that can operate optimally [9]. In this project, Fuzzy Logic Controller is implemented on a single-phase inverter using dsPIC30F4012 microcontroller. The experiment was done by looking of the differences membership function curve to obtain maximum output. Required calculation of the difference in the value of the errors and the correct derivative errors to get the maximum output response. Fuzzy Logic Controller using microcontrollers can work in real-time and practically [10].

This research implemented a fuzzy logic-based control method with different membership function curves. The first curve is used error variables (error min/2 = -2; error max/2 = 2) and derivative errors (derivative error min/2 = -4; derivative error max/2 = 4). The second curve is used error variables (error min/2 = -3; error max/2 = 3) and derivative errors (derivative error min/2 = -6; derivative error max/2 = 6). The third curve is used error variables (error min/2 = -1; error max/2 = 1) and derivative errors (derivative min/2 = -2; derivative max/2 = 2). The experimental results were done to verify the analysis. The output signals are shown in this paper.

2. Fuzzy Logic Controller

The Fuzzy Logic Controller is implemented in a single-phase inverter. The implementation of this control is beneficial to solve the nonlinearity between the input and the output voltage that were not appropriate. This research is used as a closed-loop control system that described in figure 1. The output voltage in the inverter is controlled to follow the reference voltage. The reference voltage is generated by AFG (Audio Function Generator). Then, the switching of duty cycle in the inverter are adjusted by the Fuzzy Logic Controller system.

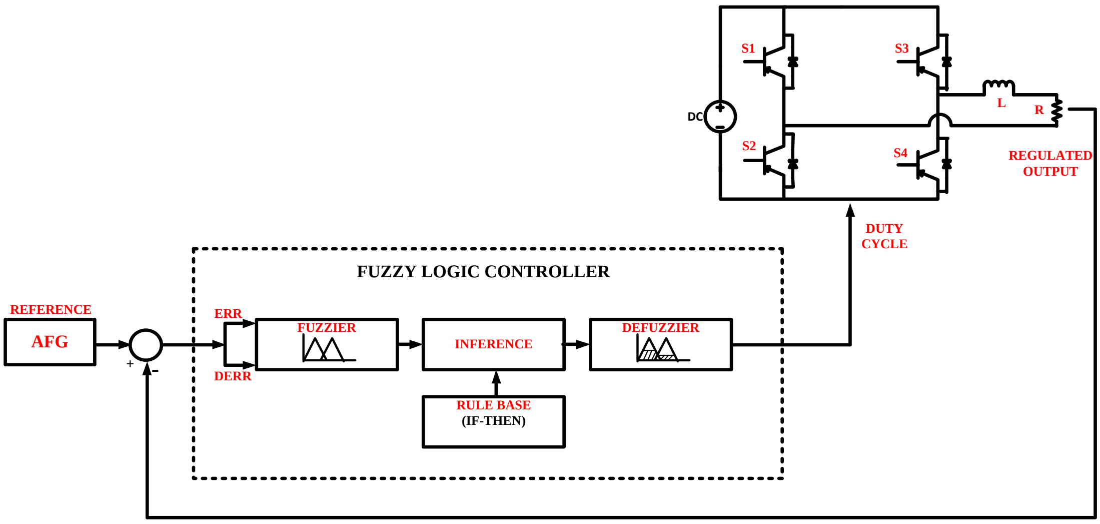

Figure 1. Block diagram of control structure.

Fuzzy Logic Controller system has a functional block diagram consist of fuzzification, rule base, inference, and defuzzification processes. The Fuzzy Logic Controller input signal represents an error signal that produced by the difference between the reference voltage and the actual output voltage. Fuzzification (fuzzier) is a process transforming real numbers into fuzzy numbers. Fuzzy logic system consists of linguistic variables and fuzzy variables. The linguistic variable involves the error and derivate error value of the input voltage. Meanwhile, fuzzy variable includes the sets of error X (negative), error Z (zero), and error Y (positive) [1]. The value of derivative error is the error value that compared to the previous error value. The fuzzy logic system has a membership function as the illustration fuzzy logic control is shown in figure 2, which refers to the memberships functioning curve. In the curve, there are two membership values derived from error and derivative error.

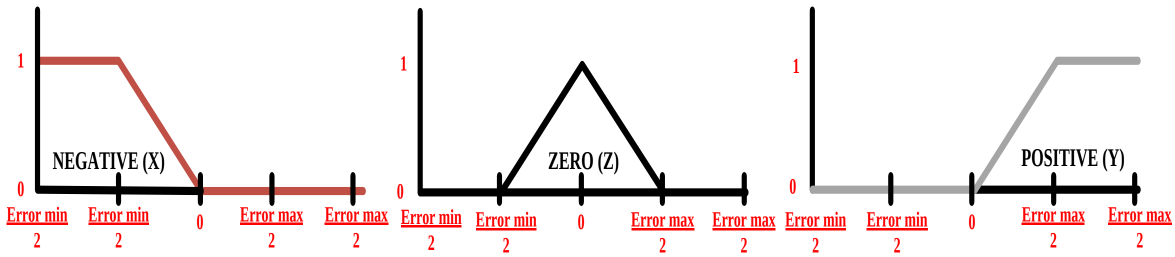

Figure 2. Membership function curves.

In the fuzzy logic controller, there are basic rules that have been determined to process the input generated by the fuzzification process. The basic rules (IF-THEN) are called the rule base that was discussed in the relationship between input and output [11]. In the fuzzification process, each produces three error and derivative error values contained in the fuzzy variable. The basic rules (IF-THEN) obtained amount to nine rules presented in the following table:

Table 1. Rule base.

IF		THEN
Error	Derivative error	Output
Negative	Negative	Negative
Zero	Negative	Positive
Positive	Negative	Positive
Negative	Zero	Negative
Zero	Zero	Zero
Positive	Zero	Positive
Negative	Positive	Negative
Zero	Positive	Negative
Positive	Positive	Positive

The nine rules that have been obtained that shown in table 1. It converted into the matrix form presented in figure 3.

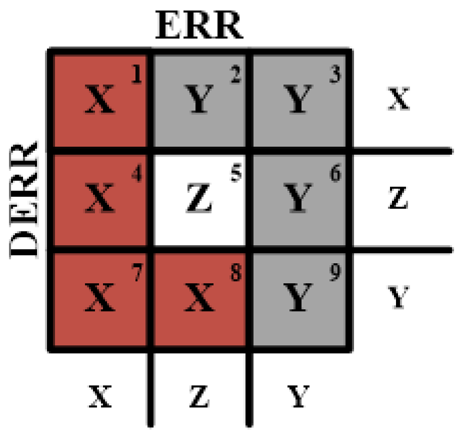

Figure 3. Rule base matrix ordo 3x3.

Based on the matrix structure that determined in figure 3, the inference process is continued to determine the output value. The inference is a process in determining the value of X, Z, and Y which is composed to control output values that have the same properties [6]. Based on figure 3, the inference negative output is as follows:

$$OutputX = X_1, X_4, X_7, X_8 \tag{1}$$

In zero inference has only one matrix, the inference output is as bellow

$$OutputZ = Z_5 \tag{2}$$

The positive inference output has an output value matrix is as bellow

$$OutputY = Y_2, Y_3, Y_6, Y_9 \tag{3}$$

In the inference process, the output is still a fuzzy number. The defuzzification process is needed to convert these fuzzy numbers into real numbers. So, the numbers can be applied to the system. The defuzzification is the reversed process of the fuzzification [1][4]. The method was used in the defuzzification process is the fuzzy centroid method. This method can determine the specific output value [12] in considering rules because it uses arithmetic [13].

$$\%Output = 100 * \left(\frac{OutputY - OutputX}{OutputY + OutputZ + OutputX} \% \right) \tag{4}$$

In equation (1) until (4) X output is represented negative, Z output is represented zero, and Y output is represented positive.

3. Results and Discussion

The proposed method that implemented on the prototype using a single-phase inverter. A block diagram schematic of Fuzzy Logic Control implementation is shown in figure 4. The power supply injected the voltage on dsPIC30F4012 microcontroller and optocoupler driver to isolate the signal and set a switching time.

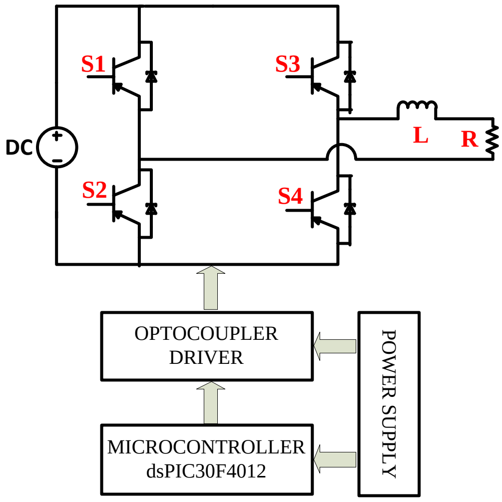

Figure 4. A block diagram scheme of the FLC implementation.

The prototype used an SK20GB123 IGBT, the dsPIC30F4012 microcontroller, the power supply, an 11.2Ω*J* load resistor, and a 6 *mH* inductor are shown in figure 5. A function generator was used as a reference voltage and a current sensor as an actual output voltage. In this experiment, the absolute value of the voltage error is 4 Volt and the absolute value of the voltage error derivative is 8 Volt/s.

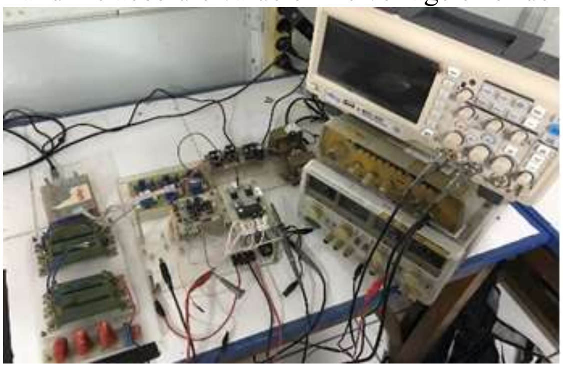

Figure 5. The prototype of FLC implementation.

Table 2. Fuzzy Logic Controller (#1).

Parameters	
Error	Derivative Error
Min = -2	Min = -4
Max = 2	Max = 4

Table 3. Fuzzy Logic Controller (#2).

Parameters	
Error	Derivative Error
Min = -3	Min = -6
Max = 3	Max = 6

Table 4. Fuzzy Logic Controller (#3).

Parameters	
Error	Derivative Error
Min = -1	Min = -2
Max = 1	Max = 2

The parameters of the error values can be seen in Table 2 until Table 4. In Table 2, the parameter values used are able to produce good tracking abilities. In Table 3, the parameter value used has an error value which has a wide error value difference. In Table 4, the parameter value used have an error value which has a narrow error value difference. The results of experiments on the three conditions above can be seen in figure 7 until figure 13. The difference in error values should not be too wide and narrow, the proper values in error are required to obtain better tracking capability.

The experimental result of the FLC implementation on the prototype is shown in figure 6 until 13. The blue signal (A) represented the reference voltage. The red signal (B) represented the actual voltage. Both signals are shown in figure 6. The response of the output voltage to the input voltage on the first membership function curve (#1) with error values (-2; 2) and derivative errors (-4; 4) are shown in figure 7 and 8. In this curve, the output voltage goes to the input voltage does not change based on rules. The experimental results on the curve (#1) shown in figure 8, shows produce an output signal voltage response that approaches the reference signal waveform during the tracking process. This response produces a good signal tracking capability and maximum output voltage response.

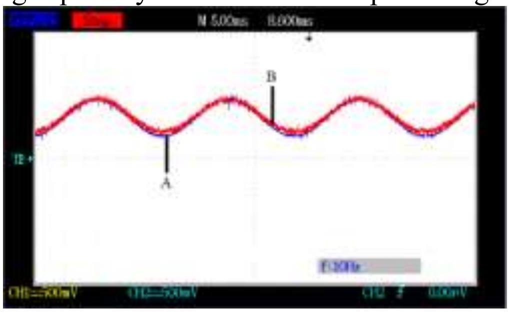

Figure 6. Experimental result of the prototype (A) Reference voltage and (B) Actual voltage.

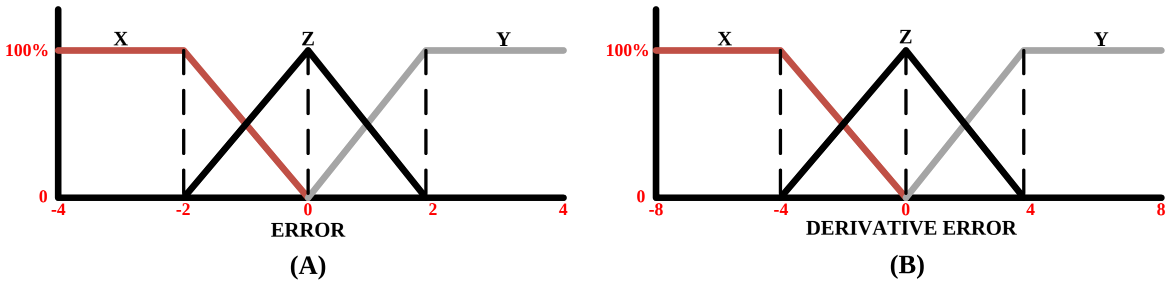

Figure 7. Membership function (#1) curve, (A) Error and (B) Derivative Error.

Figure 8. Experimental results of error (-2; 2) and derivative error (-4; 4).

Experimental result of the second membership function curve (#2) shown in figure 9 and 10 with error values (-3; 3) and derivative errors (-6; 6). In the membership function curve (#2) of this experiment using a wide difference in errors and derivative errors values. The results of this test cause response of the output signal voltage when tracking does not approach the reference signal as shown in figure 10. The response of the output voltage signal has decreased significantly and the exit signal becomes less than optimal.

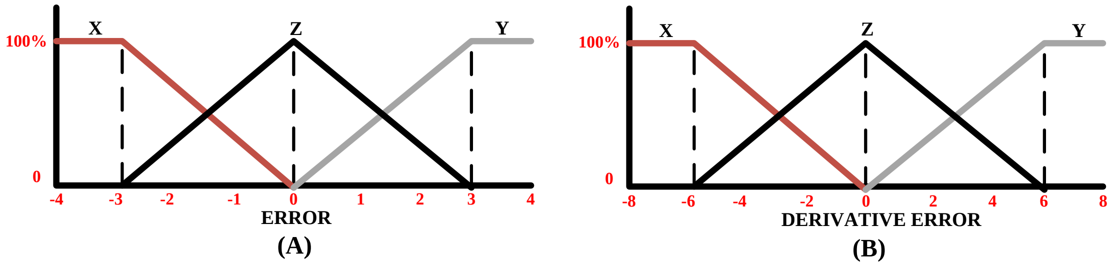

Figure 9. Membership function (#2) curve, (A) Error and (B) Derivative Error.

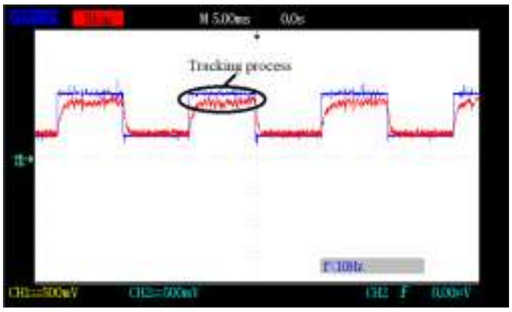

Figure 10. Experimental results of error (-3; 3) and derivative error (-6; 6).

Experimental result of the third membership function (#3) is shown in figure 11 and 12 with error values (-1; 1) and derivative errors (-2; 2). In the membership function curve (#3) of this experiment carried out using a narrow difference in the value of errors and derivative errors shown in figure 12. In a narrow curve, the response of the output signal voltage is almost close to the reference signal, but the waveform when tracking is not optimal. Output signal voltage response has decreased slightly and the results are less than the maximum as in the curve (#2).

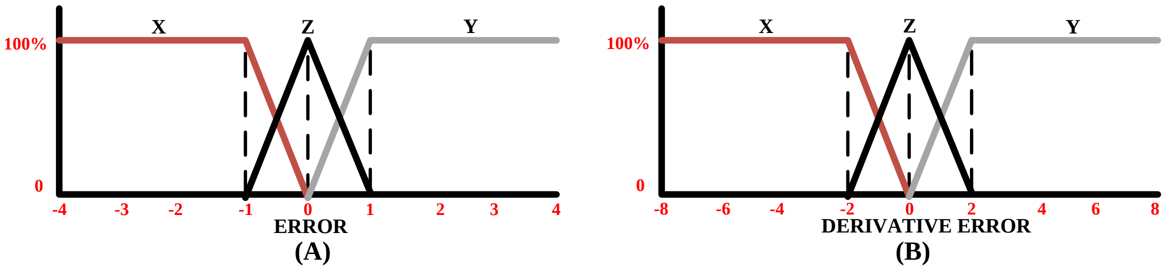

Figure 11. Membership function (#3) curve, (A) Error and (B) Derivative Error.

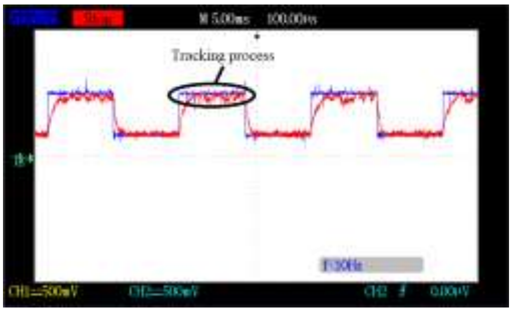

Figure 12. Experimental results of error (-1; 1) and derivative error (-2; 2).

The response of the output voltage to the input voltage changes on the rule base are shown in figure 9 until 12. The actual output voltage has shifted at the reference voltage. In figure 7 and 8, it appears that the difference of the experimental results of (#1) are following the reference and have better tracking capability than the membership function curves (#2) and (#3).

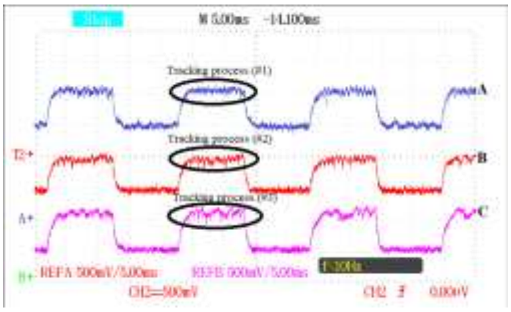

Figure 13. Experimental result of (A) Membership function (#1) curve, (B) Membership function (#2) curve, and (C) Membership function (#3) curve.

The difference in membership function curves (#1), (#2), and (#3) are shown in figure 13. The signal (A) is an experimental result on the membership function (#1) curve with errors (-2; 2) and derivative errors (-4; 4), signal (B) is an experimental result on the membership function (#2) curve with errors (-3; 3) and derivative errors (-6; 6), and signal (C) is an experimental result on the Membership function (#3) curve with errors (-1; 1) and derivative errors (-2; 2).

In the membership function curve (#1) with the exact difference in the value of errors (-2; 2) and derivative errors (-4; 4) the output signal voltage wave was generated at the time of maximum tracking. In the membership function curve (# 2) with wide differences in the value of errors (-3; 3) and derivative errors (-6; 6) produce non-optimal output signal voltage waveforms when tracking. In the membership function curve (#3) with a narrow difference in the value of errors (-1; 1) and derivative errors (-2; 2). The results of the output signal waveform during tracking are not optimal.

4. Conclusion

The proposed Fuzzy Logic Controller implementation based on dsPIC30F4012 microcontroller is use different membership function curves. Those were three curves are compared to obtain the signal that can reach optimally to the reference signal. In the membership function curve (#1) it produces the proper output voltage signal wave that approaches the reference signal waveform. In the second membership function curve (#2) that is too wide, causes the output signal voltage waveform with the reference signal waveform is less than the maximum value. On the third membership function curve (#3) is too narrow, causes the result in the output voltage signal waveform with the reference signal waveform is less than maximum. The proposed method is used in three different membership function curves. The first membership function (#1) is better than the second (#2) and third membership function (#3) curves. Because the error variables and derivative errors difference in the output voltage signal waveform are approach the reference signal waveform. The results indicate that the Fuzzy Logic Controller has an optimal response and good tracking capability. This proposed method can still be developed using a higher order fuzzy logic controller in future works.

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