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A PC based Fuzzy Controller for DC Voltage Stabilization

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Abstract – A fuzzy based voltage regulator is reported in this paper. The performance of the controller for two popular fuzzy inference models, Mamdani and Sugeno, are studied. The digital implementation of the proposed controller is done using a PC equipped with a data acquisition system. A typical application is shown for a step down switching regulator. A PWM pulse stream of desired width and frequency is generated and communicated to a MOSFET based step down switching regulator. The fuzzy controller makes the necessary adjustments and corrections in the PWM pattern needed for regulating the output voltage. The performance of the controller is studied and found to work well. Design methodology and experimental results are presented.

Keywords -- Fuzzy controller, DC voltage stabilization, PC based controller.

1. Introduction

Classic control theory uses a mathematical model to define a relationship that transforms the desired state (requested) and observed state (measured) of the system into input or inputs that will alter the future state of that system. Classical systems use PID controllers for closed loop control. Both analog and digital versions of PID controllers are used in practice for system control. PID controllers are intended for use with linear systems although it works for non-linear systems also. Tuning of PID controllers needs a structured input output relationship of the system to be controlled. As the complexity of the system increases it becomes more difficult to formulate a mathematical model. Most real world systems are non-linear in nature and the input output relationships are often simplified for control with a PID controller.

Fuzzy controllers on the other hand do not require any mathematical modeling of a system. Fuzzy controllers are built from a number of smaller rules that in general only describe a small section of the whole system. The process of inference binds them together to produce the desired outputs. That is, a fuzzy model has replaced the mathematical one. PC based fuzzy controllers are evolving because of the computation complexity involved. In this paper a new application of a fuzzy controller is reported that can be extended for high power DC voltage stabilization as well as control of speed in a DC motor.

2. Fuzzy Controller

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth, i.e. truth values between "completely true" and "completely false". It was introduced by Dr. Lotfi Zadeh [1] of UC/Berkeley in the 1960's as a means to model the uncertainty of natural language. Fuzzy controllers are conceptually very simple; they consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs to the appropriate membership functions and truth-values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules; and finally the output stage converts the combined result back into a specific control output value. The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and placement.

The general inference process of fuzzy system in a controller is progressed according to the following steps.

Step 1 Under FUZZIFICATION, the membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule premise.

Step 2 Under INFERENCE, the truth-value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule.

Step 3 Under COMPOSITION, all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable.

Step 4 Finally DEFUZZIFICATION is used when it is useful to convert the fuzzy output to a crisp number.

FUZZIFICATION: As input membership functions, three triangular functions are chosen. The range for the error voltage (V_{err}) is from –10 to +10. Membership functions of negative far values (NF), close value (C) and positive far value (PF) are used.

INFERENCE: Crisp input value, V_{err}, is given to input membership functions and corresponding fuzzified values of the input subset is evaluated.

COMPOSITION: The weighted values from input are given to the output membership functions and a subset is formed. The three triangular shaped output membership functions assigned are low value (LV), medium value (MV) and high value (HV).

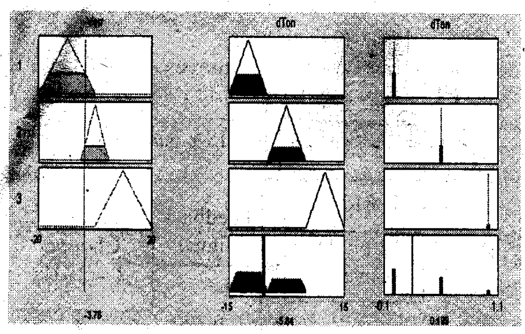

Fig. 1 Fuzzy membership function for Mamdani and Sugeno model.

DEFUZZIFICATION: The difference between Mamdani and Sugeno method lies principally on defuzzificaion method. For Mamdani method, the output crisp value is taken as the CENTROID of the output subset obtained, whereas WEIGHTED AVERAGE is used in Sugeno method.

Formulation for the two models:

The symbols used for the formulation are summarized bellow:

NF: Negative far value — LV : Low value
C : Close value — MV : Medium value
PF : Positive far value — HV : High value

A. Mamdani model

Three input and three output membership functions, each of triangular shape are used for the Mamdani model. The parameter of the membership functions (MF) are shown in Table I.

Table I Input and output membership functions and their parameters for the Mamdani Model.

Input MFs				Output MFs			
	Start	Peak	End		Start	Peak	End
NF	-20	-10	0	LV	-9	-6	-3
C	-0.2	0	0.2	MV	-3	0	3
PF	0	10	20	HV	3	6	9

The shape of a membership function becomes trapezoidal during computation of its contribution to the desired output. A trapezoid can be considered as combinations of two triangles and one rectangle. The output of the three membership functions can be divided into six triangles and three rectangles. Thus for computing the centroid of the crisp output, nine segments are needed. In the proposed controller, the centroid (dT_{on}) is calculated using

$$dT_{on} = \frac{\sum_{j=1}^{9} x_j A_j}{\sum_{j=1}^{9} A_j} \quad (1)$$

where x_j is the distance of the centroid of the segment 'j' having area A_j.

B. Sugeno model:

Three input membership functions of triangular shape and three output functions (standard sugeno spike of unit amplitude) are used in Sugeno model. The parameters of the input and output functions are shown in Table II.

Table II Input and output membership functions and their parameters for the Sugeno Model.

Input MFs				Output Function	
	Start	Peak	End		Spike positions
NF	-20	-10	0	LV	-6
C	-0.3	0	0.3	MV	0
PF	0	10	20	HV	6

The three weighted output spikes are used to calculate the weighted average (dT_{on}) using

$$dT_{on} = \frac{\sum_{j=1}^{3} a_j x_j}{\sum_{j=1}^{3} a_j} \quad (2)$$

where x_j are positions in x-axis and a_j are magnitudes of the corresponding spikes.

Rules for both models:

Three rules are used for composition of output subset from the weighted input values and are same for both Mamdani and Sugeno models.

- Rule 1 If (V_{err} is NF) then (dT_{on} is LV)
- Rule 2 If (V_{err} is C) then (dT_{on} is MV)
- Rule 3 If (V_{err} is PF) then (dT_{on} is HV)

3. Implementation Technique

A chopper is used for dc voltage stabilization as shown in Fig. 2. The input to the chopper is a fixed dc voltage. The output voltage of the chopper is filtered using a half section T filter.

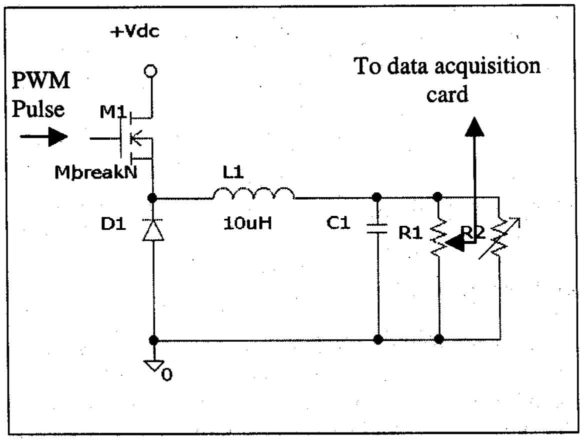

Fig. 2 Step down chopper fed dc voltage stabilizer.

The average output voltage of the chopper is given by

$$V_{out} = V_{dc}\frac{T_{on}}{T} = DV_{dc} \qquad (3)$$

Where, T_{on} is the duration of the pulse within a period T (Fig. 3) and D is the duty cycle ($D = T_{on}/T$).

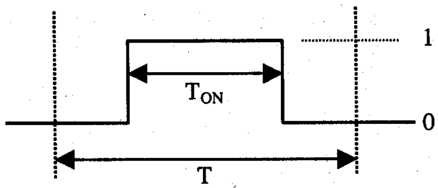

Fig. 3 PWM pulse pattern for the chopper circuit.

The L-C filter acts as an average circuit. The ripple at the output voltage depends on the L-C values and also on the switching frequency f_s ($f_s = 1/T$). In the proposed PC based scheme, the PC is used for computing the appropriate duty cycle (D) needed for stabilizing the output voltage. The real time PWM pattern can be generated from the PC [6] running in DOS mode. For WINDOWS based application, the real time waveforms generated by the PC are affected by other applications [7] and the overall performance degrades. For this reason, the real time PWM pattern for the chopper is generated from an EPROM through a 10 bit binary counter. The PC is directed to act as an intelligent supervisor. The detail scheme is shown in Fig. 4. The dc voltage feedback from the output of the stabilizer is feedback to the PC through a data acquisition system card (DAS PCLS-812PG). The DAS card has a 12-bit A/D converter and can be set to a conversion rate of 30kHz.

PWM patterns of different duties are stored in the EPROM. In the proposed scheme 27C64 EPROM is used. It has 16-bit address and 8-bit data bus. The upper 6 bits (AD_{10}-AD_{15}) of the address bus are used for the PWM pattern selection and the lower 10 bits (AD_0-AD_9) are used for generating the real time PWM waveform.

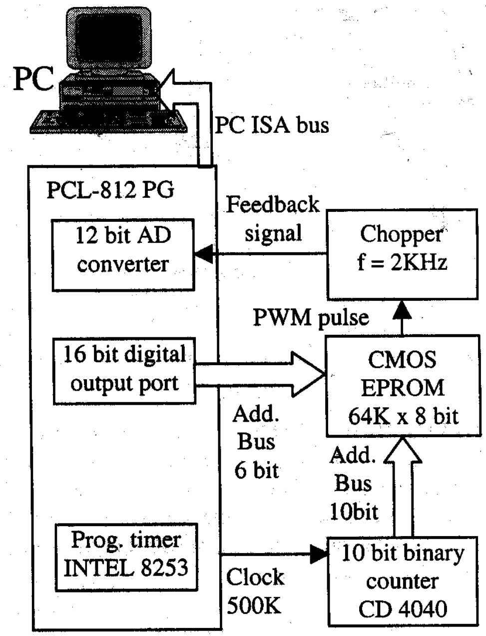

Fig. 4 Block diagram of the proposed PC based dc voltage stabilization scheme.

With this setup upto 64 different patterns (duty cycles) can be accessed. The setting of minimum and maximum duty cycle of the chopper depends upon the input and output voltage ratio and also on the limit of disturbance. In the experimental setup the minimum and maximum duties are set to 5% and 95% respectively. The duty is mapped to the desired PWM pattern of the EPROM using

$$EPROM_{address} = \left(\frac{D - D_{min}}{D_{max} - D_{min}}\right)2^6 - 1 \qquad (4)$$

The PWM pattern at the starting address of the EPROM $(0000000000000000)_b$ to $(0000011111111111)_b$ are set to zero. During reset state the EPROM is assigned this starting address ensuring OFF state of the chopper in idle condition. The real time waveform is generated at the D_0 line of the data bus. The analog feedback voltage is acquired through the DAS A/D converter. The digital output of the converter is weighted and this feedback voltage is deducted from the desired voltage. This gives an error voltage (V_{err}). The crisp error voltage is then supplied to the fuzzification process. Two popular fuzzy models, Mamdani and Sugeno are used. After defuzzification, a crisp value is obtained for the error correction. The crisp output value from the fuzzification process is used to determine the new duty cycle for the chopper by

$$D_{new} = \frac{T_{on} + dT_{on}(\text{fuzzy value})}{T} \qquad (5)$$

A new address of the PWM pattern is then evaluated using (5).

A. Software Program

A real time program is written to accomplish the fuzzification process, operating the Lab-card and selecting the appropriate PWM pattern. A flow chart for the program is shown in Fig. 5. The program starts with initializing the DAS card and the timer clock frequency. A desired value of output voltage is set within the program that can be changed on-line during the program execution using the keyboard. The digital value of the analog feedback voltage from the AD converter is then acquired and error voltage is determined. This error voltage is used as the crisp input value for the fuzzy processor. The program has options to select either the Mamdani model or the Sugeno model. The output value of the fuzzy process is checked.

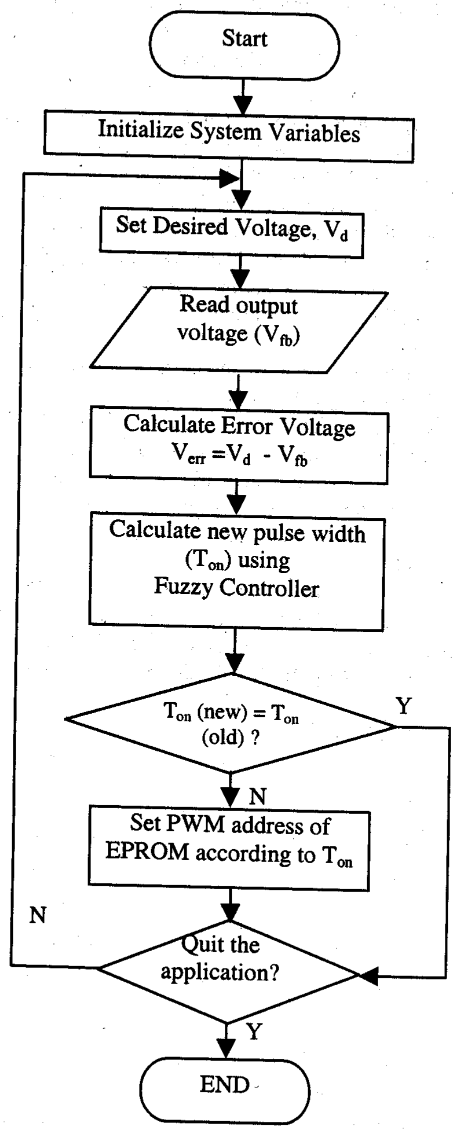

Fig. 5 Program flowchart of the fuzzy controller.

If any modification of the PWM pulse is required, it is done by changing the address value of the EPROM accessed by the digital output port of the Lab-card. Then the program searches for any user request. If a quit request is got from the keyboard, the program stops all the running processes and resets the PWM data to 0% duty (starting PWM address of the EPROM). Otherwise the program repeats the normal loop.

4. Experimental Results

The proposed fuzzy controlled dc voltage stabilizer is built in the laboratory and tested on a prototype chopper. One counter of 8253 of the DAS card is set to square wave clock generator mode at a frequency of 500KHz. The chopper is driven from a 12V-dc supply. An inductor of 1mH and a capacitor of 4700μF and a load of 96Ω are used for the chopper. The start up, steady state and dynamic state responses of the controller are studied for both Mamdani and Sugeno models. The reference voltage is set to 6V.

The steady state performance of both the models are comparable. The chopper frequency is set to 2kHz. This is a comparatively low frequency for stabilizer applications. This frequency is chosen intentionally to see the behaviour of the controller that can be extended to chopper based dc motor control.

The dynamic response is experimented for a sudden load change (load current doubled). In the Sugeno model, defuzzification process is relatively simpler than Mamdani model. For this reason, processing time in Sugeno model is less, making the system response faster. This fast response has the disadvantage of more oscillations about the final value. On the contrary, the Mamdani model is comparatively slow in response but have lesser oscillation. The start up settling time in the Mamdani model is 1.4 second (Fig. 6), whereas in the Sugeno model it is 0.75 second (Fig. 8). The peak overshoots for the two models are 0.3V and 0.35 V respectively. The dynamic response is recorded for a sudden load change from 62.5 mA to 127.7 mA. In the Mamdani model, the time taken to settle the voltage to previous level is 0.52 second (Fig. 7) and in Sugeno model it is 0.4 second (Fig. 9). Peak overshoot/undershoot for Mamdani is 0.26V and that of Sugeno is 0.3V.

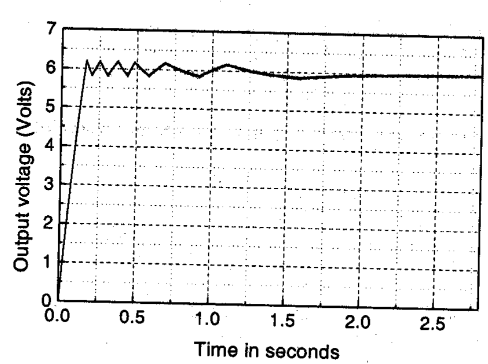

Fig. 6 Startup response with Mamdani model.

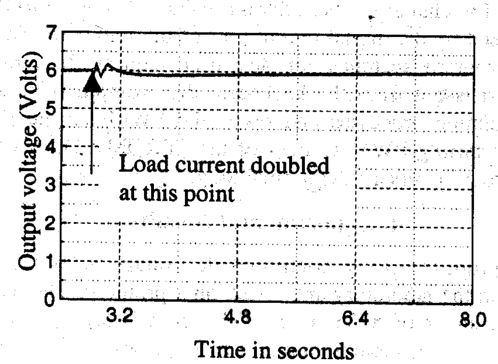

Fig. 7 Dynamic state response with Mamdani model.

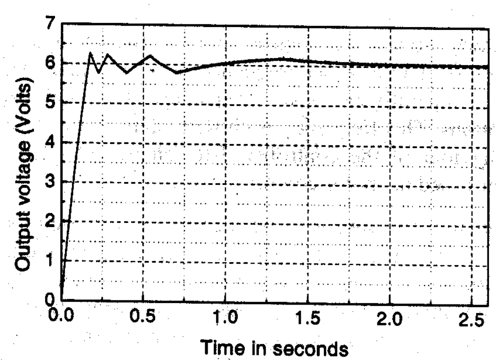

Fig. 8 Startup response with Sugeno Model.

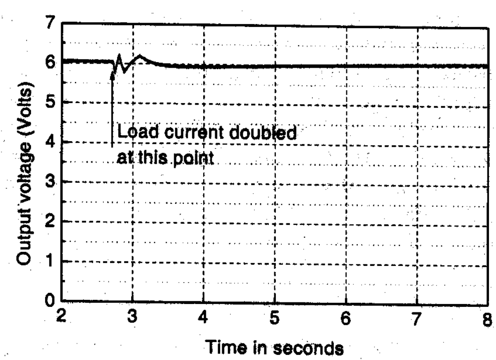

Fig. 9 Dynamic state response with Sugeno model.

5. Conclusion

A new application of Fuzzy Controller is presented in this paper for DC voltage stabilization. Two different fuzzy models are applied for realization of the controller. The performances of both models are found comparable. The Sugeno model is computationally faster than the Mamdani model. The controller is experimentally tested with a Pentium III 450MHz PC. In the proposed design only three membership functions are used. The steady state and dynamic response of the controller found very good for both models. There are scopes of further improvement by fine tuning the circuit parameters as well as increasing the number of membership functions. The computation time of the fuzzy controller is not very high and can be implemented with any 32-bit processor.

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