PARITANTRA
Vol. 9, No. 1
JUNE 2004

FUZZY REMOTE CONTROLLER FOR CONVERTER DC MOTOR DRIVE

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Abstract: *In this paper fuzzy speed and current controllers are proposed for closed loop speed control of a converter fed dc motor drive. The performance of the fuzzy controlled system is compared with that of P-I controlled system to establish its suitability. The controller is implemented in a 486 based PC, and attempt is made to control the motor from a remote operating point via FM transmitter and receiver.*

1. INTRODUCTION

DC motor drive is a good choice for high performance motion control systems requiring four-quadrant operation including field weakening, minimum torque ripple, rapid speed recovery under impact load torque in addition to fast dynamic torque and speed responses. Development of a high performance controller to ensure competitive, robust and reliable speed/position controlled dc drive is a topic of interest of many researchers. The Proportional-cum-Integral (P-I) controller was so far the most widely used controller for dc drives [1].

Fuzzy logic, the logic of approximate reasoning, continues to grow in importance, as it provides an inexpensive solution for controlling ill-known complex systems. Fuzzy logic controllers [2] are already used in appliances, computer subsystems, industrial systems, automotive-related applications, consumer electronics, and so on. In last decade, fuzzy controllers have received adequate attention in motion control systems, as the later possess nonlinear characteristics, and a precise model is most often unknown. Fuzzy controller is already applied to phase controlled converter dc drive [3], linear servo drive [4], and induction motor drive [5-6].

Remote controllers [7] are increasingly being used to control a system from a distant place due to inaccessibility of the system or for comfort reasons. In this work, a fuzzy remote controller is developed for speed control of a converter fed dc motor. The performance of the fuzzy controller is compared with conventional P-I controller.

2. CONTROLLERS FOR DC DRIVE

The schematic diagram of the dc drive system is shown in Fig. 1. The power circuit consists of a three phase, fully controlled bridge converter that drives a separately excited dc motor. For simplicity, the converter drive system is used in motoring mode only with fixed field excitation. Inner current control loop is provided in addition to the speed control loop to achieve fast transient response as well as to limit the armature current. The output of the current controller is the control voltage V_c for the converter firing circuit. The firing pulses for the SCRs are generated with a delay angle α, by cosine wave crossing method. The speed and current controllers in Fig. 1 may be P-I controllers or fuzzy logic controllers. The design methodology for both type of controllers are discussed below.

2.1. P-I Controller

P-I controllers are designed for the drive system using transfer function approach. The block diagram of the dc drive system with P-I controllers is shown in Fig. 2. K_P and K_I are the proportional and the integral gains of the P-I speed controller respectively. The output of the P-I speed controller is the current reference, I_{ref}. Only a proportional controller of gain C_1 is used in the current loop. Gain of the power converter is K_C. The electrical time constant of the motor is neglected, since it is very small compared with the mechanical time constant. The gain of the tacho-generator and current transducer are taken as unity.

The transfer function between the motor speed ω and reference speed ω_{ref} is given by

$$\frac{\omega(s)}{\omega_{ref}(s)} = \frac{A\,K_P\,s + A\,K_I}{K_1\,s^2 + K_2\,s + K_3} \qquad (1)$$

where, $A = C_1\,K_C\,K$

$$K_1 = J\,(R_a + C_1\,K_C) \qquad (2)$$

$K_2 = R_a\,B + K^2 + C_1\,K_C\,B + A\,K_P$

$K_3 = A\,K_I$

R_a, K, J and B are the motor constants given in Table 1. In order to design the P-I speed controller for this dc motor drive, taking $C_1 = 1$, and using Modulus Optimum method [8]

$$A\,K_P \approx K_2 \qquad (3)$$

and, $(A\,K_P)^2 = 2\,(A\,K_I)\,K_1$ (4)

But from eqn. (2), $K_2 = A\,K_P + 0.357$ (5)

Eqns. (3) and (5) are reasonably satisfied when

$$A\,K_P = 200 \times 0.357 = 71.4 \qquad (6)$$

Substituting the value of A from eqn. (2), in eqn. (6):

$$K_P = 10 \qquad (7)$$

Substituting the values of A, K_1 from eqn. (2) and K_P from eqn. (7), in eqn. (4) we get

$$K_I = 565 \qquad (8)$$

With these gain values, the P-I speed controller is simulated and realized by the discrete time equation:

$$I_{ref}(n) = I_{ref}(n-1) + K_P\,[e(n) - e(n-1)] + K_I\,e(n)\,T_s \qquad (9)$$

where, $e(n) = \omega_{ref}(n) - \omega(n) =$ the speed error at n^{th} sampling instant

I_{ref} (n) = reference current at n^{th} sampling instant

T_s = sampling time

Output of the proportional current controller at n^{th} sampling instant is given as:

$$V_c(n) = C_1\,[\,I_{ref}(n) - I(n)\,] \qquad (10)$$

where, I = dc motor armature current

TABLE 1 - PARAMETERS OF DC DRIVE

DC Motor: 2.5 hp, 110 V, 20 A, 1800 rpm
R_a =0.6 Ω, L_a = 8 mH, K = 0.55 V.sec/rad
J = 0.0465 Kg.m^2, B = 0.004 N.m.sec/rad
Converter: K_C = 13, Input line voltage = 90 V

2.2. Fuzzy Controller

Fuzzy controllers are used in the speed and current loops in Fig. 1, replacing the conventional P-I controllers. The objective is to explore the control robustness in the presence of parameter variation, load disturbance and noise. The same fuzzy control strategy is used for both speed and current loops.

The basic structure of a fuzzy controller is shown in Fig. 3. The input variables in the fuzzy rule base are:

$$E(n) = R(n) - C(n) \qquad (11)$$

$$CE(n) = E(n) - E(n-1) \qquad (12)$$

where, E(n) = loop error at the n^{th} sampling instant

CE(n) = change in loop error

R(n) = reference signal

C(n) = output signal

These input variables are first normalized and expressed in per unit quantities as follows:

$$e = E(n)/GE, \quad ce = CE(n)/GCE \qquad (13)$$

where, GE and GCE are the respective normalization factors. These normalized inputs ***e*** and ***ce*** are fuzzified by a three member fuzzy set:

{ **P** : Positive, **Z** : Zero, **N** : Negative }

The degree of membership (μ) of ***e*** and ***ce*** in each subset are computed by using the membership functions, shown in Fig. 4-a. The fuzzy control rules are listed in Table-2. The structure of a typical rule is given as: IF ***e*** is **P** AND ***ce*** is **P** THEN ***du*** is **LP**. Where, ***du*** is the change in normalized controller output, or the change in control setting. The attributes of the fuzzy controller output ***du*** (shown in Fig. 4-b) are:

{**LP**: Large Positive, **MP**: Medium Positive, **Z**: Zero, **MN**: Medium Negative, **LN**: Large Negative}

Degree of membership of the control output ***du*** for each rule is computed by '*Zadeh **AND***' or

MINIMUM operator. For the rules having same linguistic control output, the final degree of membership is found out by '*Zadeh* ***OR***' or MAXIMUM operator. Then the resultant crispy value of ***du*** is calculated by Center-of-Height defuzzification method [9]. In this method, for the output membership functions shown in Fig. 4-b, the defuzzified output is given as:

$$\boldsymbol{du} = (- \mu_{LN} - 0.5 \times \mu_{MN} + 0.5 \times \mu_{MP} + \mu_{LP}) / \mathbf{S} \qquad (14)$$

where, $$\mathbf{S} = \mu_{LN} + \mu_{MN} + \mu_{Z} + \mu_{MP} + \mu_{LP} \qquad (15)$$

Then the next control signal is given as:

$$U(n) = U(n-1) + GU \times \boldsymbol{du} \qquad (16)$$

Where, GU = denormalization gain factor

Symmetrical triangular membership functions are selected for both inputs and output for their ease of realization. For the fuzzy speed controller, R and C in eqn. (8) are ω_{ref} and motor speed ω respectively. The output (U) of the speed controller is the current reference I_{ref}. For the current controller, R and C are I_{ref} and the motor armature current I respectively, and output U is the control voltage V_c for the converter firing circuit. The gain factors GE, GCE and GU are normally different for the speed and current controllers. A trial-and-error iterative approach is taken to compute these gain factors.

TABLE 2- FUZZY CONTROLLER RULE BASE

Error, ***e***	Change in error, ***ce***	Control output, ***du***
P	P	LP
	Z	MP
	N	Z
Z	P	MP
	Z	Z
	N	MN
N	P	Z
	Z	MN
	N	LN

3. REAL TIME IMPLEMENTATION

A prototype system has been developed and tested in order to evaluate the performance and the implementation problems of the proposed control scheme. The realized system consists of a three phase fully controlled SCR converter feeding a separately excited DC motor, converter firing circuit based on cosine wave scheme, a tacho-generator for speed feedback, a current transducer, and a digital control system based on a 486 PC along with PCL-718 interfacing card. A remote controller is also developed, and the reference speed signal is applied to the PC controlled system from a distant point through the remote controller. The block diagram of the remote controller is shown in Fig. 5. In the remote controller, the reference speed signal is applied to a voltage controlled oscillator (VCO). The output frequency signal of the VCO is modulated and transmitted by a ready-made FM transmitter. This signal is received near PC by a ready-made FM receiver and demodulator. The demodulated signal is then passed through amplifier, zero crossing detector, monostable multivibrator, filter and level shifter in sequence, before being fed to the PCL-718 card. Averaging technique is used in the software to eliminate noise.

4. RESULTS AND DISCUSSIONS

In order to validate the control strategies as described above, digital simulation and experimental investigation were carried out on a converter dc motor drive system whose parameters are given in Table-1. A comparative study of the results obtained with P-I controller and fuzzy logic controller is presented in this section.

The step response of the drive system is obtained by giving a large step change in the reference speed (from 680 rpm to 1360 rpm for the P-I controller and 750 rpm to 1400 rpm for the fuzzy controller). Corresponding results are given in Fig. 6. Step change in the reference speed is also given through the remote controller. Corresponding results for a speed change from 880 rpm to 1280 rpm with P-I controller, and for a speed change from 1000 rpm to 1280 rpm with fuzzy controller are given in Fig. 7. Results in Fig. 6 and Fig. 7 show that the fuzzy controller performs slightly better than the P-I controller, though the difference is not much.

To see the effect of sudden load change on drive performance, the motor is loaded by a dc generator. The set-up is made to run at a certain speed (nearly 1000 rpm) on no load. After certain time the generator is loaded to about 50% of the rated load and response is shown in Fig. 8. Then the load is switched off and response is shown in Fig. 9. To study the effect of ac supply voltage change on the drive performance, a voltage variation of 20% of the rated voltage is made and the corresponding response is shown in Fig. 10. From Fig. 8 to Fig. 10, it can be observed that fuzzy controller performs as good as P-I controller.

Random tracking from a remote point is also carried out and response is shown in Fig. 11 for the fuzzy controller. Drive system with P-I controller failed to track randomly varying reference signal.

In spite of the advantages in fuzzy control, the main limitations are the lack of a systematic design methodology and the difficulty in predicting stability and robustness of the controlled system. A trial-and-error iterative approach is taken for the controller design, which is time consuming. A few other difficulties in fuzzy control are: (1) Lack of completeness of the rule base. The controller must be able to give a meaningful control action for every condition. (2) There is no definite criterion for selection of the shape of membership functions, degree of overlapping of the subsets and the level of quantization. So there exist ample scope for improvement of the fuzzy controller used in the present study.

5. CONCLUSIONS

This work is intended to demonstrate the successful application of fuzzy logic control to a phase controlled converter dc motor drive. Fuzzy logic was used in the design of speed and current controllers of the drive system, and the performance was compared with that of conventional P-I controlled system. Although there exists ample scope for improvement of the fuzzy controller, the comparative study indicates the superiority of the fuzzy controller over the P-I controller. The same speed and current control algorithm are also applicable to vector controlled ac drives

In addition to above, control of the speed from a remote place with the help of noise immune technique like FM, made this drive system, compatible with industrial environments where the noise is unavoidable.

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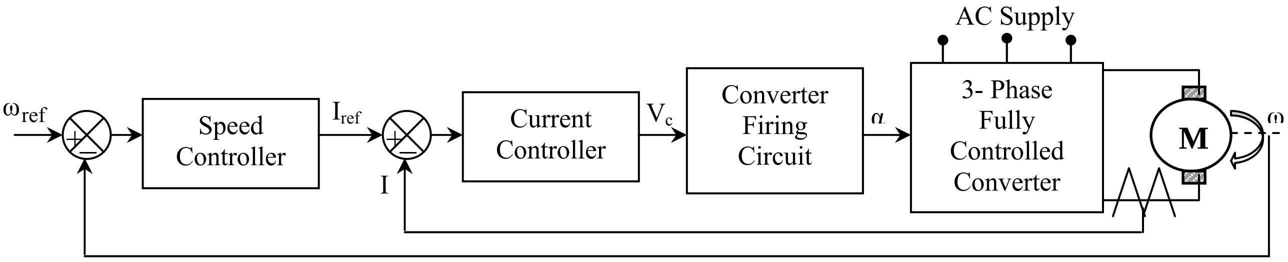


Fig.1 Schematic diagram of the dc drive system

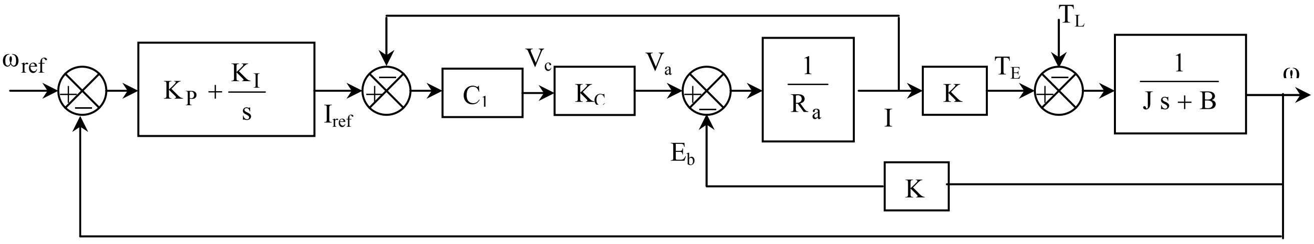


Fig. 2 Block diagram of the dc drive with P-I controller

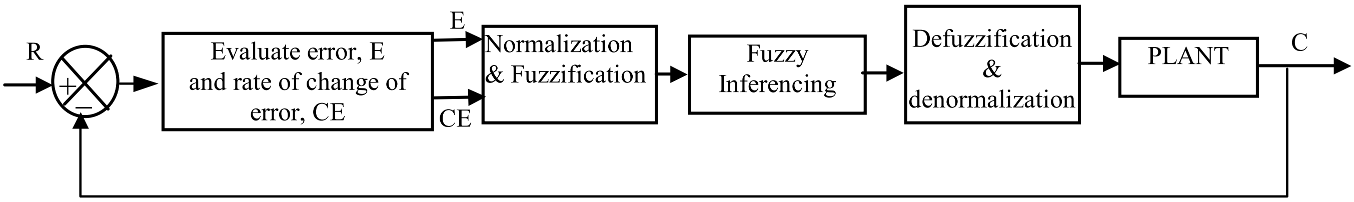
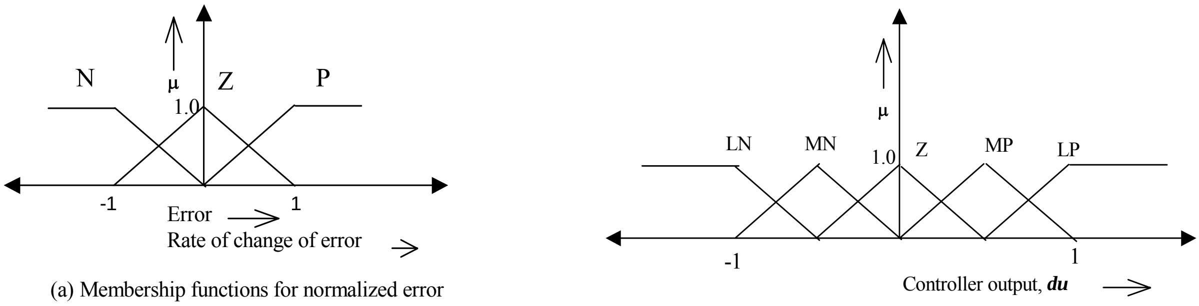


Fig. 3 Basic structure of a fuzzy controller



(a) Membership functions for normalized error and rate of change of error

(b) Membership functions for normalized output

Fig.4 Membership functions for the normalized inputs and output

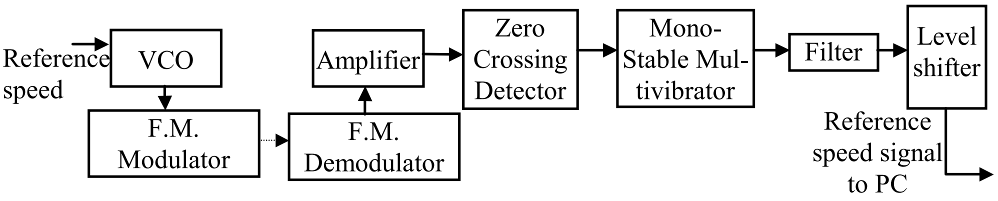


Fig. 5 Block diagram of the remote controller

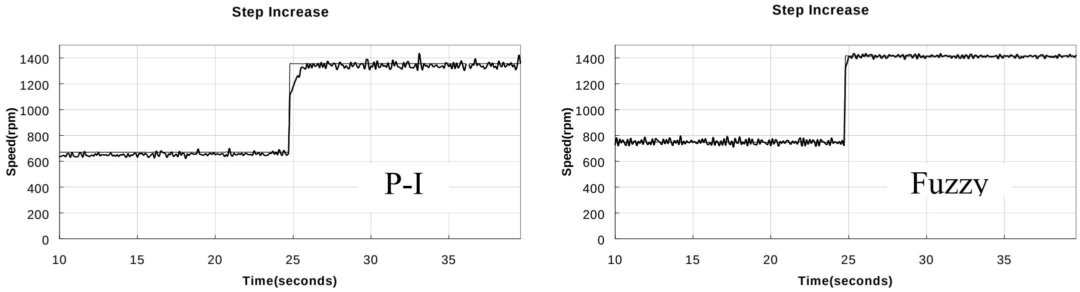


Fig. 6 Increasing the speed reference at a local point (near PC)

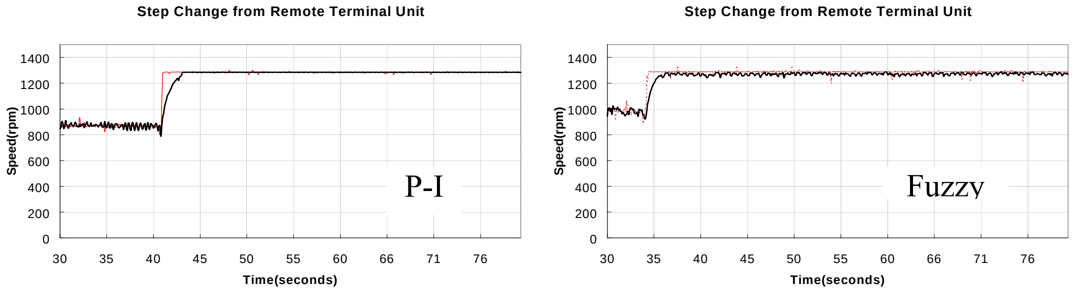


Fig. 7 Control from the remote unit

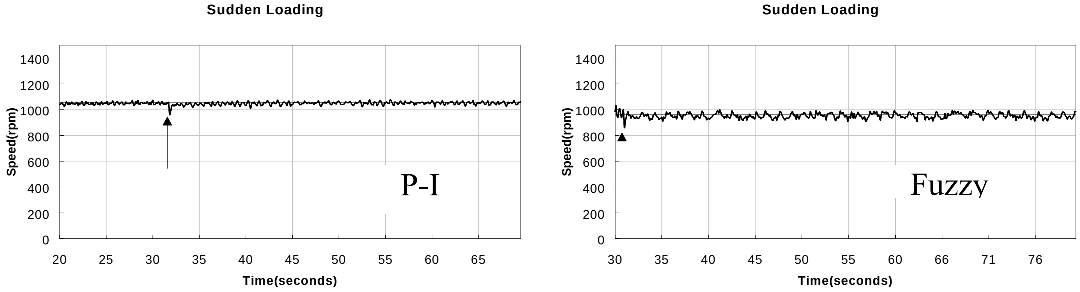


Fig. 8 Sudden loading (From No load to about 50% load)

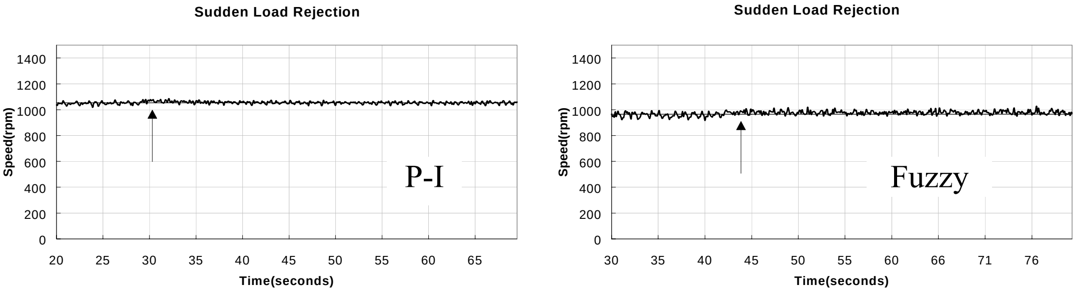


Fig. 9 Sudden load rejection (about 50% load to No load)

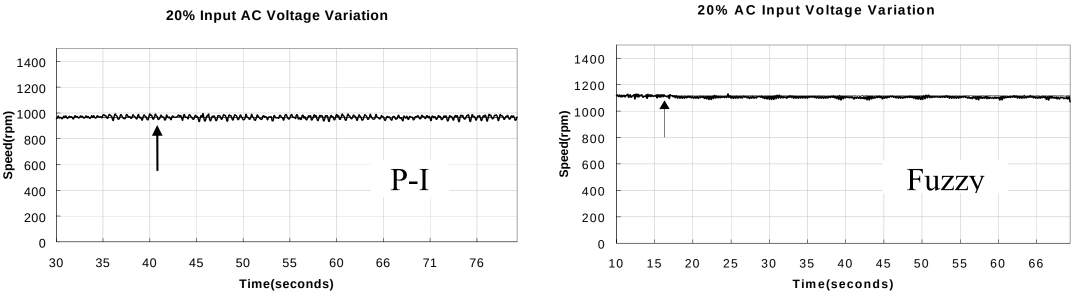


Fig. 10 20% Input voltage variation

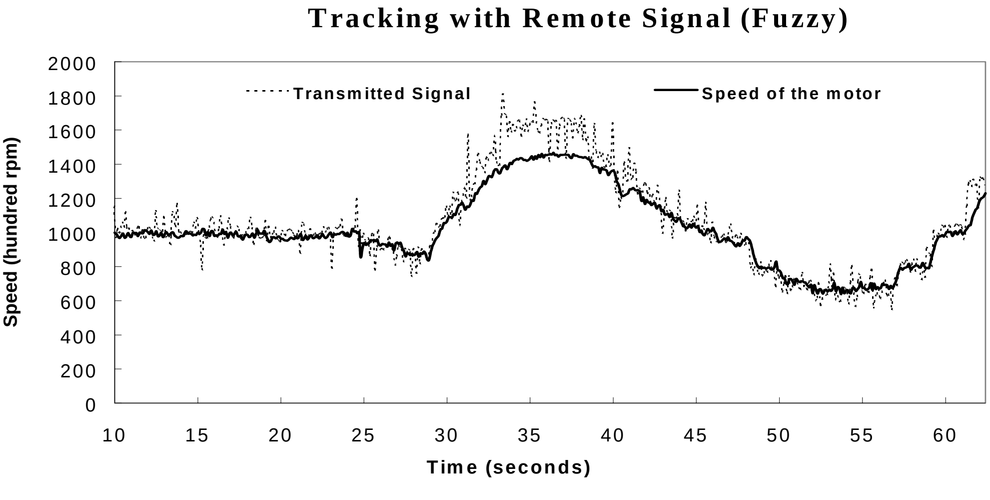


Fig. 11 Tracking from remote point