FUZZY IMPLEMENTATION OF MODEL REFERENCE ADAPTIVE CONTROL OF DC DRIVES

K. Keerthi[1] , M.Siva Sathyanarayana[2]

[1]*M.Tech student,Electrical & Electronics Engineering,G.Pullareddy Engg. College,A.P.,India,***kirthi.veeny@gmail.com**
[2]*Associate Professor, Electrical & Electronics Engineering,G.Pullareddy Engg. College,Andhra Pradesh.,India*
sathya_varma@rediffmail.com

Abstract

Now a days DC drives are being used in versatile variable speed applications in industries. A separately excited DC motor is taken as a plant. The dynamic behaviour of a DC motor varies with the moment of inertia, friction of the load, temperature etc. which are evident from the applications such as rolling mills, wiring machines and tracking telescope. Non-linearities cannot be neglected when the system works close to the rated conditions. The most important non-linearity in DC drive is the saturation of the magnetic core, which determines the non-linear growth of both the flux and voltage when the field current increases. Converter bridge also introduces some structural perturbations when the firing angle varies. Hence high performance control systems are needed mainly for two reasons. The first reason is concerned with the needs of the process, either in terms of steady state error or dynamic performance. The second one arises from the economic demand for the maximum utilization of costly power. All these pointing to the need of high performance control system.

Intelligent, self-learning or self-organizing controls using expert systems, fuzzy logic and neural networks have been recently recognized as important tools to enhance the performance of power electronic systems. The combination of intelligent control with adaptive control appears today the most promising research accomplishment in the drive control area and in the meantime, as the best approach for the optimal exploitation of intelligent control and practical realization of adaptive motor drives.

This paper deals with the conventional model reference adaptive control (MRAC) and replaces conventional control technique such as PI control with model reference fuzzy adaptive control (MRFAC) scheme . The Model Reference Adaptive Control (MRAC) speed control systems do not achieve consistent satisfactory performance over wide range of speed demand, especially at low speed and there is no defined rule to guide designers to choose the adaptation gains. The fuzzy logic model reference adaptive control maintains satisfactory response irrespective of the magnitude of the inputs. It enhances the performance of the DC drive compared to conventional MRAC. The performance of the drive system, thus obtained, is forming a set of test conditions with model reference fuzzy adaptive control. The performance of the drive is tested for load disturbances along with reference model. This work compares the performance of Model Reference Fuzzy Adaptive scheme over conventional MRAC. This work is carried out by using MATLAB-SIMULINK.

Index Terms: *DC motor, Fuzzy Logic, Speed Control, Model Reference adaptive control (MRAC), Model Reference Fuzzy adaptive control (MRFAC), Reference model(RM)*

--- *** ---

1. INTRODUCTION

Model reference adaptive control (MRAC) is one of the ways to deal with the uncertainties of plants.Industrial drives are usually subjected to uncertainties in many ways and MRAC such drives are quite capable of dealing with these problems. Model reference fuzzy adaptive controller (MRFAC) of DC drives subjected to disturbances and uncertainties avoids all these complexities. It does not require state variable filters.

Well –established simple linear control techniques are used for the stability studies. A stable reference model (RM) which decides the degree of stability (DS) of the complete scheme is selected such that, its steady state speed is the same as the desired speed of the plant. The objective of the adaptive controller is to make the plant output (the speed (ωd) for dc drive) to follow the desired speed(ωm) specified as the output of the chosen stable RM. It incorporates the simple well-known proportional plus integral adaptive law and generates an input to the plant (which consists of the converter and dc drive) such that the scalar output error(ed) between the outputs of the plant and RM approaches zero .In the present work, a fuzzy adaptive process is developed and used instead of conventional algorithms in MRAC speed control system. Such a fuzzy adaptive process is based on a suitable set of fuzzy rules, which are carried out from the knowledge on the behavior of the control system. Fuzzy adaptive control scheme combines fuzzy logic control and adaptive control for controlling nonlinear, time-varying and structurally partially known system. A fuzzy adaptive controller can generate or modify a fuzzy controller's knowledge base in order to cope up with nonlinear and time varying characteristics of the system so that the closed loop system meets the desired specifications

2. SYSTEM DESCRIPTION

The entire MRAC scheme is shown in Fig.1. The scheme consists of a poorly known plant, which is separately excited dc drive supplied through a converter whose gain may vary with the operating point, the appropriately chosen stable RM which governs the DS of the entire scheme and the adaptive controller. The moment of inertia of the drive consists if the combined moment of inertia of the motor and load that may vary with time as in rolling mills.

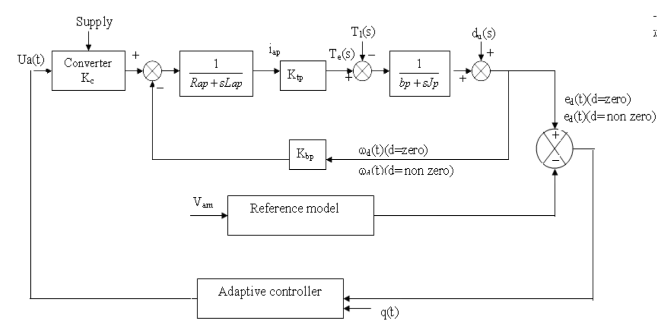

Fig 1. MRAC scheme of DC drive

The plant consists of a dc drive incorporating a separately excited dc motor, fed through a converter whose gain is Kc.

There are three inputs to the plant, namely, the input signal to the plant or adaptive controller output Ua, load torque Tl and output disturbances due to uncertainties du. The resultant or ultimate speed of the plant is given by□ □ □ □ □ □ □

$$\omega_d = \omega_0 + d_1 + d_u = \omega_0 + d \text{.......(1)}$$

Where $d = d_1 + d_u$

The dynamics of a separately excited dc motor with negligible load torque and disturbances due to uncertainties is governed by

$$\frac{d\omega 0(t)}{dt} = \dot{\omega} 0(t) = \frac{Bp}{Jp}\omega 0(t) + \frac{Kap}{Jp} iap(t) \text{ ....(2)}$$

$$T_c = K_{ap} i_{ap}(t) \text{ ......(3)}$$

The motor is fed from a converter, whose input is obtained as the output of adaptive controller Ua and it is expressed as

$$\frac{diap(t)}{dt} = \dot{iap}(t) = -\frac{Kap}{Lap}\omega 0(t) - \frac{Rap}{Lap} iap + \frac{KcUa(t)}{Lap} \text{ ....(4)}$$

The transfer function of the plant with no load torque and uncertainties (Ua≠0, dl≡0,du≡0) is obtained from (2), (3) and (4) as

$$Gp(s) = \frac{\omega 0(s)}{Ua(s)} = \frac{Kp}{S^2 + a1pS + a0p} \text{ ....(5)}$$

Where

$$\left.\begin{aligned} a1_p &= \frac{B_p}{J_p} + \frac{R_{ap}}{L_{ap}} \\ a0_p &= \frac{B_{ap}R_{ap} + K_{bp}K_{tp}}{J_{ap}L_{ap}} \text{ .....(6)} \end{aligned}\right\}$$

$$K_p = \frac{K_{bp}K_c}{J_p L_{ap}}$$

First let us consider the case with only load disturbances

(Tl≠0)

$$dl(s) = \frac{-Tl(s)(R^1ap + sL^1ap)}{s^2 + a1ps + a0p} \text{ ....(7)}$$

Where

$$R^1{}_{ap} = \frac{R_{ap}}{J_{ap}L_{ap}} \quad , \quad L^1{}_{ap} = \frac{1}{J_p}$$

Similarly, when load torque and uncertainties in the input supply are present, the resultant speed is obtained from equations (1),(5) and(7) as

$$\omega d(s) = \frac{Ua(s) - Tl(S)(R^1 ap + sL^1 ap)}{s^2 + a^1 ps + a0p} + du(s) \quad \text{....(8)}$$

A stable second or first order reference model is chosen whose pole position decides the stability of the whole system. The input to the reference model is Vam for an output of ωm,

This is the desired speed response of the plant.

The parameters of the reference model is selected such that the poles of transfer function are positioned at -am' and –am" in the left half of the s-plane.

The transfer function Gm(s) of the reference model is

Defined as

$$Gm(s) = \frac{\omega_m(s)}{V_{am}(s)} = \frac{K_m}{(s + a'm)(s + am'')} = \frac{K_m}{s^2 + a^1 ms + a0m} \quad \text{....(9)}$$

Where

$$a^1 m = am' + am'' \ \& \quad a^0 m = am' am''$$

The adaptive controller generates the plant input signal

Ua(t) which is expressed as follows with Ua(t) known as adaptive control due to absence of multipliers. The adaptive controller output Ua (t) is:

$$\left.\begin{aligned} U_a(t) &= K(t)q(t) \\ m(t) &= e_d(t)q(t) \end{aligned}\right\} \quad \text{.....(10)}$$

Where K (t) - adjustable gain vector ,q (t) - driving signal vector, ed(t) - error signal vector and m (t) - gain vector

The adaptive control employed here offers several

advantages and renders the adaptive scheme simpler. There is no need to get all the states of the plant. Also there is no need of state variable filters.

The adjustable gain vector k(t) can also be varied according to PPI law which is expressed as

$$k(\dot{t}) = \delta(\dot{t}) = -G_1 m(t) - G_2 m(t) \quad \text{.....(11)}$$

$$.\, m(t) = q(t)e_d(t)$$

Where

$$G_2{}^{\mathrm{T}} = G_2 = g_2 \mathrm{I}, g_2 > 0$$

The error signal ed(t), is derived as follows. Let the error vector between the plant and the reference model states be defined as from (1)

$e\ (t) = x_p(t) - x_m(t)$ ….(12)

Let e_d (t) and e_0 (t) represents the error when the disturbance is present and when disturbance are absent.

That is

$$e_0(t) = \omega_0(t) - \omega_m(t) \quad \text{....(13)}$$

When the disturbances are present, the error in the output speed e_d (t) is obtained as

$$e_d(t) = \omega_d(t) - \omega_m(t) \quad \text{....(14)}$$

(2.16)

Incorporating (13)and(14) becomes

$$e_d(t) = \omega_0(t) + d(t) - \omega_m(t)$$

$$e_d(t) = e_0(t) + d(t)$$

The adaptation process can be explained on the basis of the control laws explained above. When the scalar speed error ed(t) converges to zero, from(11) , this implies that k(t) converges to a constant vector, signifying the end of the adaptation process. At this the control input to the plant also converges to a constant value and □d(t) converges to □m(t), which is the objective of the MRAC scheme.

Further, the elements of □ (*t*) settles down to constant value (which need not be zero). However, if by any chance, due to disturbances or any changes in the reference input to the reference model □d(t) differs from □m(t), the adaptation process starts again till error between□□d(t) and □m(t) converges to zero.

3. FUZZY IMPLEMENTATION OF MRAC

In Model Reference Adaptive Control (MRAC) scheme, the adaptive gain k(t) is varied according to an adaptive law. The same can be obtained by fuzzy logic methods, which results in Model Reference Fuzzy Adaptive Control (MRFAC) scheme.

A schematic representation of MRFAC scheme is shown in Fig. 2 To enhance the control performance, a reference model can be adopted to generate the desired response trajectory, and the error between the outputs of the reference model and the plant is used to drive the fuzzy controller. The reference model is chosen according to the control specifications and the speed controller of the drive is a simple proportional type.

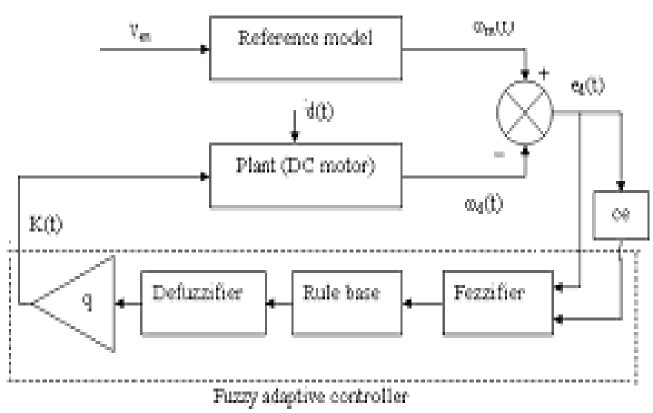

Fig.2. Basic control diagram for MRFAC scheme

3.1. Design of Fuzzy Adaptive Controller:

To design the fuzzy adaptive controller, the model following dynamic is analyzed first, as follows [1]. The dynamic signal analysis of the speed tracking response is implemented to acquire some information concerning the plant before designing a fuzzy controller. A step command is issued at the beginning of the time axis, as shown in Fig. 3. and the desired motor speed step tracking response of the fuzzy adaptive controller and the output of the reference model are also sketched in Fig.3. The error (e) and error change (ce) are defined as

$$e(k) = \omega m(k) - \omega d(k)$$

$$ce(k) = e(k) - e(k-1)$$

Where

$\omega m(k)$ = the response of the reference model at kth sampling

Interval;

$\omega d(k)$ =the rotor position signal at kth sampling interval;

e (k) =The error signal at kth sampling interval;

ce (k) =The error change signal at kth sampling interval.

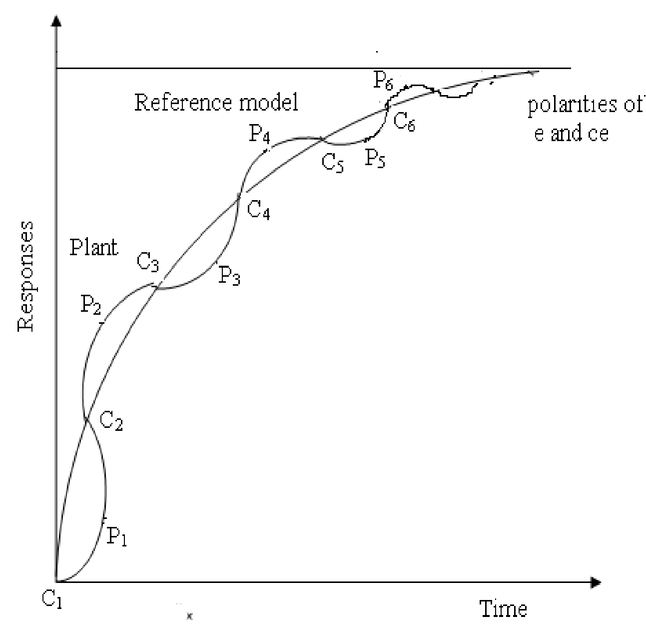

Fig.3. Model following characteristics in Model Reference Fuzzy Adaptive Control

3.2. Construction of Fuzzy Rule:

ce \ e	NB	NM	NS	ZE	PS	PM	PB
NB				C_2			
NM	A_3	A_7		C_4		A_2	A_6
NS			A_{11}	C_6	A_{10}		
ZE	P_2	P_4	P_6	ZE	P_5	P3	P1
PS			A_{12}	C_5	A_9		
PM	A_4	A_8		C_3		A_1	A_5
PB				C_1			

Table 1. The indexes in the state plane

The fuzzy IF-THEN rules from human operators provide good control strategies, and then the adaptation will converge quickly.

ce CI \ e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZE	ZE
NM	NB	NM	NM	NS	NS	ZE	ZE
NS	NM	NM	NS	NS	ZE	ZE	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	ZE	ZE	PS	PS	PM	PM
PM	ZE	ZE	PS	PS	PM	PM	PB
PB	ZE	ZE	PS	PM	PM	PB	PB

Table 2. The Linguistic Rule Base Table

3.3. Membership Functions:

The input to the fuzzy controllers is selected as error (e) between the DC drive and the reference model speed, and change of error (ce) .The membership functions used for input variables is shown in Fig.4.Triangular membership functions are chosen because of its simplicity. Bisector method is used as defuzzification method.

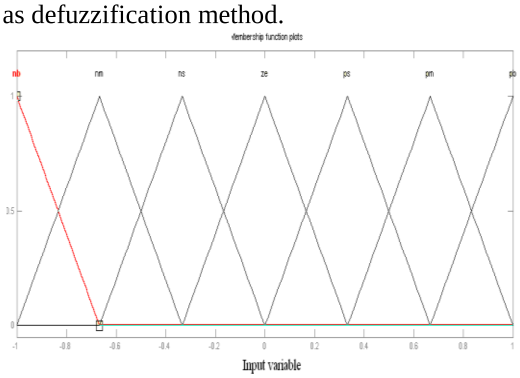

Fig 4. Input membership function (error (e) and change of error (ce))

4. SIMULATION RESULTS

The simulation has been performed with the help of software named Simulink. In this study a 3 hp, 240 V, 1500 rpm separately excited DC Motor is considered for simulation purpose. The different parameters of the systemareKc=10,Ktp=0.55,Rap=1.0Ω,Lap=0.046Ω,Jp=0.093 Kg-m2 Bp=0.08Nm/s/rad.with transfer function of the RM as 150/s2+10s+24 with poles -6, -4,PI controller specifications are integral gain (Ki)=3.proportional gain(Kp)=16

4.1. Conventional MRAC of DC drive

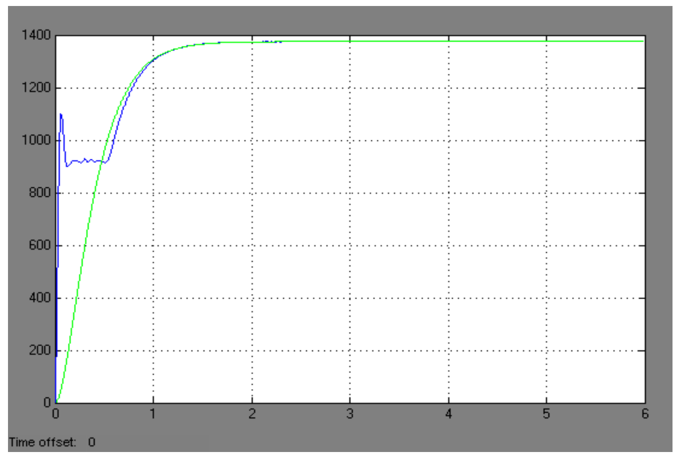

Fig.5. Speed plot at no load condition using MRAC

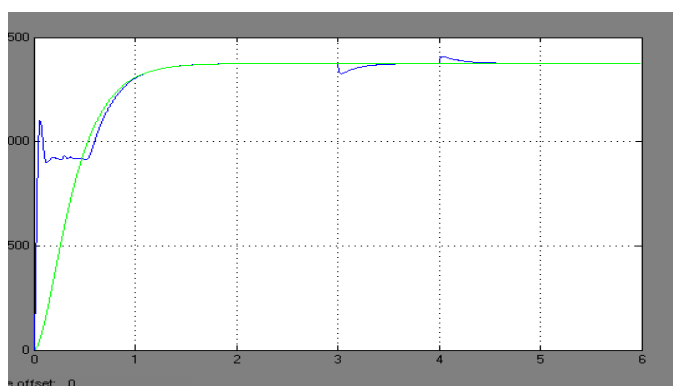

Fig.6. Speed plot at variable load condition using MRAC

ISSN: 2250–3676

[IJESAT] INTERNATIONAL JOURNAL OF ENGINEERING SCIENCE & ADVANCED TECHNOLOGY Volume-2, Issue-3, 605 – 611

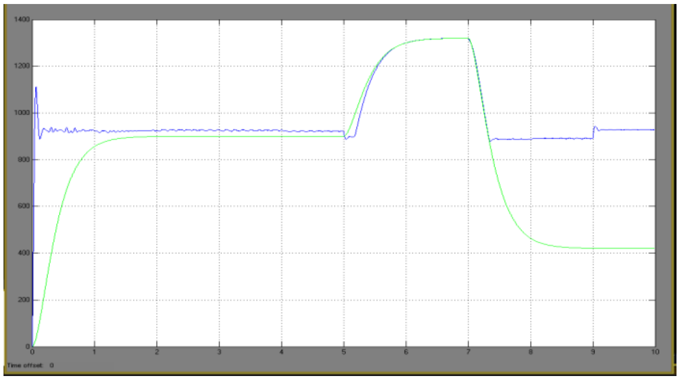

Fig.7. Reference and Actual speed plot at load and supply voltage variations using MRAC

4.2. MRAC with fuzzy controller(MRFAC):

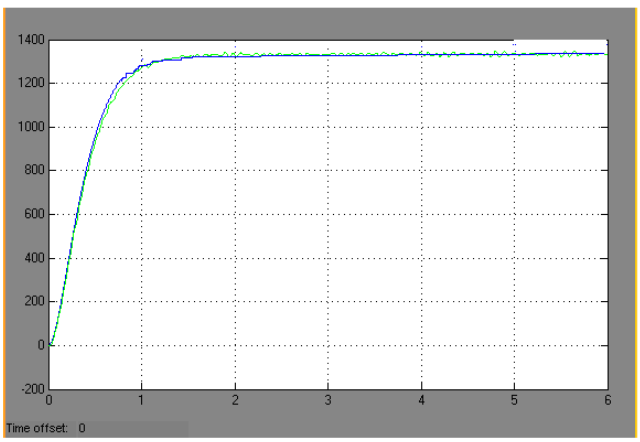

Fig.8. Speed plot at no load condition using MRFAC scheme

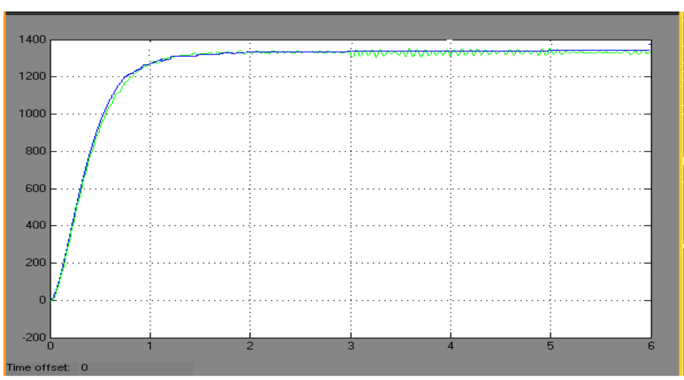

Fig.9. Speed plot at variable load condition using MRFAC scheme

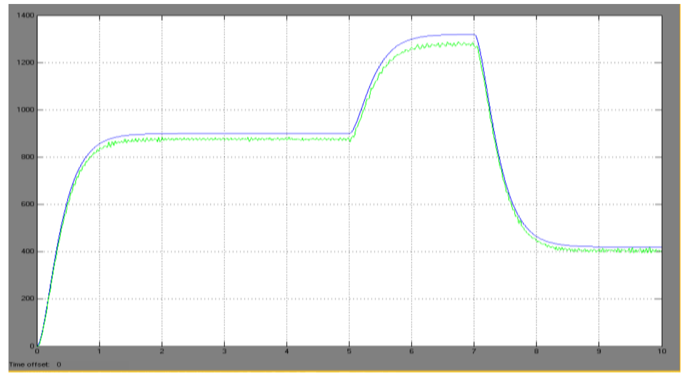

Fig.10. Reference and actual speeds at no load and supply voltage variations

From the figures the comparisions between MRAC and MRFAC are shown in below tales.

S.NO.	Particular	MRAC	MRFAC
1.	Over shoot	1100 rpm	Approx.Reference speed
2.	Settling time	1.2 sec	0.2 sec

Table-3: At no load condition

S.NO.	Load	MRAC	MRFAC
1.	22 N-M	1310 rpm	1364 rpm
2.	7 N-M	1425 rpm	1372 rpm

Table-4: At no load condition

5. CONCLUSION

The work basically exhibits versatility of the high performance Model Reference Fuzzy Adaptive Control (MRFAC). Hence, the implementation of the fuzzy controller in the simulation results is a very cost effective solution to the drive control design. Furthermore, the MRFAC enhances the performance of the drive system. The work can also be effectively applied to higher order systems without any complications. The simulation results show that error tends to zero whenever a load disturbance or supply voltage variation is introduced.

APPENDIX

ωo **:** plant output speed with no disturbance

ωd : plant output speed with disturbance

Tl: load torquedl**:** Effect of load torque on output speed

du: effect of uncertainties on output speed

Bp, Jp**:** plant friction coefficient and moment of inertia

Rap, Lap**:** plant armature resistance and inductance

Ua**:** adaptive controller output

Kc, Kbp: converter gain and back emf constant

K (t)**:** adjustable gain vector

q(t)**:** constant amplifier gain of adaptive controller

ed :error in output speed with $d\neq 0$

e0: error in output speed with $d=0$

ACKNOWLEDGEMENT

Thanks to the H.O.D Mr.T.Bramhananda Reddy sir, my guide Mr.M.Sivasathyanarayana sir & the staff for this precocious suggestions for the work& special thanks to Mr. K.Ramamohan Reddy sir for his suggestions & encouragement.

REFERENCES

[1] Faa-Jeng Lin," *Fuzzy Adaptive Model-Following Position Control for Ultrasonic Motor*", IEEE Transactions on Power Electronics, Vol. 12,March 1997

[2] Gilbert C.D.Sousa, and Bimal K. Bose, "*A Fuzzy Set Theory Based Control of a Phase-Controlled Converter DC Machine Drive*", IEEE

transactions on Industrial Electronics, Vol .30, January 1994

[3] Emanuele Cerruto, Alfio Consoli, Angelo Raciti and Antonio Testa "*Fuzzy Adaptive Vector Control of Induction Motor Drives*", IEEE

Transcations on Power Electronics, Vol 12,November 1997

[4] Saly George, F. Gajendran, "*Model Reference Linear Adaptive Control of DC Drives Subjected to Disturbances*", Journal of Institution of Engineers (India), vol. 81, September 2000, pp. 70-77.

[5] Fouad Mrad, Ghassan Deeb"*Comparative Analysis of Conventional, Fuzzy Logic, and Adaptive Fuzzy Logic Controllers*", IEEE Transactions, 1999.

[6] Tarun Gupta, R. R. Boudreaux, R. M. Nelms and John Y. Hung"*Implementation of a Fuzzy Controller for DC–DC Converters Using an Inexpensive 8-b Microcontroller*", IEEE transactions on Industrial

Electronics, October 1997

[7] Zurada"*Fuzzy and Neural Networks*" PHI India publishers

[8] R.K.Kirshanan "*Electric Motor Drives modeling, analysis, and control*" Prentice-hall of India, publications

[9] Bimal k.Bose"*Modern Power electronics and AC Drives*" PHI India publishers

[10] V.V.Chalam"*Adaptive control system techniques and applications*" DEKKER publishers

BIOGRAPHIES

K.Keerthi received B.Tech degree from Jawaharlal Nehru Technological University, Ananthapur, Andhra Pradesh& now studying Masters Degree in Power Electronics in G.Pullareddy Engineering college (AUTONOMOUS), Kurnool

Mr.M.Sivasathyanarayana working as Associate Professor in G.Pullareddy Engineering college (AUTONOMOUS), Kurnool.