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MODELLING OF INDUCTION MOTOR AND ITS PERFORMANCE WITH PI,PID(NZ METHOD),PI(ZP) , FUZZY AND GENERALISED PREDICTIVE CONTROL

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Abstract —Induction motor is robust system which runs at their rated speed, however there are many applications where variable speed operations are required. Although range of speed control of induction motor control techniques are available, here a system of fuzzy logic controller and conventional PI controllers is made.The performance of the system is improved by using these controllers. The model includes the transfer function of an induction motor (with certain parameters taken), mathematically modelled PI,PID(zn),PI(pz) controller, fuzzy logic controller and Generalised predictive controller which were coded in MATLAB editor. Simulation was done using MATLAB Simulink software

Key Words: Transfer function of Induction Motor; Fuzzy logic controller; PI controller, Generalised predictive controller, Pole zero placement method

1. INTRODUCTION

In induction motor synchronous speed depends upon frequency and poles of machine. An induction motor always run at a speed less than synchronous speed because the rotating magnetic field produced in the stator will generate flux in the rotor which helps the rotor to rotate, but due to lagging of flux, current in the rotor with flux current in the stator, the rotor will never reach speed of rotating magnetic field speed,synchronous speed .Induction motors generally run at a rated speed so their control techniques are necessary for many industrial applications.[3]

Theseare three phase machines where the speed of the stator revolving flux (N_s) is given by N_s=$\frac{120f}{P}$

where $f$is the frequency in Hz and P is number of poles. The following figure shows the per-phase equivalent circuit of an induction motor regarding stator side.

where,

r_1 = resistance of Stator
X_1 = Stator leakage reactance
I_1 = Stator current

R_c = Shunt branch resistance

X_m = Magnetizing reactance
I_e = Per-phase no-load current

I_2 = Rotor current

I_2' = Rotor Current per phase referred to stator
X_2' =Standstill rotor reactance referred to stator
r_2' = rotor resistance referred to stator
V_1 = Stator voltage
E_1 = Stator induced emf
s = slip

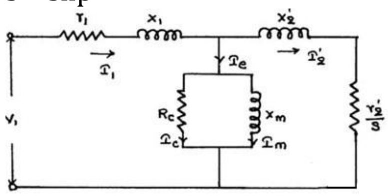


Figure 1: Per-phase equivalent circuit referred to Stator side[3]

The electrical equation of machine is$V_a = I_aR_a + JX_sI_a + E_b$

$$E_b \propto \frac{d\theta}{dt}$$

Electrical torque is given by $T_e = \frac{KE^2R}{R^2+X^2}$

Mechanical torque is given by $T_m = J\ddot{\theta} + B\theta$

This paper presents the development of efficient and versatile controllers which are used to control the speed of induction motor which is mathematically modelled.

2.BLOCK DIAGRAM AND TRANSFER FUNCTION OF INDUCTION MOTOR

Mathematical modelling of induction motor can be obtained by taking all the basic equations

The electrical equation of machine is

$$V_a = I_a R_a + JX_s I_a + E_b \qquad (1)$$

$$E_b \propto \frac{d\theta}{dt} (2)$$

Applying laplace transforms,

$$V_a(s) = I_a(s)(R_a + jX_s) + E_b(s) \qquad (3)$$

We know that

$$E_b = K_t s\boldsymbol{\theta}(\boldsymbol{s})(4)$$

Substituting, we get ,

$$V_a(s) = I_a(s)Z(s) + K_t s\theta(s) \qquad (5)$$

$$\frac{V_a(s) - K_t(s)s\theta(s)}{Z(s)} = I_a(s)$$

Electrical torque is given by $T_e = \frac{KE^2R}{R^2+X^2}$

Taking laplace transforms ,

T_e $=E^2 \sin\theta$ (6)

Mechanical torque is given by $T_m = J\ddot{\theta} + B\dot{\theta}$

Taking laplace transforms,

$$T_m(s) = (Js^2 + Bs)\boldsymbol{\theta}(\boldsymbol{s})$$

$$T_m = T_e \Longrightarrow E^2\boldsymbol{\theta}(\boldsymbol{s}) = \boldsymbol{Js^2} + \boldsymbol{Bs}(\boldsymbol{\theta}(\boldsymbol{s}))(7)$$

$$(\boldsymbol{Js^2} + \boldsymbol{Bs} - \boldsymbol{E^2})\boldsymbol{\theta}(\boldsymbol{s}) = \boldsymbol{T_m}$$

$$\boldsymbol{Js^2} + \boldsymbol{Bs} - \boldsymbol{E^2} = \frac{\boldsymbol{T_m}}{\boldsymbol{\theta}(\boldsymbol{s})}$$

$$\frac{\boldsymbol{\theta}(\boldsymbol{s})}{\boldsymbol{T_m}(\boldsymbol{s})} = \frac{\mathbf{1}}{\boldsymbol{Js^2+Bs-E^2}}(8)$$

We know that $T \propto \phi I_a \cos\theta$ (take $\boldsymbol{\theta}$=0)

$$T = K\phi I_a (9)$$

$$T = K\ \phi(s) I_a(s)$$

From above we know $\frac{K_a[V_a(s)-K_t s\theta(s)]}{Z(s)} = (\boldsymbol{Js^2} + \boldsymbol{Bs} - \boldsymbol{E^2})\boldsymbol{\theta}(\boldsymbol{s})(10)$

$$\boldsymbol{K_a V_a(s)} = (\boldsymbol{Js^2} + \boldsymbol{Bs} - \boldsymbol{E^2})\boldsymbol{\theta}(\boldsymbol{s})\boldsymbol{z}(\boldsymbol{s}) + \boldsymbol{K_t s\theta}(\boldsymbol{s}) \quad \frac{\boldsymbol{V_a}(\boldsymbol{s})}{\boldsymbol{\theta}(\boldsymbol{s})} = \frac{(\boldsymbol{Js^2+Bs-E^2})\boldsymbol{z}(\boldsymbol{s})+\boldsymbol{K_a K_t s}}{\boldsymbol{K_a}}$$

$$\frac{\boldsymbol{\theta}(\boldsymbol{s})}{\boldsymbol{V_a}(\boldsymbol{s})} = \frac{K_a}{(\boldsymbol{Js^2+Bs-E^2})\boldsymbol{z}(\boldsymbol{s})+\boldsymbol{K_a K_t s}}$$

$$= \frac{K_a}{(\boldsymbol{Js^2+Bs-E^2})(\boldsymbol{R_a+L_a s})+\boldsymbol{K_a K_t s}}$$

$$\frac{\theta(s)}{v_a(s)} = \frac{K_a}{JL_a s^3+(R_a J+BL_a)s^2+(BR_a+K_a K_t)s} \qquad (11)$$

Parameters taken: $K_a = 0.0190$

Where $K_a = \frac{3}{2\Pi n_s}$

K_t = 0.5

J(Inertia constant) = $0.076 kgm^2$

R = 4.2Ω

B(Friction coefficient) = 8

L = 3mH

Transfer function gives $\frac{\theta(s)}{v_a(s)} = \frac{0.0190}{0.228s^3+24.31s^2+33.6s}$

$$\frac{\theta(s)}{v_a(s)} = \frac{0.0190}{(s+1.4)(s+105.26)s}$$

$$\frac{\theta(s)}{v_a(s)} = \frac{0.0190}{1.4\left(1+\frac{s}{1.4}\right)105.26\left(1+\frac{s}{105.26}\right)s}$$

$$G(s) = \frac{0.0190}{(1+0.71s)(1+0.0095s)s}$$

Transfer function= G(s) =

$$\frac{\theta(s)}{V_a(s)} = \frac{0.000128\, s^1 + 0}{0.00067\, s^3 + 0.7195\, s^2 + s + 0} \quad (12)$$

The circuit shown in Fig. is simulated using MATLAB Simulink's Sim Power Systems software.

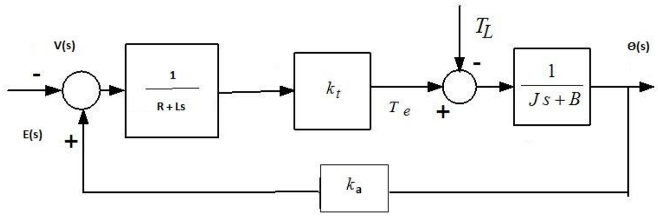


Figure 2: Block diagram of motor

Transfer function =

$$\frac{\theta(s)}{V_a(s)} = \frac{0.000128 s^1 + 0}{0.00067 s^3 + 0.7195 s^2 + s + 0}$$

3.FUZZY LOGIC CONTROLLER

Fuzzy logic based on degrees of truth rather than the usual true or false (0and1).Boolean logic on which the modern computer is based. The actual meaning of fuzzy is not clear or precise.Fuzzy logic is a form of representation in form of knowledge suitable for notions that cannot be defined precisely, but which depend upon their contexts Fuzzy Logic provides a more efficient and resourceful way to solve Control Systems.[6]

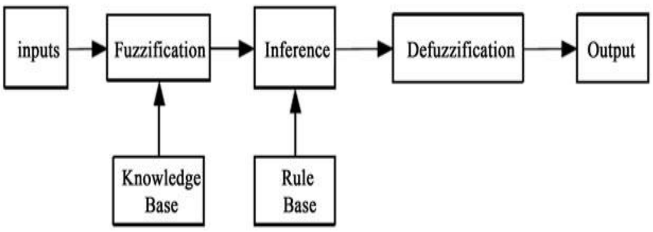


Figure 3: Block diagram of fuzzy logic controller

e / Δe	NL	NS	ZE	PS	PL
NL	NL	NL	NM	NS	ZE
NS	NL	NM	NS	ZE	PS
ZE	NM	NS	ZE	PS	PM
PS	NS	ZE	PS	PM	PL
PL	ZE	PS	PM	PL	PL

Figure 4: Rule table

e	Error	ZE	Zero
Δe	Changein error	PS	Positive small
NL	Negative large	PL	Positive large
NS	Negative small	NM	Negative medium
PM	Positive medium		

Figure 5:Terminology of rule table

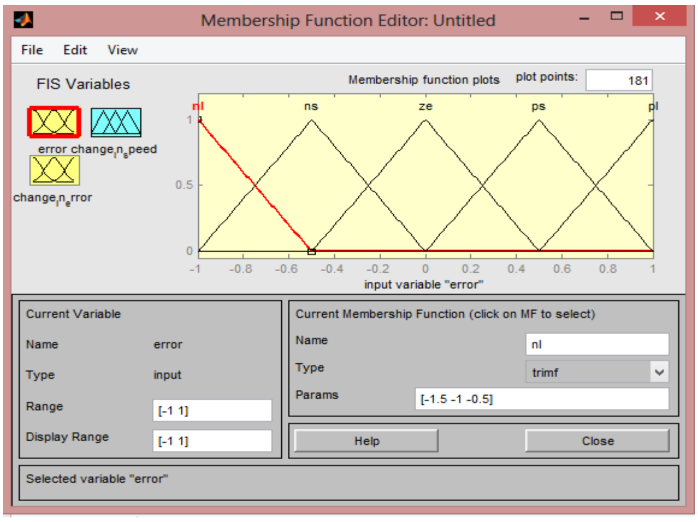


Figure 6:Membership function editor

4.PI,PID CONTROLLER

The PI (proportional plus integral) controller function is most frequently used controller function in practical applications. It does not cause offset associated with proportional control. It yields much faster response than integral action. It is widely used for process industries for controlling variables like level, flow, pressure,, those do not have large time constants[2].

The definition for a proportional feed back control is still

$$U=K_p e \quad (13)$$

where
e = is the "error"
K_P = Proportional gain

The definition of the integral feed back is

$$U=K_1 e\int dt \quad (14)$$

where KI is the integration gain factor.

In the PI controller we have a combination of P and I control, ie.:

$$U=K_p e+K_I \int e\,dt \quad (15)$$

$$U=K_p e+\frac{1}{t_1}\int e\,dt \quad (16)$$

$$U=K_p (e+\frac{1}{t_N}\int e\,dt) \quad (17)$$

For PI controller the transfer function is generally of the form $K_p+\frac{K_i}{s}$

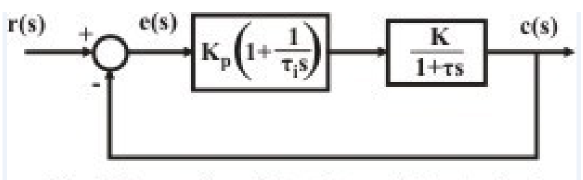


Figure 7: Blockdiagram of PI controller

Total transfer function with PI controller is given by

$$\frac{0.01268\,s+0.000064}{0.00067\,s^4+0.7195\,s^3+s^2} \quad (18)$$

Transfer function of PI controller $=k_p+\frac{k_i}{s}=\frac{4999.7s+21729}{s}$ (19)

Overall transfer function$=\frac{0.639s+2.78}{0.00067\,s^4+0.7195\,s^3+s^2}$ (20)

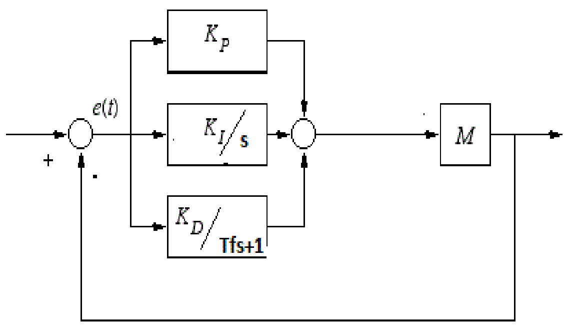


Fig.8 Block diagram of motor model with PID controller

Transfer function of PID controller

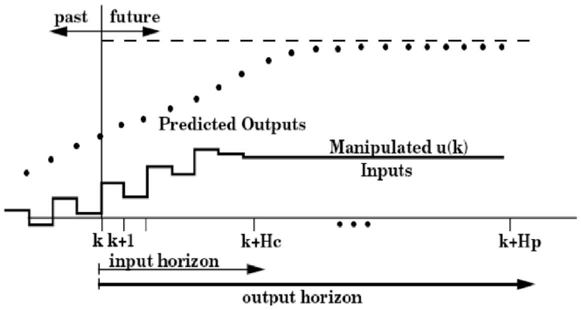
$$=k_p+\frac{k_i}{s}+\frac{K_d s}{Tf+1}=\frac{111.6s^2+350.8s+31200}{0.09s^2+s} \quad (21)$$

Overall transfer function$=\frac{\mathbf{0.014s^2+0.44s+3.9936}}{\mathbf{0.000067s^5+0.06467s^4+0.809s^3+s^2}}$(22)

5.GENERALISED PREDICTIVE CONTROL

This model is dependent of receding horizon in which future reults are predicted from that of current values.In which a dynamic ontrol matrix is formed for the purpose of formation of result.For siso case step response looks

$$Y_{k+j}=\sum_{i=1}^{N-1} S_i \Delta u_{K+j-i}+S_N u_{K+j-N} \quad (23)$$



6.PI (PZ METHOD) CONTROLLER

Pole zero placement is one of the most prominent method for design of PID controller it is based on Sylvester theorem.

$$K_p = \frac{-D_e}{N_e} \quad (24)$$

$$K_i = \frac{w^2 D_o}{N_e} \quad (25)$$

$$C(s)=\frac{sK_p+K_i}{s} \quad (26)$$

7. RESULTS AND DISCUSSIONS

All the transfer functions required for simulation were designed in simulink.The results obtained for step input are as follows for transfer function of motor and for that of the different types of controllers.

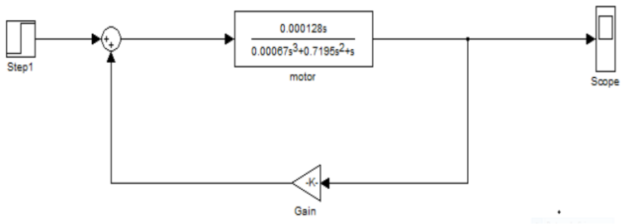


Figure 9: Simulink model for motor

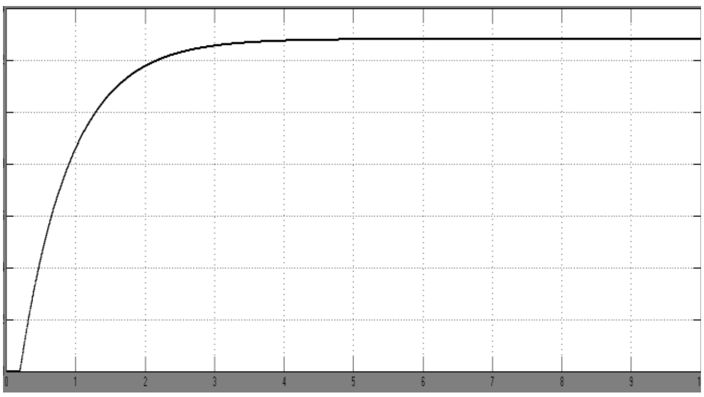


Figure 10: Result for step input

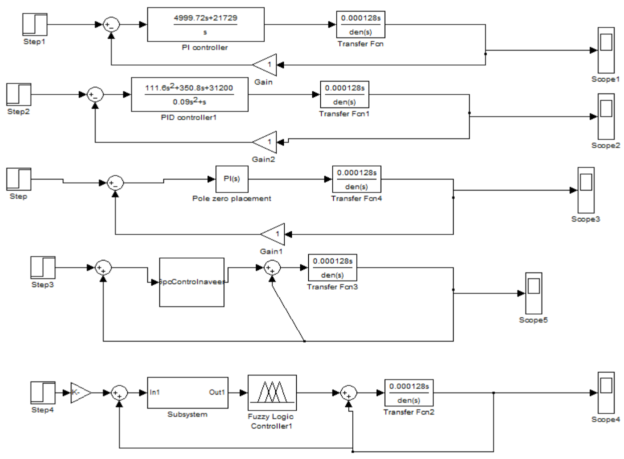


Figure 11: Simulink model with controllers applied to motor model

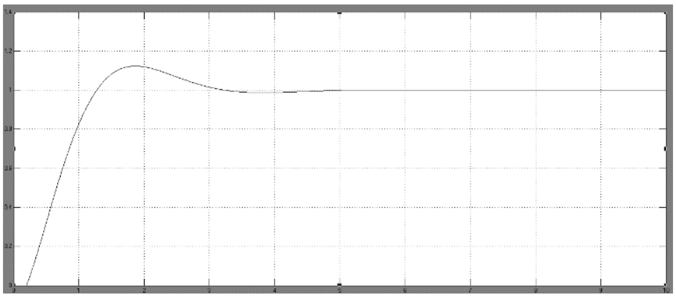


Figure 12: Output for the model with PIcontroller

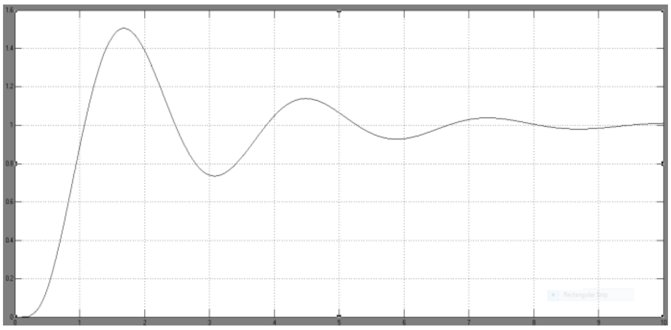


Figure 13: Output for model with PID controller

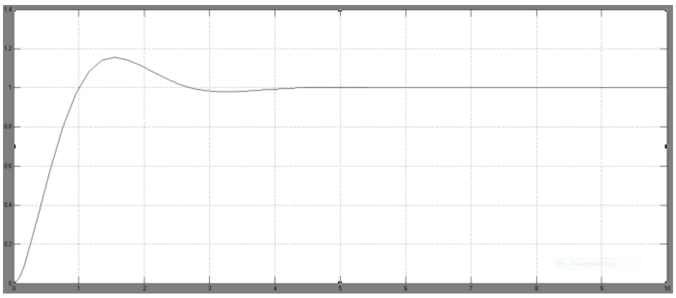


Figure 14: Output for the model with PI(pole placement)controller

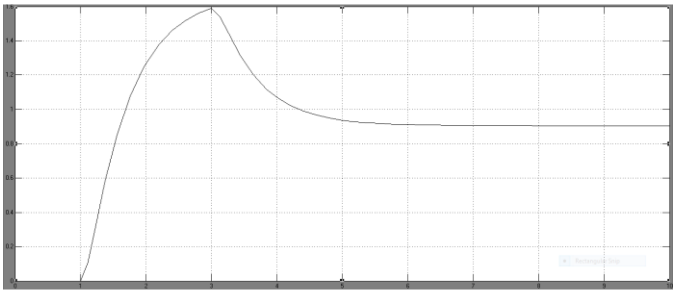


Figure 15: Output for the model with Generalised predictive controller

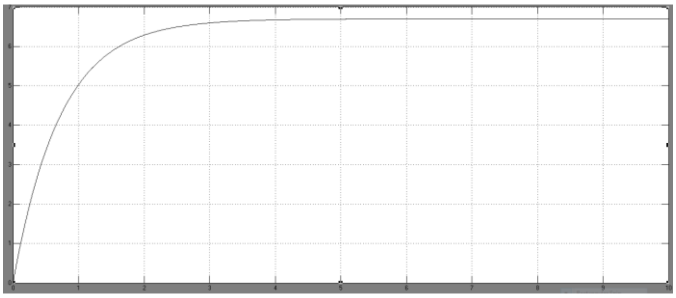


Figure 16: Output for the model with Fuzzy logic controller

CONTROLLER	RISE TIME(Sec)	SETTLING TIME	OVERSHOOT PERCENTAGE	PEAK
PI	0.627	5.42	36.5	1.37
PID	14	17.2	1.35	1.01
PI(Pole zero)	0.812	4.3	30.43	1.40
Fuzzy controller	0.6	4	0.82	0.67
GPC	0.9	6	14.6	1.6

Comparatively better responses are given by PI (Pole zero). PID (ZN) has transient behavior when compared to other two controllers. Settling time of PI (ZN) is large. PI (Pole zero) has no transients and less settling time. Fuzzy logic controller gave a response with lesser peak but the overshoot percentage of GPC is of higher percentage. The conventional controllers designed by Zeigler-Nicolas method gives better performance than Fuzzy and GPC controllers. Amongst all these controllers PI (Pole zero) gives the better performance.

8.CONCLUSION

This paper presents a study between the different types of controllers which were used to regulate the speed of an induction motor which were mathematically modeled in SIMULINK of MATLAB[3].The designed system was successfully simulated for PI,PID,PI(Pole zero),GPC and fuzzy logic controllers to improve the performance of induction motor.

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