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# PERFORMANCE EVALUATION OF PMSM DRIVE USING HYBRID FUZZY LOGIC PROPORITIONAL PULSE CONVENTIONAL INTEGRAL DERIVATIVE CONTROLLER.

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**ABSTRACT** The Permanent magnet synchronous-machine (PMSM) drives have been progressively more applied in a various of industrial applications which require fast dynamic response and accurate control over wide speed ranges. In this thesis the control of a PM Synchronous Motor (PMSM) is studied Usually Hybrid fuzzy logic proportional plus conventional integral-derivative (fuzzy P+ID) controller in an incremental form. This controller is constructed by using an incremental fuzzy logic controller in place of the proportional term in a conventional PID controller. By using the bounded input-bounded output small gain theorem, the sufficient condition for stability of this controller is derived. Based on the condition, we tend modify the Ziegler and Nichols' approach to design the fuzzy P+ID controller. In this case, the stability of a system remains unchanged after the PID controller is replaced by the fuzzy P+ID controller without modifying the original controller parameters. The HFLC consists of fuzzy proportional term and the conventional integral plus derivative control term. The parameters of proportional plus integral and derivative control gains are chosen same in both the PID controller and HFLC. The PMSM drive is tested under both PID controller and HFLC for the various operating conditions such as load perturbation, speed reversal and step change in the speed at different speeds below the rated speed of PMSM. The performance of PMSM drive is compared between PID controller and HFLC in terms of different performance specifications and error constants. The simulation results are confirming that there is an improvement in the overshoot during starting and dip in speed during load perturbation with HFLC over the PID controller without reducing the performance in terms of the remaining performance specifications and error constants.

## I. INTRODUCTION

PMSM drives becomes an suitable choice in present as fine as future market used for a various of applications such as adjustable speed drives, electric vehicles, robotics, computer peripheral application and in a lot of other fields due to their advantages like high efficiency, higher power density, high torque (or) inertia ratio and maintenance free operation Eliminating the shaft position and speed sensors is desirable due to cost and reliability constraints .Among various types of ac motors,

PM synchronous motor has been generally used in a lot of industrial applications. There has been wonderful research for providing suitable speed controller for PMSM motor. Various control strategy have been proposed till today. The main disadvantage of fixed gain controllers is that their presentation deteriorates as a result of changes in system operating conditions. This has resulted in the increased demand of modem nonlinear control structures. Very few adaptive controllers have been practically employed in the control of electric drives due to their complexity and inferior performance Fuzzy logic though developed many years ago, has recently emerged as a useful tool in industrial organize applications. It is fine that this control methods depends on human being capability to understand system behaviour and also on control rules. Fuzzy controllers have been productively used for a lot of years [7- 12] these controllers are inherently healthy to load disturbances. Another advantage is that fuzzy logic controllers can be easily be implemented. The combination of intelligent control with robust control appears nowadays the most hopeful research achievement in the area of drive control.

The applications of FL controllers are limited because of some drawbacks. In order to eliminate them, many researchers are now combining fizzy logic and conventional techniques have presented an approach to the design of a hybrid fuzzy proportional plus conventional integral derivative controller. According to him, one of the purposes for propose the fuzzy P+ID controller is to get better control performance of a lot of industrial plants that are already controlled by PID controllers. In this paper, we discover the possibility of hybrid FP+ID controller for the speed Control of PMSM motor drive. In this, the proportional term in the conventional PID controller is replaced with an incremental fuzzy logic controller improving the behaviour of conventional PID controllers. This controller uses fuzzy rules that are based on eliminating the overshoots. Our results show significant improvement in both transient and steady state responses of the drive. Unlike PID controller, this controller make the PMSM drive more robust to load variations. The key feature of this PMSM High-Level Schematic fig

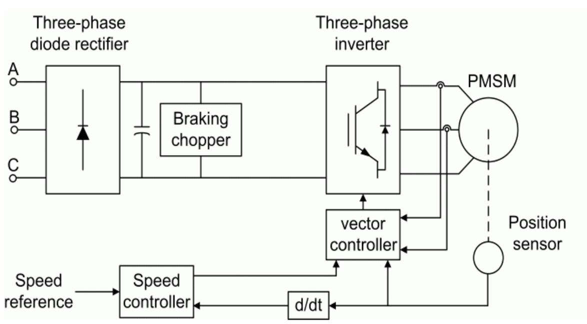



**Fig1.PM Synchronous Motor High-Level Schematic**

Is to compensate for overshoots and oscillations in the response of the PMSM motor this paper is organized as follows. In the basic components of PMSM motor drive is described. Different components of the drive system like speed controller, current controller and inverter, braking chopper are analyzed in sections**.** The present scheme is simulated under real time operating conditions and compared with PID controller in section

## II. THE MATHEMATICAL MODEL OF PMSM

. The PMSM equations are develop in rotating reference frames. The stator of the PMSM and the wound rotor synchronous motor are similar. The permanent magnets used in the PMSM are of a modern rare earth range with high resistivity, therefore induced currents in the rotor are insignificant. In addition, there is no difference between the back EMF shaped by permanent magnet and that produced by an excited coil. Hence the mathematical model of PMSM is parallel to that of the wound rotor Synchronous Motor [3]. The model of the PMSM is developed by using the following assumptions.

1. Saturation is neglected.

2. The induced EMF is sinusoidal.

3. Eddy current and hysteresis losses are negligible.

4. There are no field current dynamics.

With these assumption, the stator d, q equations of the PMSM in the rotor reference [3], [4],

$$V_q = R_S i_q + L_q P i_q + \omega_r L_d i_d + \omega_r \varphi_f \quad (1)$$

$$V_d = R_S i_d + L_d P i_d - \omega_r L_q i_q \quad (2)$$

Also flux linkage equation can be write as,

$$\varphi_d = L_d i_d + \varphi_f \quad (3)$$

$$\varphi_q = L_q q \quad (4)$$

Where Vd and Vq are the d, q axis voltages, id , iq are the d, q axis stator currents, Ld, and Lq are the d, q axis inductances, φd and φq are the d, q axis stator flux linkages, Rs is the stator winding resistance per phase and ωr is rotor electrical speed

The electro mechanical torque is known by

$$T_e = \frac{3}{2}\frac{p}{2}[\varphi_f i_q - (L_d - L_q) i_d i_q] \quad (5)$$

And the equation of motor dynamics is

$$T_e = T_L + B\omega_m + jp\omega_m \quad (6)$$

Where P is the number of poles, TL is the load torque, B is the damping co-efficient, ωm is the rotor mechanical speed, J is the moment of inertia and p is the differential operator.

$$\boldsymbol{\omega_r} = \left(\frac{\boldsymbol{p}}{\boldsymbol{2}}\right) \boldsymbol{\omega_m} \quad (7)$$

The model equations of PMSM can be rearranged in the form of following first order differential equations as [6],

$$pi_d = (V_d - R_s i_d + \omega_r L_q i_q) / L_d \quad (8)$$

$$pi_q = (V_q - R_s i_q + \omega_r L_d i_d - \omega_r \varphi_f) / L_d \quad (9)$$

$$p\omega_m = (T_e - T_L - B\omega_m) / j \quad (10)$$

$$p\Theta_m = \omega_m \quad (11)$$

$$\Theta_m = \int \omega_m \quad (12)$$

Where $\Theta_m$ is the position angle of rotor In order to achieve maximum torque per ampere and maximum efficiency with linear characteristics, direct axis current component id forced to zero [5] and the reluctance torque is zero.

$$T_e = \left(\frac{3}{2}\right)\left(\frac{p}{2}\right)\varphi_f i_q \quad (13)$$

The d, q variables are obtained from a, b, c variables through the park transform as [3],

$$V_q = \frac{2}{3}[V_a cos\Theta + V_b \cos\left(\Theta - \frac{2\pi}{3}\right) + V_c \cos\left(\Theta + \frac{2\pi}{3}\right) \quad (14)$$

$$V_d = \frac{2}{3}[V_a sin\Theta + V_b \sin\left(\Theta - \frac{2\pi}{3}\right) + V_c \sin\left(\Theta + \frac{2\pi}{3}\right) \quad (15)$$

The a b c variables are obtained from the d, q variables through the inverse of the park transform as,

$$V_a = V_q cos\theta + V_d sin\theta \quad (16)$$

$$V_b = V_q \cos\left(\theta - \frac{2\pi}{3}\right) + V_d \sin\left(\theta - \frac{2\pi}{3}\right) \quad (17)$$

$$V_c = V_q \cos\left(\theta + \frac{2\pi}{3}\right) + V_d \sin\left(\theta + \frac{2\pi}{3}\right) \quad (18)$$

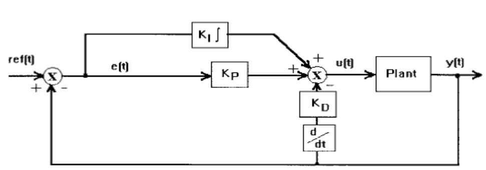
The torque equation is similar to that of separately excited dc motor [2], and this completes the transformation of a PMSM to an equivalent separately excited dc motor

**III Control schemes**

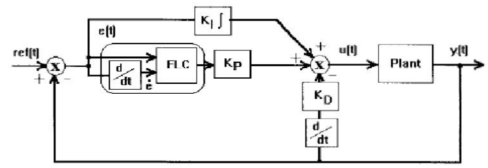
The fuzzy PID controller can be determined by an optimization approach, such as genetic algorithms .In comparison with the exiting fuzzy PID controllers, the proposed fuzzy PID controller combines the advantages of a fuzzy logic controller and a conventional controller. The fuzzy term plays an important role in improving an overshoot and a rise time response. The conventional integral (I) term reduces a steady-state error, and the conventional D is responsible for the stability of the system and the flatness of the response. Furthermore, this controller has the following features.

1) Since it has only one additional parameter to be adjusted based on the original PID controller it is easy to design.

2) The fuzzy P ID controller keeps the simple structure of the PID controller. It is not necessary to modify any hardware parts of the original control system for implementation fig2




(a)




(b)

**Fig 2 Control schemes (a) PID-type controller. (b) Fuzzy P+ID controller**

3) The sufficient stability condition shows that the same stability remains unchanged if the original PID controller is replaced by the fuzzy P ID controller. This paper is organized as follows: In the next section, we present the Hybrid fuzzy P ID control scheme. In Section IV, we Implementation of PMSM Motor Drive with FLC In Section V, In Next Section formulate an incremental fuzzy logic controller. In Section VI; we talk about the Approaches to Design of the controller. In Section VII, we propose approaches to design of the proposed controller. In Section VI, we report simulation results PMSM using on control of a nonlinear system by the PID-type controller and the fuzzy PID controller. Finally, a few notes are given in the conclusion section

**IV. HYBRID FUZZY P+ID CONTROLLER SCHEME**

At present, the PID-type controller is most generally adopt in industrial application due to its easy structure, as given away Fig.2 (a). Its control signal is simply compute by combine proportional integral-derivative terms

$$u(t)=K_P e(t) + K_1 \int e(t)dt - K_D \dot{y(t)} \ (1)$$

Where and are the controller parameters. Its discredited and incremental form is expressed by

$$\Delta u(t) = u(k) - u(k-1) = k_p \int e(k) - e(k-1)$$

$$+ k_1 T_e(k) - k_d \frac{y(k) - 2y(k-1) + y(k-2)}{T} \quad (2)$$

The reason for the in style use of the PID-type controller is that this controller can be simply designed by adjusting only three controller parameters and .In addition its control performance can be accepted in a lot of applications. so, we would like to keep the advantages of the PID type controller while designing a fuzzy logic controller. This idea leads to propose a hybrid fuzzy PID controller shown in Fig. 1(b). This hybrid controller uses an incremental fuzzy

| e/Δe | LN | MN | SN | ZE | SP | MP | LP |
|---|---|---|---|---|---|---|---|
| LN | LN | LN | LN | MN | SN | SN | ZE |
| MN | LN | MN | MN | MN | SN | ZE | SP |
| SN | LN | MN | SN | SN | ZE | SP | MP |
| ZE | LN | MN | SN | ZE | SP | MP | LP |
| SP | MN | SN | ZE | SP | SP | MP | LP |
| MP | SN | ZE | SP | MP | MP | MP | LP |
| LP | ZE | SP | SP | MP | LP | LP | LP |

$$\Delta u(t) = u(k) - u(k-1) = K_P^{*}\Delta u_f(k) + k_1 T_e(k) - K_D \frac{y(k)-2y(k-1)+y(k-2)}{T} \quad (3)$$

logic controller in place of the proportional term while the integral and derivative terms keep unchanged where and are identical to the conventional PID controller in (3), is the output of the incremental fuzzy logic controller, and is its proportional coefficient. The relationship between and will be discussed in Section IV. The most important part in the fuzzy P ID controller is the fuzzy P term because it is responsible for improving overshoot and rise time. The conventional I term is mainly responsible for reducing a steady-state error if an actual value is close to a reference signal. fig3

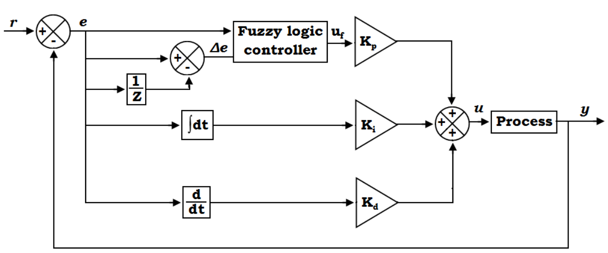



**Figure 3 Hybrid PID Fuzzy Logic Controller**

## V Implementation of PMSM Motor Drive with Hybrid FLC

The inputs of FLC are signals of error (e) and Change in error (Δe) in the speed of PMSM motor from the reference value the seven membership functions chosen for the representation of inputs and the output of FLC. They are large negative (LN), medium negative (MN), small negative (SN), zero (ZE), small positive (SP), medium positive (MP) and large positive (LP). The triangular membership functions are chosen for the membership functions of MN, SN, ZE, SP and MP while the trapezoidal membership functions are chosen for the membership functions of LN and LP. The ranges of input and output membership functions of FLC over the universe of discourse are shown in figure. The output control signal of FLC is as per the fuzzy control rules stored in the rule base shown in table 1

**Table1.Fuzzy rules for the control signal**

The membership functions of E, DE and DU are triangular distribution functions. The membership functions for each variable are shown in Figure

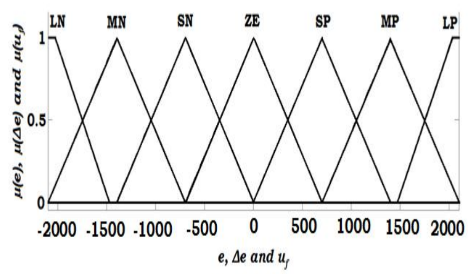



**Fig: 4 Membership function for error, change in error and fuzzy**

## VI.FORMULATION OF INCREMENTAL FUZZY LOGIC CONTROLLER

In the fuzzy P ID controller in 2(b), its proportional terms used in place of in the incremental PID controller, as shown in Fig. 2(a). The incremental fuzzy logic controller is a standard one which has two inputs and an output. In this paper, the membership functions of the inputs and the output are defined, as shown in Fig. 5. The parameters and are variables of the membership functions with regard to the fuzzy PID controller's inputs and we define. In this controller, membership functions assigned with linguistic variables are used to fuzzy physical quantities. For inputs and we have and .For the output, we have. The fuzzified inputs are inferred to a fuzzy rule base, which is used to characterize the relationship between fuzzy inputs and fuzzy outputs. In this study, the fuzzy rule base of the incremental fuzzy logic controller is fixed, a shown in Table 2

| e[k] | N | Z | P |
|---|---|---|---|
| N | N | N | Z |
| Z | N | Z | P |
| P | Z | P | P |

**Table 2.Incremental Fuzzy Logic Controller**

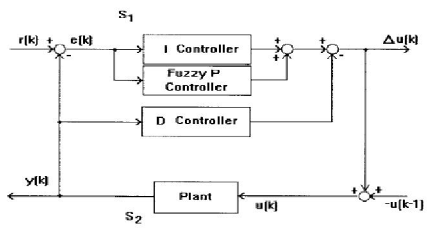



**Fig. (5).A nonlinear control system**

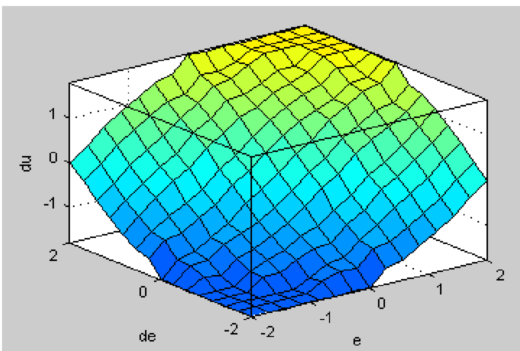



**Fig6.Control surfaces of the incremental fuzzy logic controller**

## VII. APPROACHES TO DESIGN OF THE CONTROLLER

The works in proposed different methods for tuning of the PID control parameters. Because these methods do not need to use any model of a controlled object, they are still widely used in industrial applications. In order to take this advantage, we systematically present the design process based on the Ziegler and Nichols' approach. In the Ziegler and Nichols technique, the parameter tuning is based on the stability limits of a system. The derivative and integral terms are initially put out of the system and proportional gain is increased until the critical oscillation point the purpose for design of the fuzzy P ID controller is to improve the control performance of the industrial plants without deteriorating the stability. We select the parameter of the derivative controller by using the sufficient stability condition in instead of the Ziegler and Nichols' formula. This result implies that stability of a system does not change after the conventional PID controller is replaced by the fuzzy P ID controller without modifying any PID-type controller parameter. The selection of the sampling period is done in two stages:

1) During the loop design. And 2) during the controller design the empirical rule of Franklin and Powell [21] suggests that the sampling frequency must be from 4 to20 times the bandwidth of the closed-loop system. For the controller design, should be increased to be greater than the sum of the error computation time, the digital analogue converter (DAC) and analogue digital converter (r hold delay time. In selecting, one must's in large conversion times of the DACDC's (i.e., to small In this control scheme, proportional control (Kp) is used to improve the rise time, derivative control (Kd) to improve the overshoot, an integral control (Ki) to eliminate the steady-state error. The stator currents are here less "noisy", as compared to PI speed controller, which is to be expected when using PWM inverters. The rotor speed increases fast to its synchronous value after a few oscillations and preserves its desired value (Figure1). The current takes initially a high value in order to develop the kinetic energy to accelerate the rotor. After a delay, the current stabilizes to their nominal value. The present model takes into consideration the movement equations in the PMSM model and the operating principle of the PWM voltage converter associated with the current controller.

## VIII. RESULT AND DISCUSSION

The fig shows the overall simulation of the speed control of PMSM motor and it consists of AC Voltage source, Permanent Magnet Synchronous Motor (PMSM) drive, speed and current reference as inputs fig

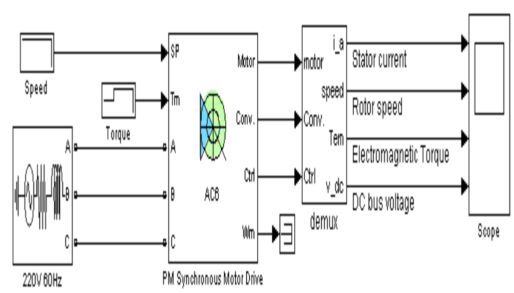



**Fig.7.Overall Simulation**

The Subsystem of PMSM motor drive consists of speed controller, current controller, inverter and rectifier along with braking chopper, measuring circuit and estimation of speed and commutation circuit is shown in fig

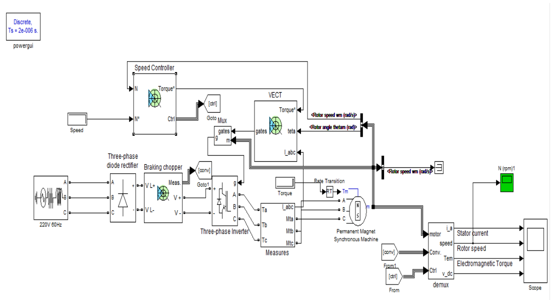


**Fig.8 (a) PM Synchronous Motor drive subsystem**

The set speed and the actual speed from the motor is given as input to the speed controller and the both inputs are compared by the fuzzy logic controller and torque is calculated. The output of the PI controller in time domain is defined by the following equation (1):

$$V_c(t) = K_P \, e(t) + K_i \, DT \qquad (1)$$

Where $V_c(t)$ is the output of the PI controller,

$K_P$ Is the proportional gain

$K_i$ Is the integral gain, and

E (t) is the instantaneous error signal

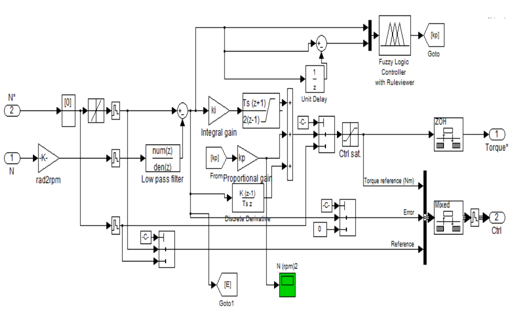


**Fig 8(b) Subsystem of speed controller of PMSM HFLC**

The input error is given by:

E (k) = N*(k) – N (k)

Where N*(k) is the reference speed and N (k) is the actual speed

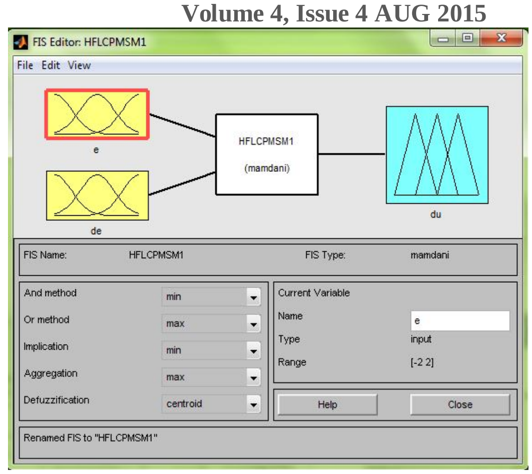



**Fig.8 (c) FIS editor of PM Synchronous Motor speed control**

The torque calculated from the speed controller, Hall Effect value and currents from signal and commutation circuit is used to calculate the switching control signals to gates of MOSFET.

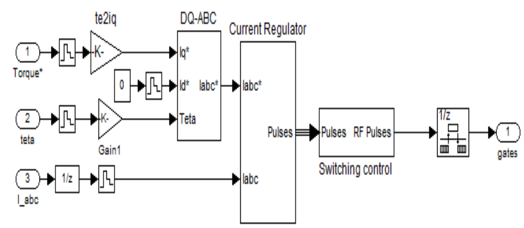



**Fig.8 (d) Subsystem of current controller**

**Braking Chopper Section**

The braking chopper resistance used to avoid bus over-voltage during motor deceleration or when the load torque tends to accelerate the motor (ohms).The braking chopper frequency (Hz).The dynamic braking is activated when the bus voltage reaches the upper limit of the hysteresis band. The following figure8 (d) illustrates the braking chopper hysteresis logic.

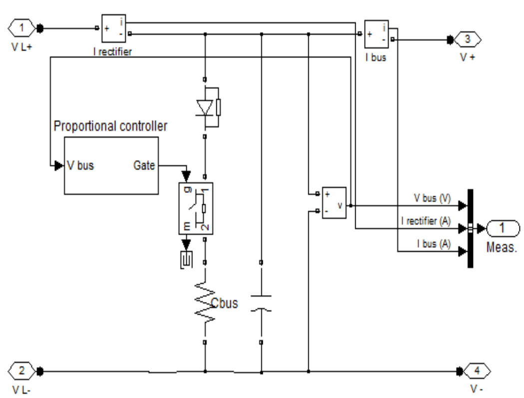
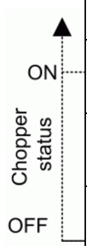


Fig8 (e) Subsystem of braking chopper hysteresis logic




| Reference speed in rpm | Type of Controller | settling time in second | Rise time in second | Steady state error in rpm | Dip in speed at a load of 11N-m in rpm | Overshoot in rpm | Settling time during speed reversal in second |
|---|---|---|---|---|---|---|---|
| 1800 | PID | 1.26 | 0.9825 | 0.04 | 2 | 3 | 2.2 |
| | HFLC | 1.26 | 0.9824 | 0.03 | 1.35 | 2.288 | 2.2 |
| 1500 | PID | 1.1 | 0.8133 | 0.04 | 2.05 | 3.04 | 1.9 |
| | HFLC | 1.1 | 0.8132 | 0.03 | 1.45 | 2.314 | 1.9 |
| 1200 | PID | 1 | 0.647 | 0.025 | 2 | 3.08 | 1.6 |
| | HFLC | 1 | 0.646 | 0.02 | 1.45 | 2.34 | 1.6 |
| 900 | PID | 0.8 | 0.4826 | 0.025 | 2 | 3.12 | 1.3 |
| | HFLC | 0.8 | 0.4826 | 0.02 | 1.45 | 2.37 | 1.3 |
| 600 | PID | 0.65 | 0.32 | 0.02 | 2 | 3.15 | 1.05 |
| | HFLC | 0.65 | 0.3199 | 0.02 | 1.46 | 2.41 | 1.05 |
| 300 | PID | 0.54 | 0.1591 | 0.02 | 2.008 | 3.2 | 0.7 |
| | HFLC | 0.54 | 0.1591 | 0.02 | 1.46 | 2.44 | 0.7 |

Table 3 Performance specifications with PID and HFLC

The dynamic braking is shut down when the bus voltage reaches the lower limit of the hysteresis band. The chopper hysteresis logic is shown in the following fig8 (e)

| Reference speed in rpm | Type of Controller | IAE | ISE | ITAE | ITSE |
|---|---|---|---|---|---|
| 1800 | PID | 552.6 | 4.147e+5 | 246.8 | 1.761e+5 |
| | HFLC | 552.6 | 4.147e+5 | 246.8 | 1.761e+5 |
| 1500 | PID | 381.8 | 2.388e+5 | 141.6 | 8.428e+4 |
| | HFLC | 381.8 | 2.388e+5 | 141.5 | 8.427e+4 |
| 1200 | PID | 243.4 | 1.218e+5 | 71.94 | 3.429e+4 |
| | HFLC | 243.4 | 1.218e+5 | 71.91 | 3.429e+4 |
| 900 | PID | 136.5 | 5.126e+4 | 30.16 | 1.079e+4 |
| | HFLC | 136.4 | 5.126e+4 | 30.13 | 1.079e+4 |
| 600 | PID | 60.63 | 1.524e+4 | 8.937 | 2133 |
| | HFLC | 60.6 | 1.524e+4 | 8.91 | 2133 |
| 300 | PID | 15.33 | 1960 | 1.187 | 137.1 |
| | HFLC | 15.31 | 1959 | 1.161 | 137 |

Table 4 Error constants with PID and HFLC

**4.1 Parameters of PMSM**

**3 HP, 220 V, 60 Hz, 300 v dc, 1800 r.p.m, 8 poles**

**Pairs of poles=4**

**Rated torque = 11 N-m**

**Stator resistance/phase ($R_{s)}$ = 0.2 Ω**

**Inductance ($L_d$ ) = 8.5e-03 H**

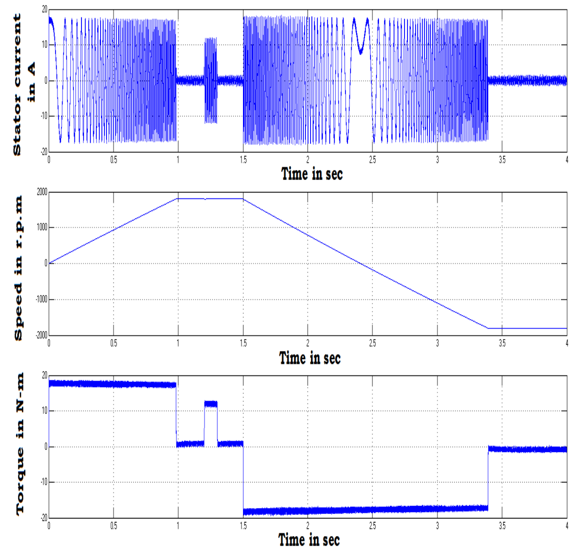
**Inductance ($L_q$ ) = 8.5e-03 H**

**Inertia (J) =0.089 Kg-m$^2$**

**Friction factor (B) =0.005 N-m-s**

**Flux =0.175 Wb**

**Torque limits=±17.8 N-m**




**Current hysteresis band = 0.1 A**

**PID controller parameters**

**$K_p$=5, $K_i$=100 and $K_d$=0.01**

The PMSM drive with PID controller and HFLC is simulated for different operating conditions at different set speeds of 1800 rpm, 1500 rpm, 1200 rpm, 900 rpm, 600 rpm and 300 rpm. At every speed the PMSM motor is applied with rated load torque 11 N-m at 1.3 second and withdrawn at 1.5 second. The motor is also subjected to speed reversal at 1.5 second for all the different set speed conditions. The simulation results are shown in the following figures for speed, stator current and torque at the set speed of 1800 rpm as a function of time

**Describes the simulation results of PMSM drive with PID:-**

## SIMULATION RESULTS

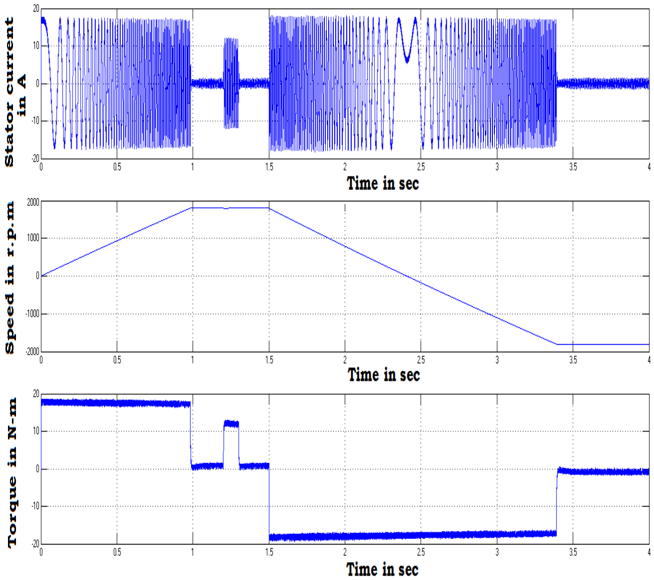



**Fig.9 Dynamic response of PMSM during starting, load perturbation and speed reversal at 1800 r.p.m with PI controller**

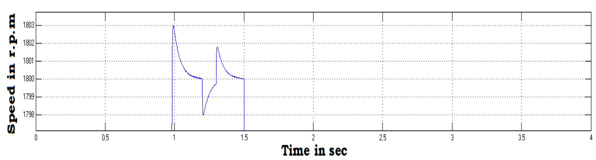



**Fig 10 Magnified view of speed response of PMSM during starting and load perturbation at 1800 r.p.m with PI controller**

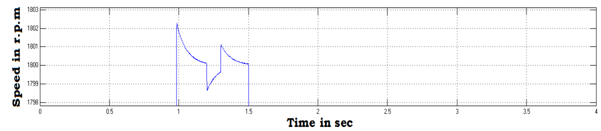
## SIMULATION RESULTS

**Fig.11 Dynamic response of PMSM during starting, load perturbation and speed reversal at 1800 r.p.m with HFLC**

**Fig.12 Magnified view of speed response of PMSM during starting and load perturbation at 1800 r.p.m with HFLC.**

## CONCLUSIONS

The HFLC consists of fuzzy proportional term and the conventional integral plus derivative control term. The




parameters of proportional plus integral and derivative control gains are chosen same in both the PID controller and HFLC. The PMSM drive is tested under both PID controller and HFLC for the various operating conditions such as load perturbation, speed reversal and step change in the speed at different speeds below the rated speed of PMSM. The performance of PMSM drive is compared between PID controller and HFLC in terms of different performance specifications and error constants. The simulation results are confirming that there is an improvement in the overshoot during starting and dip in speed during load perturbation with HFLC over the PID controller without reducing the performance in terms of the remaining performance specifications and error constants.

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