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Comparative Study of Speed Control Techniques of PMSM using PI and Fuzzy based PI-Controller

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Abstract– Permanent Magnet Synchronous Motors (PMSM) are brushless type of motor. They have very high reliable and efficient for different industrial applications. It provides high torque and smaller size of motor as compared to other motors. PMSM motors are used in different type of industrial applications of drives. Speed Control of PMSM motors is an important issue because of its high ranges of speed. There are number of parameters like starting current, torque, rise time, etc. which are be at center of attention for controlling speed performance. There are numerous methods for control the speed of PMSM such as PI Controller, Fuzzy controller, Fuzzy PI controller etc. Each methods of Speed Controlling are providing different performances. This paper provides an overview of the performance of the Speed Controlling techniques using PI controller, Fuzzy PI controller speed control for PMSM motor. The Simulation results of these techniques are validated using Matlab-Simulink tool.

Keywords- Permanent Magnet Synchronous Motor (PMSM) motors, PI controller, Fuzzy Controller, Fuzzy PI controller.

I. INTRODUCTION

The motors can be divided into two categories as per industrial use - First is the conventional dc motor where the production of flux is done by the current from the field coil of the stationary pole arrangement. The second type is the PMSM motor, as the name implies, PMSM motors have a permanent magnet as a rotor and do not use brushes for commutation; instead, they are electronically commutated. High-performance PMSM is widely used now a days in Electric Vehicles.

Designing of a PMSM drive is a very complex process which involves the modeling, control scheme selection, simulation and parameters tuning etc. It needs to be an expertise when it comes to parameter tuning of control of PID or PI, to get the optimal performance. In recent years various new methods have been proposed for speed control of PMSM [1][2][3].

An advantage of conventional PID controller algorithm is that it is simple, easily can be adjusted and have a high reliability rate [4][5]. On the contrary PI is easy and has lesser degree of reliability and accuracy but it is simpler to design and utilize. But when it comes to industrial applications or processes which is having higher non-linearities as well as variable parameters are at higher end with added uncertainty of mathematical model of the system tuning of PID or PI becomes extremely difficult thus resulting in poor robustness which in turn makes it more difficult to reach optimal state under field conditions in production facilities. So Fuzzy PI method is more reliable control method to the complex and dynamic plant model it is a very simple and trustable control strategy. It has characteristics like, better rise time, improved dynamic response, control robustness and better overshoot characteristics.

In the case of imprecise system which is having complex and non-linear characteristics Fuzzy Logic control (FLC) has proven extremely effective as compared to standard model-based control techniques which are impractical or sometimes impossible [6][7][8][9]. For the problems which have vagueness, uncertainty, it uses a membership function and has values ranging in between 0 and 1 fuzzy logic comes to rescue.

It can be said that, if the system is too much complex and don't have any reliable expert source of knowledge of derivation of the required decision rule, setting up of membership functions, it becomes extremely time consuming, tedious or sometimes impossible and also the tuning of the controller can become extremely time consuming [6][7]. In addition to this, an optimal Fuzzy logic controller cannot be achieved by using trial and error. This drawback limits the application of fuzzy logic controllers. Some research works have been made to solve this issue and simplify the task of tuning the parameters using some standard rule of mathematical calculation.

The objective of this paper is to show the responses of the different control methods employed and plotting the dynamic response of speed in all the proposed method and speed responses with varying load and setting time to the reference speed. In this paper different controller is used for speed control of PMSM also this paper find out the best possible combination of PI and Fuzzy to get the optimal operating speed.

II. PMSM Motor

In PMSM the excitation of the field is provided by Permanent Magnets but it has sinusoidal back EMF waveform. PMSM is enable to generate torque at the start means zero speed. The torque density of PMSM is high as compare to induction motor also operation efficiency high but controlled the inverter.

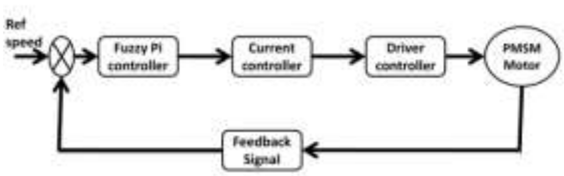

Fig.1. Block diagram of speed control of PMSM

The block diagram of speed control of PMSM is shown in fig 1. PMSM motor consists of stator and rotor part. The position of rotor is sensed using hall sensor placed on coil. The generated feedback signal is then compared with reference signal which generates an error signal. This error signal is sent to the PI or Fuzzy controller to generate current signal. The current is sent to inverter to drive the PMSM and when the reference speed is reached near to reference value error becomes zero and it maintains the speed.

III. CONTROLLER DESIGN

1. PI controller:

PI controller has two parameters proportional (P) and integrator (I) block as shown in the diagram below. Here, the actual sensed speed is compared with reference signal where error signal is generated at the output. The regulation of speed is done with the PI controller according to value of error signal.

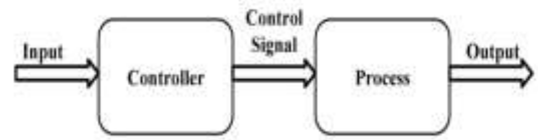

Fig. 2.Block diagram of PI Controller

$$e(t) = \omega sp(t) - \omega as(t)$$

where, e(t) - error function of time.
ωsp(t) - reference speed or set point speed.
ωas(t) - actual speed or motor speed function.

PI controller has two terms the first term is proportional of error function of time, multiplied with constant gain denoted by Kp and the Second term is integration of error function of time multiplied with constant gain is denoted by Ki.

$$u(t) = Kpe(t) + Ki \int e\,(t)dt$$

where, kp(t) - Proportional Gain.
ki(t) - Integral Gain.
e(t) - error function of time

The four major characteristics of PI Controller are

a) Rise Time (Tr): This is nothing but the time taken by response to achieve the 90% of its final value.
b) Overshoot: It is difference between maximum speed responds and set point divided by set point can be calculated as given below equation.

$$\text{Overshooting} = \frac{\text{Max. speedResponds} - \text{Set point}}{\text{Set point}}$$

c) Settling Time (Ts): The time it takes for the system to converge to its steady state, is called the settling time.
d) Steady-state Error: the difference between the steady-state output and the desired output.

PI controller reduces rise time, settling time, steady error and overshoots and minimizes the error. There are number of parameters which should be taken into account in case of motor speed control, like current, torque, speed variation percentage.

2. Fuzzy PI Controller:

Fuzzy controller rules are in terms that can easily understand like slow, medium, fast. Fuzzy logic is a form of number valued in a matrix form eg 3*3, 2*2 etc matrix, based real number.

- **Fuzzification**-It is first step of fuzzy input parameter for fuzzy system output is base done result calculation. Its convert analogy input of fuzzy sets and the set values go into rule matrix.
- **Rule matrix**-There are number of operators used at a time that is more than one input AND= min, OR=max and NOT=additive, also required condition.

- **Defuzzification**-It is the last step of fuzzy for output to convert the set value to analogue output.

The block diagram of fuzzy controller is shown in fig.3.

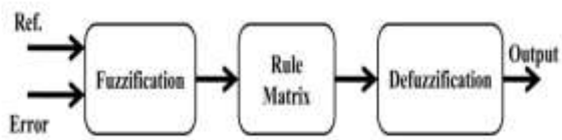

Fig. 3. Block diagram of Fuzzy Controller

IV. SIMULATION RESULT AND DISCUSSION

A. PI Controller Base Model:

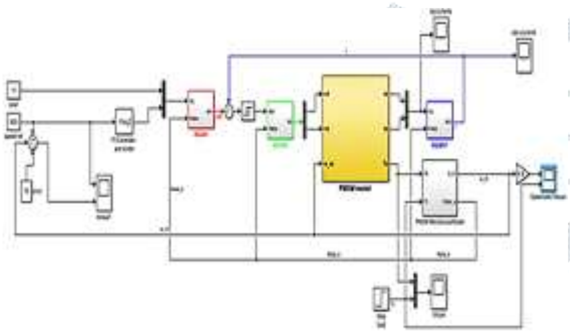

Fig. 4. Simulink model of PI Controlled Speed Controller

Fig. 4 shows the simulink model for conventional PI controller used for the speed control of PMSM. In this system, two references are taken - first one is current reference and second one taken as speed reference. The reference value for current vector is 11A and there are two values of reference speed 700 rpm and 900 rpm. The performance of system is analyzed for combination of various conditions and two values of reference speed using both PI and Fuzzy PI controller simulink model. The speed regulations are obtained at set speed and simulation result are shown in fig 5.

Fig. 5. Speed responses of PI Controller reference speed 700 rpm at No load condition.

The performance of PMSM motor is controlled by using the PI controller having PI coefficient as the follows Kp =0.01 and Ki = 100. In the first case, the reference speed is set up at 700 rpm and motor runs on no load condition. Here, at staring condition initially value of reference current is set at 11A. At starting condition, the speed of motor is zero at that time torque provided by motor is high and also current is high at start. Speed increases slowly exponentially and provided that torque is to be constant. Speed will be constantly move at 0.09 sec to 0.012 sec and the settling time achieved is 0.196 sec.

In the next case, the reference speed is increase at 900 rpm at no load condition. Below fig. 6 shows the speed characteristics where actual speed is achieved after 0.010 sec and settling time is reduced to 0.195 sec.

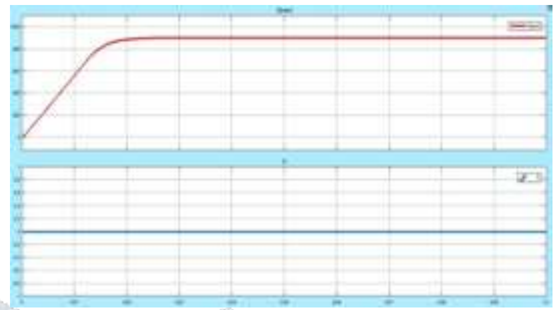

Fig.6. Speed responses of PI Controller reference speed 900rpm at No load condition.

Fig. 7 shows the result for half load condition that is 1.5 N-m for the reference speed 700rpm and current reference will be constant at 11A. The settling time and rise time is 0.0225 sec and 0.022 sec.

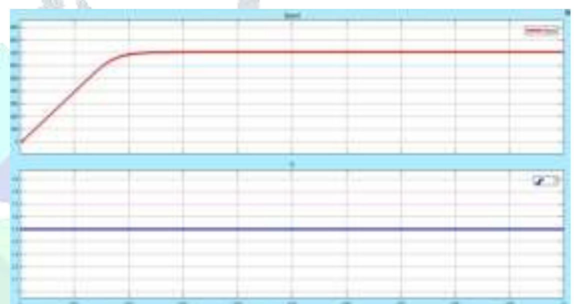

Fig.7. Speed responses of PI Controller reference speed 700rpm at Half load condition

Fig. 8 shows that the reference speed is set at 900 rpm, load condition is changed from no load to half load and current value set as 11A. The reference value of speed is achieved at the rise time 0.0205 sec and settling time 0.0210 sec.

Fig.8. Speed responses of PI Controller reference speed 900rpm at Half load condition

In further case, load is increased from half load to full load and the reference speed is taken as 700 rpm. In this case the reference value of current is set at 11A. The reference speed is achieved at the time of 0.014 sec and settling time reduced to be 0.185 sec at that position as shown in fig. 9.

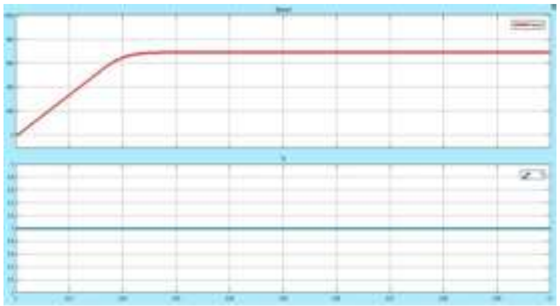

Fig.9. Speed responses of PI Controller reference speed 700rpm at Full load condition

For next case, reference speed is set at 900 rpm and full load condition is taken. The reference speed is achieved at the time 0.010 sec and settling time is 170 sec as shown in below fig. 10.

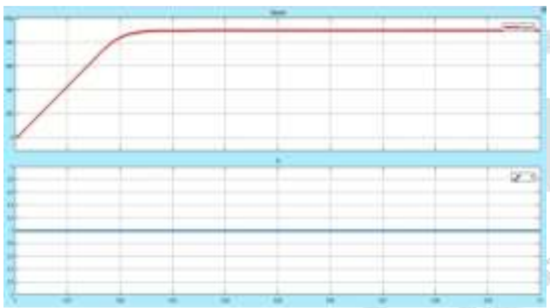

Fig.10. Speed responses of PI Controller reference speed 900 rpm at full load condition

B. Fuzzy-PI Controller Base Model:

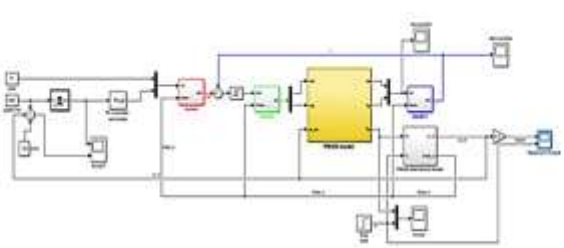

Fig. 11. Simulink model of Fuzzy-PI Controlled Speed Controller

Fig. 11 shows controller using the combination of fuzzy and PI. In this system, current reference is set at 11A and two values 700 rpm and 900 rpm of speed reference are taken for analysis. The speed of PMSM is taken as feedback and it is compared with the reference values of speed. Further, the generated error signal is provided to fuzzy controller block.

When fuzzy controller is introduced in system, it gives the value of mandarin function of two rules- one is output is less than required speed up and second is no change when required speed is reached at reference speed. Whereas in case of conventional PI controller, the value of gains Kp and Ki are adjusted to achieve near to reference speed. The motor is controlled by varying current and its range is 0A to 11A.

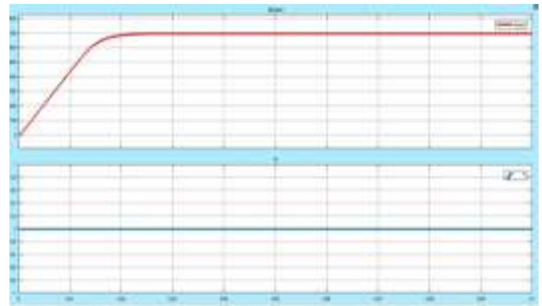

Fig.12. Speed responses of fuzzy PI controller ref. speed 700rpm at No load

The result of fuzzy and PI controller combination-based speed controller at no load condition for reference speed as 700rpm is shown in fig.12. In this case, speed waveform has smooth nature and it has settling time of 0.0154 sec. and rising time 0.015 sec. Similarly, below fig 13 shows the performance of PMSM for no load condition at reference speed of 900 rpm. In this case, motor takes some time to achieve reference speed because of no load condition. Here, reference speed 900 rpm is achieved at 0.0143 sec which has smooth waveform. There is settling time achieved is 0.0172 sec to smoothen the waveform.

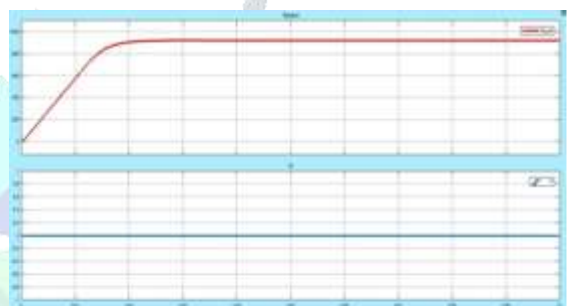

Fig.13. Speed responses of fuzzy PI controller ref. speed 900 rpm at No load

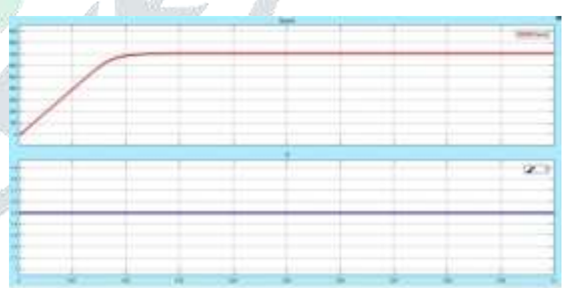

Fig.14. Speed responses of fuzzy PI controller ref. speed 700 rpm at Half load

Fig.14 shows the speed response of fuzzy PI controller the load condition will change no load to half load condition that is load torque 1.5N-m given in simulation model and the reference speed is 700 rpm and current reference 11A. Here, in 0.0202 sec, motor will achieve the reference speed. For this case rise time taken by speed response is 0.0184 sec.

Similarly, fig.15 shows the speed response for half load and the reference speed is take 900 rpm. In that case, the load is changed from no load to half load condition here settling time is achieved is 0.017 sec the result shown in the graph.

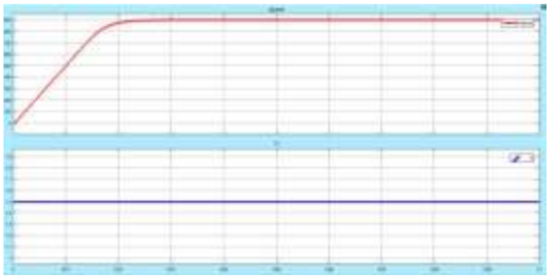

Fig.15. Speed responses of fuzzy PI controller ref. speed 900 rpm at Half load

Fig.16 shows the speed response of fuzzy-PI controller where reference speed is taken at 700 rpm. In this case, the load is changed from half load to full load condition. Here, settling time is 0.0185 sec.

Fig.16. Speed responses of fuzzy PI controller ref. speed 700 rpm at Full load

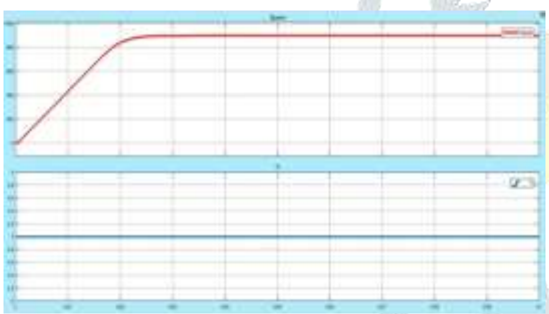

Fig.17. Speed responses of fuzzy PI controller ref. speed 900 rpm at Full load

Fig.17 shows the speed response for Full load condition and the reference speed is taken as 900rpm. Here, 0.0170 sec are taken by motor to achieve the value of reference speed. For this case, rise time taken by speed response is 0.010 sec.

V. COMPARATIVE STUDY

In this simulation work, the speed of PMSM is controlled by using PI Controller and Fuzzy-PI Controller. Table I shows comparison between the performances of these two systems.

Table I: Comparison between PI Controller and Fuzzy PI Controller

Parameter		PI Controller	Fuzzy-PI Controller
Rise Time in sec (No load)	**700 RPM**	0.0900	0.015
	900 RPM	0.017	0.0143
Settling time in sec (No load)	**700 RPM**	0.0196	0.0154
	900 RPM	0.0900	0.0172
Rise Time in sec (Half load)	**700 RPM**	0.022	0.0184
	900 RPM	0.0205	0.016
Settling time in sec (Half load)	**700 RPM**	0.0225	0.0202
	900 RPM	0.0210	0.017
Rise Time in sec (Full load)	**700 RPM**	0.019	0.0195
	900 RPM	0.03	0.032
Settling time in sec (Full load)	**700 RPM**	0.014	0.0185
	900 RPM	0.010	0.0170
Steady-State Error	**700 RPM**	0%	0.1%
	900 RPM	0%	0.1%

In case of PI controller, the settling time for the reference speed of 700rpm is 0.0196 sec and for Fuzzy PI controller the settling time is 0.0154 sec.

For the reference speed of 700rpm, the performance of Fuzzy PI controller is better than PI controller performances as Fuzzy-PI controller provides very small rise time 0.014 sec and small settling time is 0.0185 sec with no overshoot.

For the reference speed of 900rpm, the performance of the proposed fuzzy PI controller is almost better than conventional PI controller. Here, fuzzy-pi controller provides rise time of 0.010 sec and settling time is 0.0170 sec.

VI. CONCLUSION

In this work, performance analysis of speed controlling techniques of PMSM is carried out. Speed controlling of PMSM is achieved using PI controller and Fuzzy-PI controller. All the simulations and results are obtained on Matlab/Simulink tools. From the analysis carried out, it can be concluded that, conventional PI controller provides high rise time and settling time where as Fuzzy-PI Controller takes less time for risen up and settling time. Also, the speed response of Fuzzy-PI controller is smoother in nature. Thus, Fuzzy-PI controller has better performance than conventional PI Controller.

REFERENCES

[1]. J.E Miller, "Brushless permanent-magnet motor drives," Power Engineering Joumal,voI.2, no. 1 , Jan. 1988.

[2]. Yashvant Jani, “Implementing Embedded Speed Control for Brushless DC Motors”, Renesas Technology.

[3]. Uzair Ansari, Saqib Alam, Syed Minhaj un Nabi Jafri,” Modeling and Control of Three Phase BLDC Motor using PID with Genetic Algorithm”, 2011 UKSim 13th International Conference on Modelling and Simulation,pp.189-194.

[4]. Richard Valentine, “Motor Control Electronics”

Handbook, McGraw-Hill, ISBN 0-07-066810-8, 1998
[5]. K. Ang, G. Chong, and Y. Li, "PID control system analysis, design and technology," IEEE Trans.Control System Technology, vol. 13, pp. 559- 576, July 2005.
[6]. AtefSaleh Othman Al-Mashakbeh,"Proportional Integral and Derivative Control of Brushless DC Motor", European Journal of Scientific Research 26- 28 July 2009, vol. 35, pg 198-203.
[7]. ChuenChien Lee, "Fuzzy Logic in Control Systems:Fuzzy Logic controller–Part 1" 1990 IEEE
[8]. Q.D.Guo,X.MZhao. BLDC motor principle and technology application [M]. Beijing: China electricity press.
[9]. Ahmed M. Ahmed, Amr Ali-Eldin, Mohamed S. Elksasy, Faiz F. Areed "Brushless DC Motor Speed Control using both PI Controller and Fuzzy PI Controller" 10January2015