Fuzzy Logic Based Sensorless Control of Interior Permanent Magnet Synchronous Motor

[1]Megha P, [2]Krushnasamy V.S
[1]M Tech student, [2]Assoc Professor
[1]Dept of Instrumentation Technology
[1]Dayananda Sagar College of Engineering, Bengaluru, India

Abstract : There are different ways to improve the performance of IPMSM drives. In this project the speed of Interior Permanent magnet synchronous motor is controlled based on Proportional integral (PI) controller. With this approach, dynamics of the system varies in some cases with operating conditions and time which results in a poor performance. To overcome this problem Field oriented control algorithm based fuzzy logic is proposed. The response time problem in PI controller is resolved by implementing fuzzy logic controller. Sugeno type Fuzzy Inference Engine is implemented with Generalized bell shaped membership function. An internal mounted permanent magnet synchronous machine(IPMSM) is preferred in this project. From simulation results comparison of IPMSM parameters are done between PI controller and Fuzzy controller. The proposed system is implemented in MATLAB simulink.

***Index Terms* - Interior permanent magnet synchronous motor, Proportional integral, Fuzzy controller, Sugeno fuzzy inference engine.**

I. INTRODUCTION

Permanent magnet synchronous motors (PMSM) are more preferable compared to other AC drives due to its various advantages such as high efficiency, high power factor, fast dynamic response, high power density and wide power-speed range. It is an ac synchronous motor that receives field excitation by permanent magnet. PMSM is widely used in electric vehicles, robotics, nuclear power stations, agricultural and industrial applications . Owing to the recent development of permanent magnet materials, induction motors are replaced by PMSM in various fields. Due to no excitation current loss, PMSMs are more efficient than induction motors . PMSM have an ability to follow the reference command values and can operate in specified limits of current, voltage and power ratings. The availability of several control methods for controlling speed, torque and current of PMSM, makes them more suitable for industrial and domestic applications. We can distinguish between two main kinds of PMSM : internal-mounted magnets (with saliency, IM) or surface- mounted magnets (without saliency, SM). In this project internal -mounted magnets that is IPMSM (Interior Permanent magnet synchronous motor) is used and Fuzzy logic control technique is implemented to control the speed (speed should be constant) of IPMSM (interior permanent magnet synchronous motor) drive system with periodical change in load without using mechanical sensors (sensorless).

The use of interior permanent magnet synchronous motors (IPMSM) has become widespread in industrial applications, and in particular to drive compressors and air pipelines due to their high performance and high efficiency. Mounting of the position sensor inside compressors is not possible due to the concentrated solutions of certain weak acids or weak bases, and when taken into consideration along with the impact on cost and reliability of the whole drive system, the sensorless control with rotor speed/position estimation is a preferable approach.

Field oriented control (FOC) of IPMSM is one of the widely used methods in drive applications that is considered in the present work. Field oriented control of IPMSM is one important variation of vector control methods. The aim of the FOC method is to control the magnetic field and torque by controlling the d and q components of the stator currents or relatively fluxes. With the information of the stator currents and the rotor angle a FOC technique can control the motor torque and the flux in a very effective way. The main advantages of this technique are the fast response and the little torque ripple.
The implementation of this technique will be carried out using two current regulators, one for the direct-axis component and another for the quadrature-axis component, and one speed regulator.
The advantages of Field oriented control are :
1. Torque response is improved.
2. Reduction in power consumption
3.cost and size of the motor is reduced

Fuzzy logic resembles the human decision making method. It is generally used in controlling the machine. To implement fuzzy logic technique to a real application requires the following four steps:

1. Fuzzification : The first step in the fuzzy inferencing process is Fuzzification in which crisp inputs are converted into fuzzy inputs. crisp inputs are exact inputs measured by IPMSM drive system and passed into the fuzzy control system as a feedback for processing such as speed. In present work sugeno type fuzzy inference engine is used. Two crisp inputs (speed error and change in speed error) are given to the fuzzy controller. These crisp inputs are converted into fuzzy sets.

2. Rule Base : In an attempt to understand this fuzzy logic in detail, we shall consider the speed control of IPMSM drive system. In present work generalized Bell shaped membership function is used. There are two inputs speed error and change in speed error with 9 membership functions each. It results into 81 rule based. Table 1 represents the fuzzy rules. I_1 speed error and I_2 change in speed error are the two inputs and output is 1.

Table 1: Fuzzy Rules

I_1 \ I_2	MF1	MF2	MF3	MF4	MF5	MF6	MF7	MF8	MF9
MF1	MF1	MF2	MF3	MF4	MF5	MF6	MF7	MF8	MF9
MF2	MF10	MF11	MF12	MF13	MF14	MF15	MF16	MF17	MF18
MF3	MF19	MF20	MF21	MF22	MF23	MF24	MF25	MF26	MF27
MF4	MF28	MF29	MF30	MF31	MF32	MF33	MF34	MF35	MF36
MF5	MF37	MF38	MF39	MF40	MF41	MF42	MF43	MF44	MF45
MF6	MF46	MF47	MF48	MF49	MF50	MF51	MF52	MF53	MF54
MF7	MF55	MF56	MF57	MF58	MF59	MF60	MF61	MF62	MF63
MF8	MF64	MF65	MF66	MF67	MF68	MF69	MF70	MF71	MF72
MF9	MF73	MF74	MF75	MF76	MF77	MF78	MF79	MF80	MF81

For example : if input1 MF1 and input2 MF1 then output1 MF1 (output is 1)
if input1 MF1 and input2 MF2 then output1 MF2 (output is 1)
if input1 MF1 and input2 MF3 then output1 MF3 (output is 1)

Since in present work Generalized Bell shaped membership function is used. Here only peak flattened surface result is considered to get a constant speed for any change in the load. This is shown in fuzzy logic inference with the combination of 9 input error and 9 change in input error which result into 81 combinations. All the output combinations are equal to 1. Membership function in normal language means generalization of the various sets of indicator functions, which work on the concept of degree of truth.

3. Fuzzy Inference Engine : Mamdani and Sugeno are the two methods of fuzzy inference. In present work Sugeno fuzzy inference method is used. The main difference between Sugeno and Mamdani is that the output of Sugeno membership functions are either constant or linear. The advantage of sugeno system is that it is well suited to analysis of mathematical equations.

4. Defuzzification : In Sugeno fuzzy inference the output is either liner or constant . The aim of present work is that speed (1200 rpm) should be constant with cyclic fluctuating loads. The reference speed is 1200 rpm. Here crisp inputs are converted into either constant or linear rather converting fuzzy sets therefore defuzzification method is not applicable in proposed work.

II. LITERATURE SURVEY

Wenguang Li, Yu Zhao, and Kai Lin [1], discussed about the designing of fuzzy adaptive Proportional integral based on model reference adaptive system. The control parameters of Permanent magnet synchronous motor are tuned by implementing the fuzzy controller. While designing MRAS three steps need to be considered. Mamdani -type Fuzzy inference engine had been used with triangular membership function. From the simulation results we can conclude that proposed work has better than PID controller.

M.M. Khater, S.A. Mahmoud [2], discussed about estimating an induction machine rotor speed of an indirect vector controller using method of intelligent control(fuzzy logic). The direct fitting of sensor is not possible. In order to reduce the difficulty of hardware setup, cost and increasing the quality of mechanical machines. By replacing direct sensors with some speed algorithm, Performance of the system has been improved. Simulation is done using MATLAB simulink and experimental setup with TMS320C31 floating point digital signal processing. The successes of the proposed speed evaluation algorithm has been explore under dynamic and steady state operation.

Cheng Chou Lin [3], discussed about an online evaluation of sensorless stator field speed control of induction motor based on fuzzy model reference adaptive scheme. MATLAB software with Real time workshop toolbox is implemented to develop the simulation and program for results of experiment. Mamdani type fuzzy inference engine is used with triangular membership function. MRAS consists of adjustable model and reference model, the output of difference between two models gives the estimated speed. Fuzzy logic controller consists of 4 blocks they are fuzzification, fuzzy inference engine and defuzzification. Centre of sum type defuzzification method has been implemented in this paper. The results obtained from experimental setup and simulation, concludes that the proposed work gives the better results.

Jianru Wan, Guangye Li, Chenhu Yuan and Hong Shen [4], discussed about change in parameters of motor by using PI(Proportional integral) controller. Due to this reasons motor is not able to reach high accuracy. To overcome this problem fuzzy logic PI speed controller is implemented. PMSM is mounted with position sensor, which includes some disadvantages like cost is high and stability of the motor is less. Therefore new technology has been introduced that is sensorless speed control. speed of the rotor is determined based on the scheme of model reference adaptive system. Results obtained from the simulation, concludes that performance of static dynamic is highly improved. MATLAB simulink is used in this paper.

Angelo Accetta, Maurizio Cirrincione, Marcello Pucci and Gianpaolo Vitale[5], discussed about holding information about speed of stator current at the sidebands by implementing adaptive variable band filter based on neural network. ADALINE is trained by using the algorithm called Least mean squares. The proposed work had been tested experimentally based on fractional horse power of permanent magnet synchronous machine drive and also results are compared with the fixed bandwidth. Demodulation algorithm has been used for the technique of sensorless PMSM. Here ADALINE is pre owned as a band filter and helps to control the bandwidth, tracking the exact frequency etc. The adaptive band filter having following advantages. At starting point of single speed moving, setting the higher bandwidth of the filter with sequential increasing the speed of the filter and with a capacity of holding the desired signal alike in the existence of high speed evaluation error.

Z. Boulghasoul, A. Elwarraki and D. Yousfi [6], discussed about adaptation mechanism technique for speed estimation based on a fuzzy controller using model reference adaptive system (MRAS) approach in a direct filed oriented control. This technique is implemented in order to improve sensorless speed estimation of (IM) induction motor in high, low speed and the control and also under a load torque vibrations. The simulation results shows the robustness of this proposed system.

Kuang- Yao Cheng and Ying-Yu Tzou [7], discussed about the novel design approach by applying gradient optimization with fuzzy step-sizing techniques to the design of a digital permanent magnet synchronous motor (PMSM) servo drive. The servo responses are then fed back to evaluate the overall system performances, which can be expressed as objective functions with respect to the servo control parameters. In order to improve the convergent rate of the optimization process, a fuzzy-logic based step-size tuning strategy is presented. Because of the nonlinear property of the digital servo drives, the tuned servo control parameters may be only optimal for a particular operating point, therefore, once the optimum design is achieved, the proposed fuzzy optimizing controller can perform as an intelligent tuner for on-line gain adaptation under different loading conditions.

Amor Khlaief, Moussa Bendjedia , Mohamed Boussak and Moncef Gossa [8], discussed about to provide a high-performance sensorless control of interior permanent magnet synchronous motor (IPMSM) based on nonlinear position and speed observer. The speed estimation is obtained from estimated position using proportional–integral (PI) tracking controller. The observer is stable and easy to implement and does not require a large computing time. The new state variable and PI controller allowed estimation of the rotor position and speed. For this reason, implementation of sensorless technique is to estimate the initial rotor position and initial sector for SVPWM control. To improve the dynamic performance of the overall sensorless control, the implementation of space vector pulse width modulation (SVPWM) technique is necessary. This technique is characterized by lower switching loss, lower torque ripple, and lower total harmonic distortion in the motor current.

Kuang- Yao Cheng and Ying-Yu Tzou [9], discussed about the novel design approach by applying gradient optimization with fuzzy step-sizing techniques to the design of a digital permanent magnet synchronous motor (PMSM) servo drive. The servo responses are then fed back to evaluate the overall system performances, which can be expressed as objective functions with respect to the servo control parameters. In order to improve the convergent rate of the optimization process, a fuzzy-logic based step-size tuning strategy is presented. Because of the nonlinear property of the digital servo drives, the tuned servo control parameters may be only optimal for a particular operating point, therefore, once the optimum design is achieved, the proposed fuzzy optimizing controller can perform as an intelligent tuner for on-line gain adaptation under different loading conditions.

III. RESEARCH METHODOLOGY

The aim of this work is to reduce the settling time of the speed response with periodic change in loads and to minimize the torque ripples by replacing conventional PI speed controller with an Intelligent Controller (Fuzzy control). Block diagram of proposed system is shown in below fig 1.

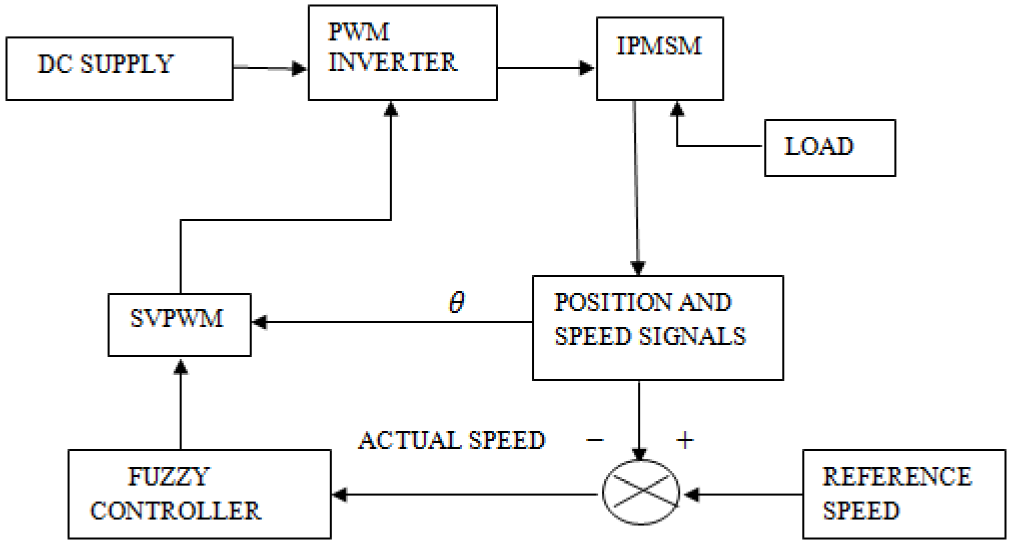

Fig 1: Block diagram of proposed system

The adjustment of control parameters is a key issue for IPMSM drive systems with periodic change in loads. In order to avoid the difficulties involved with manual tuning of the control parameters, a new scheme that is fuzzy logic is proposed in which a fuzzy controller replaces the conventional PI regulator. To implement this new scheme, fuzzy rule is designed. FOC algorithm is typically employed for rotor position or speed estimation in sensorless interior permanent magnet motor (IPMSM) drives.

Simulation model of PI controller for IPMSM drive system is designed as shown in fig 2. PI (Proportional integral control) controller is a continuous type. The reference speed is considered as 1200 rpm(revolutions per minute).

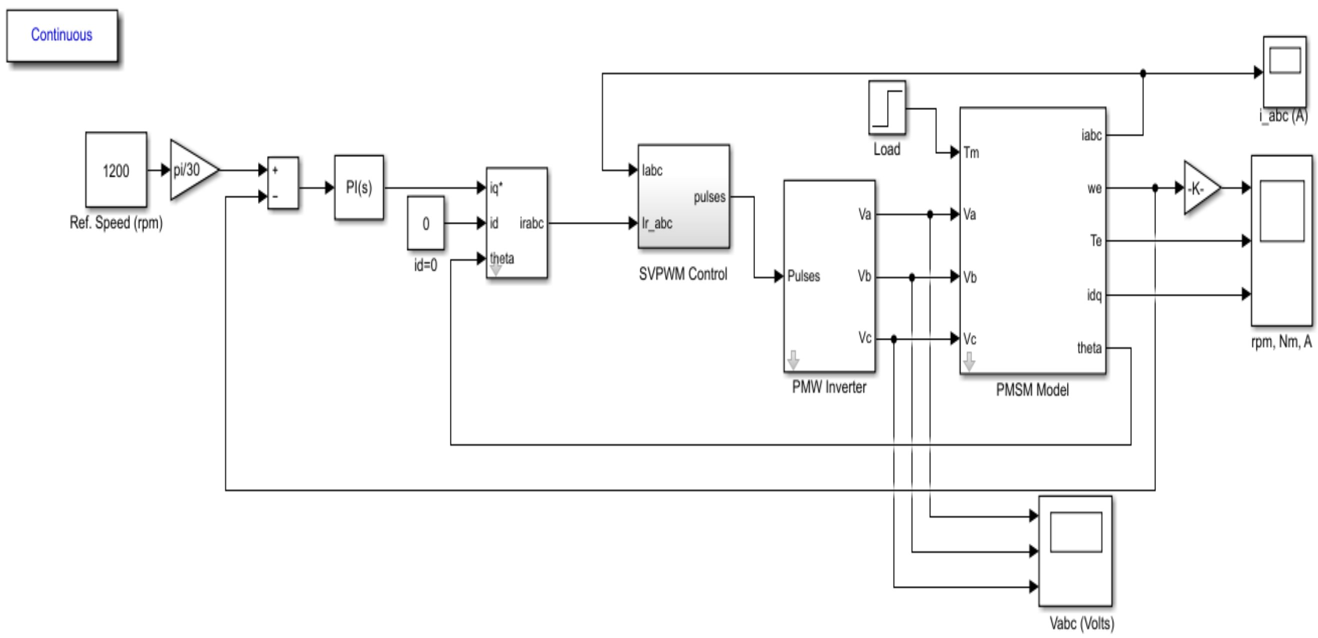

Fig 2: Simulation model of PI controller for IPMSM drive system

The output from PMSM model that is estimated speed (600rpm) and reference speed (1200 rpm) gives error value as 600rpm. Error value is fed to the PI controller to continue the process. The basic control strategy is selected as rotor flux vector control. i_q^* is the reference q axis stator current and i_d is the d axis stator current. Torque control is dependent on q axis stator reference current i_q^*. Hence flux axis stator current i_d is considered as 0. Theta represents position of the rotor. Reference current i_{rabc} and i_{abc} current from IPMSM model is fed to SVPWM control (space vector pulse width modulation). In this control carry wave is greater than sawtooth wave then it will create the sinusoidal pulses. The created pulses are fed to gate of the MOSFET bridge to amplify electronic signals and switching in the electronic devices. PWM inverter converts DC voltage into AC voltage. The electronic signals generated from MOSFET bridge is given to PMSM model in the form AC voltage. 30V ac supply is given to IPMSM model that is V_a , V_b , V_c. simulation results are discussed in result section.

Simulation model of Fuzzy Control for PMSM drive system is shown in below fig 3. Fuzzy control is a discrete type.

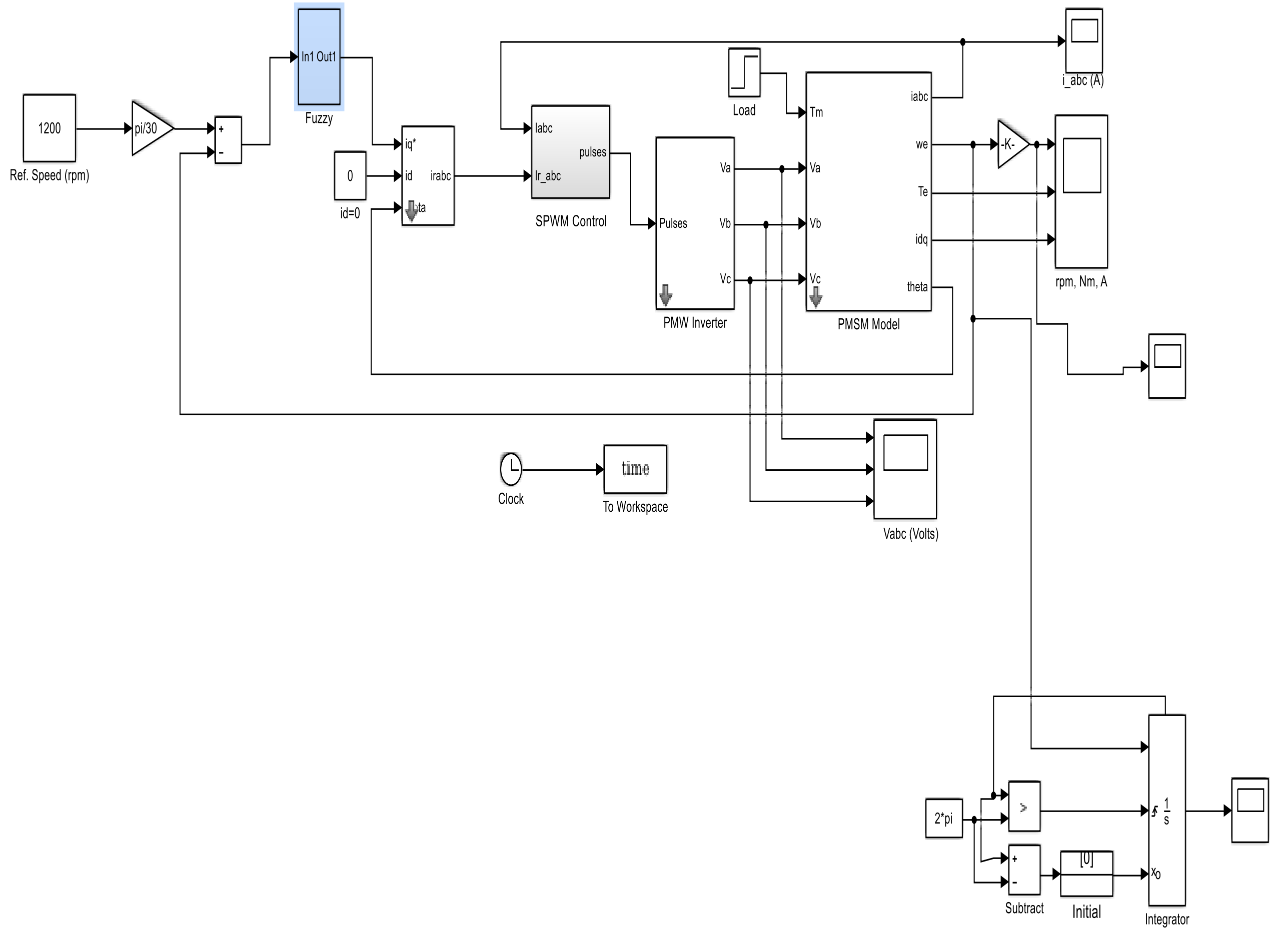

Fig 3: Simulation model of fuzzy control for IPMSM drive system

In this project work sugeno type fuzzy inference engine is used to maintain the constant speed with periodic change in load. Two inputs are given to fuzzy controller that is speed error and change in speed error after some delay. Generalized Bell shaped membership function is used. The basic control strategy is selected as rotor flux vector control. i_q^* is the reference q axis stator current and i_d is the d axis stator current. Torque control is dependent on q axis stator reference current i_q^*. Hence flux axis stator current i_d is considered as 0. Theta represents position of the rotor. Reference current i_{rabc} and i_{abc} current from IPMSM model is fed to SVPWM control (space vector pulse width modulation). In this control carry wave is greater than sawtooth wave then it will create the sinusoidal pulses. The created pulses are fed to gate of the MOSFET bridge to amplify electronic signals and switching in the electronic devices. PWM inverter converts DC voltage into AC voltage. The electronic signals generated from MOSFET bridge is given to PMSM model in the form AC voltage. 30V ac supply is given to PMSM model that is V_a , V_b , V_c. simulation results are discussed in result section.

IV. RESULTS AND DISCUSSION

1. Response of field oriented controlled IPMSM drive using PI controller.

Stator phase current, speed and torque response of field oriented controlled IPMSM drive using proportional integral controller is shown in fig 4 and 5.

1.1 Stator phase current

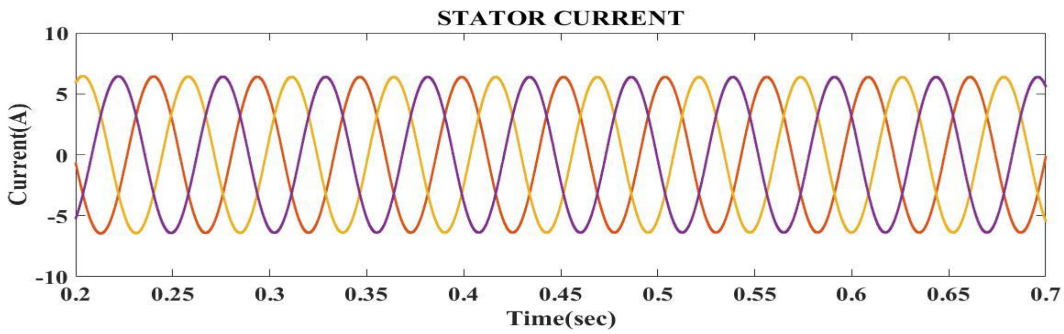

Fig 4: Stator phase current response of IPMSM

x axis represents time in sec and y axis represents current in (A). Above figure indicates simulation result of stator phase current of IPMSM drive system.

2. speed and torque response

Speed and torque response of PI controller for IPMSM drive is shown in fig 5. From simulation results we can find settling time of speed response is 0.0899sec at this time speed reaches the steady state (1200 rpm) for motor load torque of 3N-m.

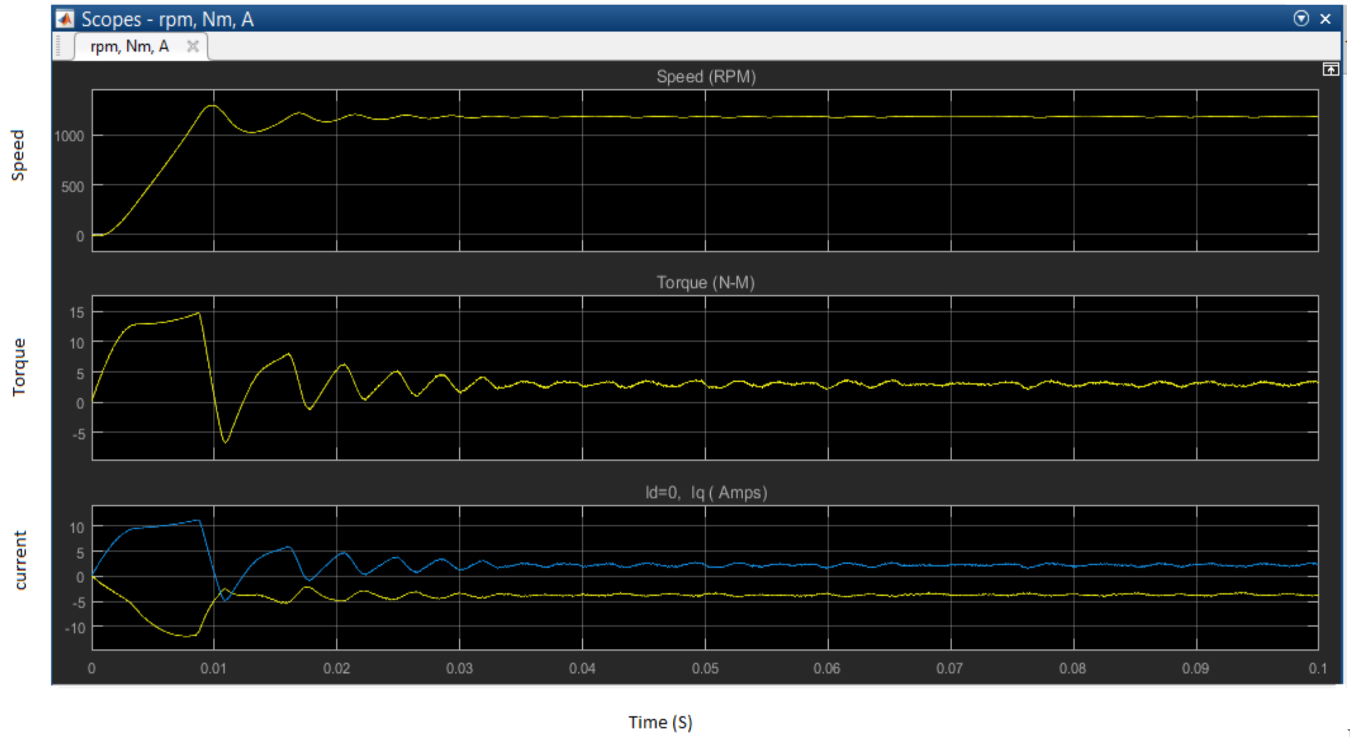

Fig 5: Speed and Torque response of IPMSM

2. Response of field oriented controlled IPMSM drive using fuzzy logic controller.

Stator phase current, speed and torque response of field oriented controlled IPMSM drive using fuzzy logic controller is shown in fig 6 and 7.

2.1 Stator phase current response

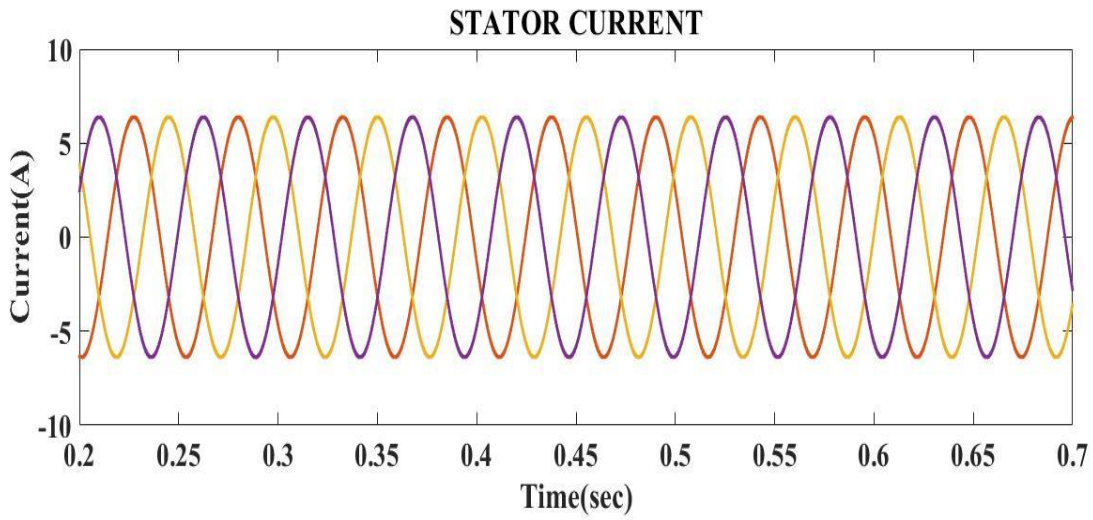

Fig 6: stator phase current response of IPMSM

x axis represents time in sec and y axis represents current in (A). Above figure indicates simulation result of stator phase current of IPMSM drive system.

2.2 Speed and torque response

Speed and torque response of fuzzy controller for IPMSM drive is shown in below fig 7. From simulation results we can find settling time of speed response is 0.0245sec at this time speed reaches the steady state (1200 rpm) for motor load torque of 3N-m.

From MATLAB simulation results settling time of speed response of IPMSM drive using PI controller is 0.0899sec and settling time of speed response of IPMSM drive using fuzzy controller is 0.0245sec.

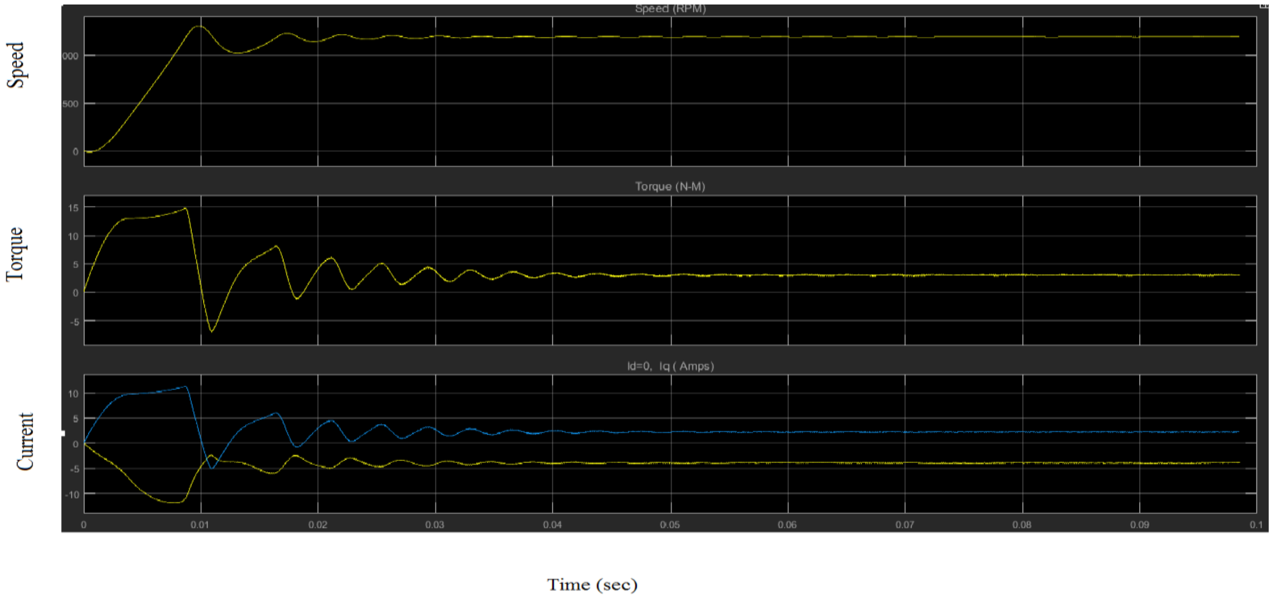

Fig 7: Speed and torque response of IPMSM

3. Parameter comparison of different controller for IPMSM drive system.

Table 1: Implementation results of PI and Fuzzy logic controller

Load Torque	Parameters	PI controller	Fuzzy Logic controller
	Settling time	0.0899 sec	0.0245 sec
3 N-m	Overshoot	11.1045 rad/sec	9.7084 rad/sec
	Undershoot	1.1545 rad/sec	0.9768 rad/sec
	Settling time	0.4974 sec	0.0240 sec
2 N-m	Overshoot	11.3762 rad/sec	10.4401 rad/sec
	Undershoot	0.5427 rad/sec	0.4170 rad/sec

From simulation results of PI controller and Fuzzy logic controller above parameters are noticed as shown in table 1. From simulation results we can write settling time, overshoot and undershoot of IPMSM using PI controller are 0.0899sec, 11.1045 rad/sec and 1.1545 rad/sec. settling time, overshoot and undershoot of IPMSM using fuzzy controller are 0.0245sec, 9.7084 rad/sec and 0.9768 rad/sec for motor load torque of 3N-m. From this we can conclude that the settling time, overshoot, undershoot of speed response have been reduced using fuzzy controller. Rated load torque is 3N-m. For different load torque the parameters of PI and fuzzy controller are changed as shown in table 1.

REFERENCES

[1].Wenguang Li, Yu Zhao, and Kai Lin, "Design and simulation a fuzzy-adaptive PI controller based on MRAS," IEEE International Conference on Natural Computation, pp.2321-2324, 2010.
[2].M.M. Khater, S.A. Kalilah, and S.A. Mahmoud, "Fuzzy logic based MRAS for sensorless induction motor drive," IEEE Middle East Power System Conference, pp.427-433, 2006.
[3].Cheng Chou Lin, "Fuzzy MRAS based speed estimation for sensorless stator field oriented controlled induction motor drive," IEEE International Symposium on Computer Communication Control and Automation, pp.152-155, 2010.
[4].Jianru Wan, Guangye Li, Chenhu Yuan, and Hong Shen, "MRAS speed identification for PMSM based on fuzzy PI control," IEEE Conference on Industrial Electronics and Applications, pp.1995-1998, 2009.
[5].Angelo Accetta, Maurizio Cirrincione, Marcello Pucci, and Gianpaolo Vitale, "Sensorless control of PMSM fractional horsepower drives by signal injection and neural adaptive-band filtering," IEEE Transactions on Industrial Electronics, vol.59, No.3, pp.1355-1366, 2012.
[6].Z.Boulghasoul, A. Elbacha, E. Elwarraki, and D. Yousfi, "Robustness of fuzzy controller based adaptation mechanism for MRAS sensorless IM drives," in IEEE International Conference on Electrical Machines, pp.1-6, 2010.
[7].Kuang-Yao Cheng, and Ying-Yu Tzou, "Fuzzy optimization techniques applied to the design of a digital PMSM servo drive," IEEE Transactions on Power Electronics, vol.19, No.4, pp.1085-1099, 2004.
[8].Amor Khlaief, Moussa Bendjedia, Mohamed Boussak, Senior Member, IEEE, and Moncef Gossa," A Nonlinear Observer for High-Performance Sensorless Speed Control of IPMSM Drive", IEEE Transactions on Power Electronics,Vol.27,NO.6,June 2012.
[9]. Kuang-Yao Cheng, and Ying-Yu Tzou, "Fuzzy optimization techniques applied to the design of a digital PMSM servo drive," IEEE Transactions on Power Electronics, vol.19, No.4, pp.1085-1099, 2004.