NEW ADAPTIVE SPEED CONTROLLER FOR IPMSM DRIVE

Aadyasha Patel[1], Karthigha D.[2], Sathiya K.[3]

[1, 2, 3] *Assistant Professor, Electrical & Electronics Engineering, PSVP Engineering College, Tamil Nadu, India*

ABSTRACT

For controlling nonlinear, time-varying, or ill-defined systems, artificial intelligent controllers have proven to be superior to conventional controllers in design and performance. This project presents a novel adaptive-network-based fuzzy inference system (ANFIS) for the speed control of interior permanent magnet synchronous motor (IPMSM) drives. The variation of load causes variation in current and speed. The speed of the motor can be calculated using the encoder, which is directly fed to the microcontroller and the controller displays the corresponding revolution per minute through a LCD. The Hall Effect sensor senses the current; this analog output is converted into a digital signal using ADC and is fed to the microcontroller. The current and speed is given as the parameters to microcontroller which consists NFC. This NFC takes the change in current and speed as reference and using the embedded C-program determines the width of pulse to maintain a constant speed of the IPMSM. Based on the output of the microcontroller the PWM drive generates the pulse which is given to the inverter, thereby, generating an AC output. The ac output is given to the motor in order to maintain a constant speed.

Keyword: - *IPMSM drive, NFC, ANFIS, Fuzzy Logic, Permanent Magnet, Hall Effect.*

---

1. INTRODUCTION

To control nonlinear, time-varying, or ill-defined system, artificial intelligent controllers have proven to be superior to conventional controllers. The speed control of Interior Permanent Magnet Synchronous Motor (IPMSM) drives can be attained by a new Adaptive Network-based Fuzzy Inference System (ANFIS). A flux control technique for different speed regions is also incorporated to achieve optimum efficiency and good speed response over the entire speed range.

A synchronous motor is a constant speed machine and rotates with zero slip at the synchronous speed which depends upon the frequency and the number of pole. Synchronous speed is directly proportional to supply frequency. So speed of synchronous motor can be directly controlled by controlling the stator frequency. It converts electrical energy into mechanical energy running at synchronous speed. Synchronous motor can be classified as wound field motor, permanent magnet motor, synchronous reluctance motor, and hysteresis motor.

In medium and small size motors, DC field can be produced by permanent magnets. Such motors are known as permanent magnet synchronous motor. A Permanent magnet synchronous motor or Permanent Magnet AC Motor (PMAC) are further classified as surface mounted permanent magnet and interior permanent magnet motor.

Interior or buried Permanent Synchronous Magnet Motors (IPMSM) has magnets mounted inside the rotor. The stator has three phase sinusoidal winding. The machine is robust permitting a higher speed of operation. The effective air gap in d-axis is larger than that in q-axis, which makes the machine a salient pole. With the effective air-gap being low, armature reaction effect becomes dominant. The advantages of IPMSM are high efficiency, high power factor, low noise, robustness etc. Despite these advantageous features, the precise speed control of IPMSM is difficult due to nonlinear coupling among its winding and rotor speed as well as nonlinearity created in the electromagnetic developed torque by magnetic saturation of rotor core.

N. Imai, *et al* (2008) have analyzed the influence of rotor configuration on sensor less control of permanent magnet synchronous motor. Two types of rotors were analyzed and their robustness of sensor less control for a control parameter was compared. To analyze the influence of magnetic saturation, nonlinear motor voltage equation was solved. Finite element analysis played an important role to analyze the influence of magnetic saturation in a short time. Type 1 rotor that had thin salient poles on surface of permanent magnets were very sensitive to the offset value of the observer. Type 2 rotors that had salient poles on the side of the permanent magnets showed much better performance of sensor less control than type 1 rotor. The proposed method was valid for evaluating the influence of magnetic saturation and rotor configuration on sensor less control for permanent magnet synchronous motors, and was very useful to design permanent magnet motors for sensor less control.

K. Malekian, *et al* (2007) have proposed a radial basis function network for online tuning of a genetic based fuzzy logic controller for interior permanent magnet synchronous motor drive over wide speed range. Initially different operating conditions were obtained based on motor dynamics incorporating uncertainties. At each operating condition, a genetic algorithm was used to optimize fuzzy logic controller (FLC) parameters in closed-loop vector control scheme. This optimization design procedure was utilized to obtain the minimum speed deviation, minimum settling time, and zero steady-state error. The drive was found robust in terms of quick response and disturbance rejection. Control regimes, such as the maximum torque per ampere control and flux weakening control with voltage and current constraints had been applied successfully.

S. Morimoto, *et al* (2006) have defined the mechanical sensor less drive system for an interior permanent magnet synchronous motor for which parameters including the inverter were identified. The rotor position was estimated by a signal injection sensor less scheme at standstill. The resistance, including the on resistance of the Insulated Gate Bipolar Transistor (IGBT), the voltage error caused by the dead time of the inverter, and the d-axis and q-axis inductances were identified. After the motor starts by the signal injection sensor less control, the sensor less scheme changes to a scheme based on the extended emf estimation, which used the identified parameters. The magnetic flux linkage was also identified for the sensor less operation. Such identification of the motor parameters was achieved without a mechanical sensor.

M.N. Uddin, *et al* (2004) have proposed a novel speed control technique based on a hybrid intelligent controller for an IPMSM drive. In the proposed hybrid intelligent approach a new neuro-fuzzy technique was used for online tuning of the parameters of a PI controller whose initial values were optimized by a Genetic Algorithm (GA). The PI controller parameters had been optimized offline using a GA with a performance index to reflect the minimum settling time, minimum overshoot/ undershoot, and zero steady-state error. Based on the optimized operating conditions and control parameters the Fuzzy Based Function Network (FBFN) structure had been developed and trained for online tuning of the PI controller parameters.

M.A. Rahman, *et al* (2003) have presented the Artificial Neural Network (ANN) based real-time adaptive controller for accurate speed control of IPMSM under system uncertainties. A field-oriented IPMSM model was used to decouple the flux and torque components of the motor dynamics. The initial estimation of coefficients of the proposed ANN speed controller was obtained by offline training method. The ANN speed controller adaptively tackles the problems of parameter changes and load variations, and enables the drive system to follow the reference speed precisely.

Z. Ibrahim, *et al* (2002) have presented a meaningful comparison of two controllers which were designed in such a way that a more or less identical speed response was obtained for the design point. Once designed for certain operating point, neither the PI nor the Fuzzy Logic (FL) speed controller was likely to offer a superior behavior for all the transients over the entire speed control region. The PI controller, being a standard industrial speed controller solution at present, would continue to be compared to various novel forms of speed controllers that would emerge in the future. Comparison based on a single operating point or a single transient was more than insufficient.

From the literature survey it is seen that the conventional PI and PID methods for speed control of IPMSM drives are very sensitive to disturbance. On the other hand, FLC has a narrow speed operation and in case of ANN, it is extremely tough to create a series of training data. Hence, an attempt has been made to develop an online adaptive network based fuzzy inference system for the speed control of IPMSM drives. [2].

2. ADAPTIVE SPEED CONTROLLER FOR IPMSM DRIVE

The speed of Interior Permanent Magnet Synchronous Motor (IPMSM) is controlled by using Adaptive Network Based Fuzzy Inference System (ANFIS) based simplified Neuro Fuzzy Controller (NFC) which is explained in this chapter. Also explained, the parameters for NFC like speed and current sensed by encoder and Hall Effect sensor respectively.

3. BLOCK DIAGRAM

The variation of load causes variation in current and speed. The speed of the motor can be calculated using the encoder, the encoder is directly fed to the microcontroller and the controller displays the corresponding revolution per minute through a LCD. The Hall Effect sensor senses the current; this analog output is converted into a digital signal using ADC and is fed to the microcontroller. The current and speed is given as the parameters to microcontroller which consists NFC. This NFC takes the change in current and speed as reference and using the embedded C-program determines the width of pulse to maintain a constant speed of the IPMSM. Based on the output of the microcontroller the PWM drive generates the pulse which is given to the inverter thereby generating an AC output. The ac output is given to the motor in order to maintain a constant speed as shown in Fig. 1.

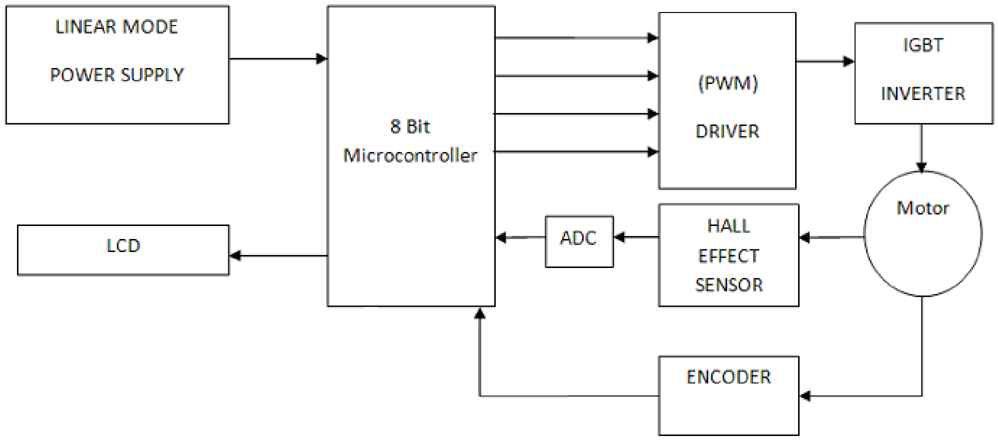

Fig -1: Block Diagram

3.1 Neuro Fuzzy Controller

Fuzzy Logic (FL) is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both. FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. It uses an imprecise but very descriptive language to deal with input data more like a human operator.

FL is different from conventional control methods in a way that it incorporates a simple, rule-based IF X AND Y; THEN Z approach to a solving control problem rather than attempting to model a system mathematically. The FL model is empirically-based, relying on an operator's experience rather than their technical understanding of the system. While variables in mathematics usually take numerical values, in fuzzy logic applications, the non-numeric linguistic variables are often used to facilitate the expression of rules and facts. However, a simple Fuzzy-Logic Controller (FLC) has a narrow speed operation and needs much more manual adjustment by trial and error if high performance is desired.

An Artificial Neural Network (ANN), usually called "Neural Network" (NN), is a mathematical model or computational model that tries to simulate the structure and/or functional aspects of biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. Neural networks are non linear statistical data modeling tools. However, it is extremely tough to create a series of training data for ANN that can handle all the operating modes.

The concept of a Neuro–Fuzzy Controller has emerged in recent years, as researchers have tried to combine the advantages of both FLC and ANN. The NFC utilizes the transparent linguistic representation of a fuzzy system with the learning ability of ANNs. The algorithm of the tuning of the consequent parameters can be developed using a reinforcement signal which is equal to the normalized speed error of the IPMSM. Since it is impossible to determine or calculate the desired ANFIS controller output iq and find the train data offline covering all operating conditions, a kind of unsupervised online self-tuning method is employed in this paper. Instead of using the desired controller’s output i_q as the target; the reinforcement signal is utilized to generate control actions to produce the desired speed response.

3.2 Interior Permanent Magnet Synchronous Motor

IPMSM is a type of permanent magnet synchronous motor. It has magnets mounted inside the rotor and the stator has three phase sinusoidal winding. The machine is robust permitting a higher speed of operation. The effective air gap in the d-axis is larger than that in q-axis, which makes the machine a salient pole. With the effective air gap being low, the armature reaction effect becomes dominant. IPMSM is popular due to some advantages over others such as its high torque-to-current ratio, large power-to-weight ratio, high efficiency, high power factor, low noise, robustness, etc. The IPMSM used is of the range of 1.5 kW, 7000 rpm.

3.3 Encoder

An encoder is an electrical mechanical device that converts linear or rotary displacement into digital or pulse signals. We are going to use an incremental magnetic rotary encoder which consists of a disk, which is mounted on the rotating shaft and has patterns of opaque and transparent sectors coded into the disk. As the disk rotates, these patterns interrupt the light emitted onto the photo detector, generating a digital or pulse signal output. An incremental encoder generates a pulse for each incremental step in its rotation.

3.4 Hall Effect Sensor

Hall Effect sensor is a transducer that varies its output voltage in response to changes in magnetic field. Hall sensors are used for proximity switching, positioning, speed detection, and current sensing applications. The Hall-effect integrated circuit included in each device includes a Hall sensing element, a linear amplifier, and a CMOS Class A output structure. Integrating the Hall sensing element and the amplifier on a single chip minimizes many of the problems normally associated with low voltage level analog signals. High precision in output levels is obtained by internal gain and offset trim adjustments made at end-of-line during the manufacturing process.

4. SIMULATION

The block diagram for speed control of IPMSM drive using ANFIS is elaborated as shown in fig. 2 for better understanding and simulation purpose. The controller part consists of ANFIS based Neuro Fuzzy Logic (NFC) controller, flux controller and vector rotator. The flux controller is used to control the flux below the rated speed in partial field weakening region and in pure field weakening region.

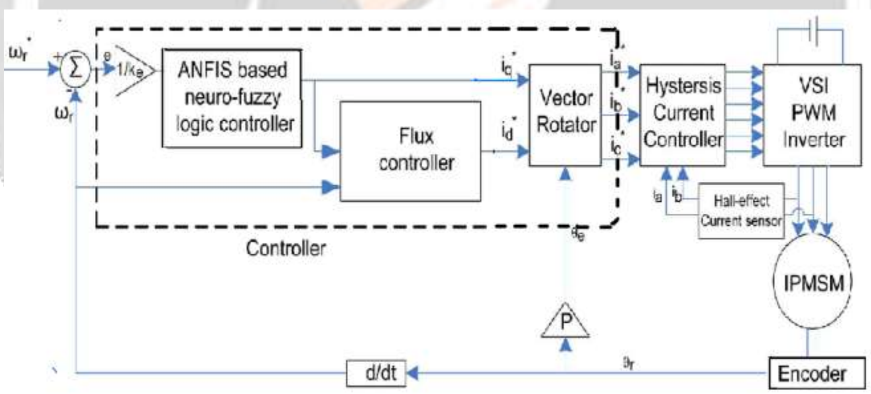

Fig -2: Simulation Block Diagram of IPMSM

In partial field weakening region flux is controlled above the rated speed and the rotor angular frequency is maintained less than the critical frequency. In pure flux weakening region flux is controlled above the rated speed and the rotor angular frequency is maintained above the critical frequency. The vector rotator as shown in the Fig. 2 is used to convert the two phase currents i_d and i_q into three phase current i_a, i_b and i_c. This is done by keeping voltage/frequency constant and varying voltage and frequency to get the desired torque and speed.work

5. OUTPUT

To get the output waveforms, the simulation circuit has to be simulated. Once the circuit is simulated the outputs are obtained by double clicking the scopes. As the load changes the i_q current must increase and the i_d current must decrease to maintain the constant speed. This can be seen in the waveform shown in Fig. 3 where in, the i_q current increases and the i_d current decreases thus maintaining the speed constant.

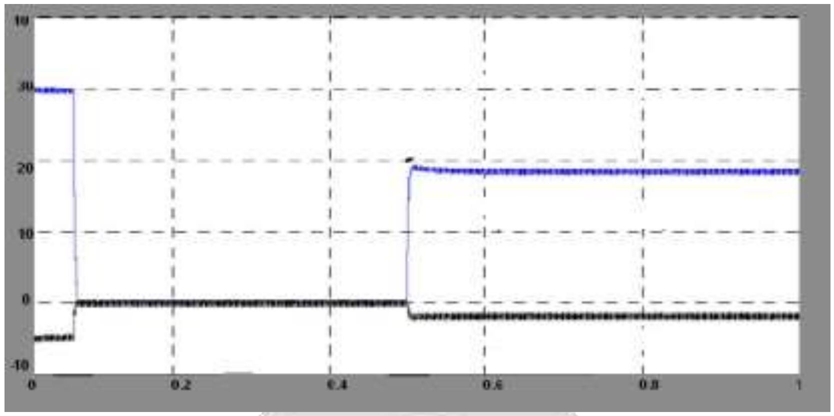

Fig – 3: I_d and I_q Axes Current

At the same time, with the increase or change in load the line current should increase which would make the speed almost insensitive to change in load. The increase in line current due to change in load is shown in Fig. 4

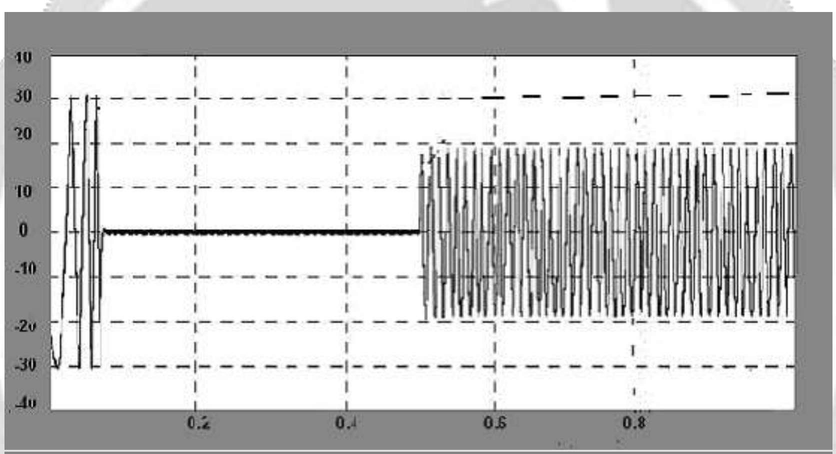

Fig - 4: Line Current

In Fig. 5 it is seen that drive can follow the change in load without any undershoot or overshoot. As the load changes the iq current as well as the line current increases and on the other hand the id current decreases maintaining a maximum torque per ampere, thus making the speed response almost insensitive to change in load.

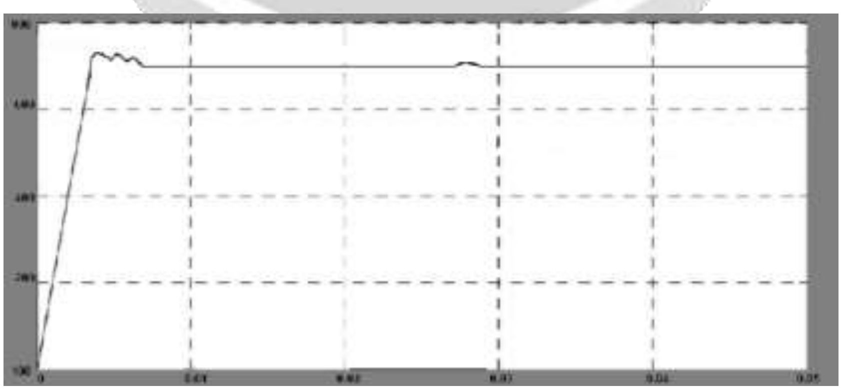

Fig -5: Speed Waveform

6. RESULT

For sets of disturbance applied the corresponding settling time i.e. the time when the motor returns to its set speed is measured. Table 1 shows the settling time of the motor for various load applied.

Table - 1 Settling Time of Motor

Set Speed	Speed after applying load (RPM)	Settling Time (ms)
250	175	900
500	430	75
750	685	500

7. CONCLUSION

The speed response of IPMSM has been simulated using MATLAB/SIMULINK. The simulated result showed that as the load applied to the motor changes or increases the i_d current decreases and the i_q and line current increases to increase the torque, thus to maintain the set command speed.

8. REFERENCES

[1] [1] C.-T. Pan and S.-M. Sue (2004), "A linear maximum torque per ampere control for IPMSM drives considering magnetic saturation", in Proc.30th Annu. Conf. IEEE Ind. Electron. Soc., Nov. 2–6, vol. 3, pp. 2712–2717.

[2] G.-Y. Choi, M.-S. Kwak, T.-S. Kwon, and X. Seung-Ki (2007), "Novel flux weakening control of an IPMSM for quasi six-step operation", in Conf. Rec. 42nd IEEE IAS Annu. Meeting, Sep. 23–27, pp. 1315–1321.

[3] M. Takiguchi, T. Murata, J. Tamura, and T. Tsuchiya (2007), "Maximum torque/minimum flux control of Interior Permanent Magnet Synchronous Motor based on magnetic energy model", in Proc. Eur. Conf. Power Electron. Appl., Sep. 2–5, pp. 1–10.

[4] R. Mohammdi-Milasi, C. Lucas, and B. Nadjar-Arrabi (2004), "Speed control of an interior permanent magnet synchronous motor using BELBIC (brain emotional learning based intelligent controller)", in Proc. World Autom. Congr., vol. 16, pp. 280–286.

[5] Y. Chen, B. Yang, X. Gu, and S. Xing (2006), "Novel fuzzy control strategy of IPMSM drive system with voltage booster", in Proc. 6th World Congr. Intell. Control Autom., Jun. 21–23, vol. 2, pp. 8084–8087.