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Method & Implementation on Fuzzy Rule based Control on PMSM Drive

Asif Ali Bhat[1], Parveen Saini[2]

Student, M. Tech - EE, EMGOI, Ambala[1]

Assistant Professor, Dept EE, EMGOI, Ambala[2]

Abstract: This paper presents a fuzzy rule based control on permanent magnet synchronous motor. This work presents the results of a detailed comparative study on Fuzzy logic speed controller in Dual PMSM drives. The main goal of the control system is to determine the effectiveness of the 'case design' for high performance PMSM drive by comparing the speed response with 'standard design' obtained. It consists of Fuzzy controller that will provide robustness for motor control. This study aims to select the most robust controller against the stator faults, load torque variation and reversing rotation speed. First, a conventional PI controller was evaluated with the Fuzzy Controller with constant gain without using the observer. The comparative aspects were the speed response, the stator currents, the electromagnetic torque. The experimental results show the demonstrated the utility of using the nonlinear control with a time-varying system. In contrast, the Fuzzy controller exhibited super performance in simulated tests.

Keywords: PMSM, Load Control, PI controller, Fuzzy Controller etc.

I. INTRODUCTION

Many types of electric motors have been used in the industry for different purposes: cranes, spinning machines, public transportation and so on. AC motors are widely used and ac drives are subject of study for many researchers. Recently, ac drives in vehicle applications are gaining attention due to pollution and fuel price problems. In the electrical system of an electric or hybrid electric vehicle based on an ac motor, the motor is producing torque from the battery through the inverter. To charge the battery the grid power is utilized in some vehicles called grid-connected version. Since the battery charging and traction power is not happening simultaneously it is possible to use inverter and motor in charger circuit to reduce the price, volume, weight and space of the charger. This is called integrated charger.

Current technological advancements in development of smaller, energy efficient and more powerful motors has opened market for wide range of products, including portable appliances, electric vehicles and entertainment devices. The latest laser based audio systems, digital audio players, actuators in various industrial processes; robotics & house appliances require sophisticated, precise and high performance motion control systems. Design engineers are not only concerned about the improved performance limited to portable device applications like drills, weed cutters but also concerned about stationary applications that are related to motors and drive electronics systems which provide control and protection.
The power requirements of motors can vary from fraction of watts to kilowatts as per application demands. Control techniques for the drive systems are changing from analog modem to digital. Improved semiconductor technology and different controlling methods can work very efficiently with Integrated Circuits (ICs) having low power consumption characteristics. The improved magnetic material, winding insulation and new design of motors are making it more useful device. The modern world is surrounded by motors everywhere. These motors have great influence on our daily life; we are using motors in heating, cooling, water controlling, work saving objects like vacuum cleaner, dish washing and in shop tools. It would be interesting to know that in normal household appliances, count for motors can reach up 50 motors per house while in single car this counting can reach up to 60 motors.

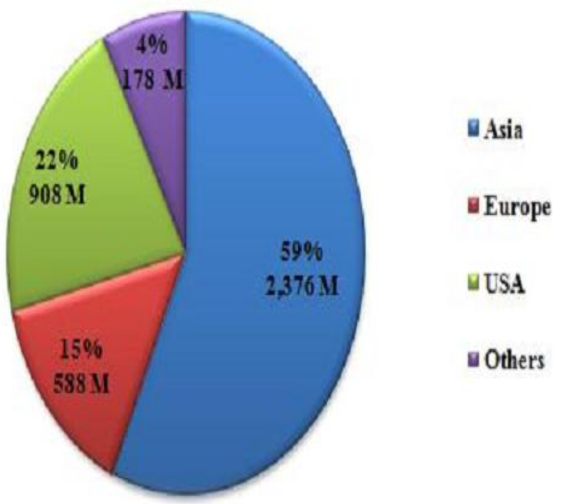

Figure 1: Worldwide Motor Production [1]

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From Figure 1 we can see that in 1994, worldwide production of motors was about 4 billion. One day production for the same year becomes about 11 million motors per day. With an expected growth rate of about 8.5% the number will reach up to 16 billion motors per day before the end of century.

In synchronous motors, rotation of the shaft is synchronized with the frequency of AC supply current. Synchronous motor has the fixed stator winding that is electrically connected to the AC supply. The rotor field windings are connected to the separate excitation source. It has the stator of induction motor and the rotor of dc motor. In synchronous machines, stator is composed of laminated stack comprised of electric sheets. In stator stack there are slots for the winding which is normally 3-phase. For implementation of rotor, there could be several options. It can be implemented as cylindrical non-salient pole rotor, salient pole rotor with separate magnetic poles, reluctance rotor or as a permanent magnet rotor in which magnetic poles are generated by permanent magnets.

The rotor has the facility to be implemented as the laminated construction or the solid one. In permanent magnet machines the excitation cannot be controlled because of permanent magnet so the excitation state is determined by supply voltage. Flux of the machine can be influenced by armature reaction, which is the magnetization of machine with stator currents. The filed winding of the salient pole machine is wound around the iron core.

The paper is ordered as follows. In section II, it represents related work with proposed system in fuzzy based PMSM System. In Section III, It describes the PMSM system. The problem is defined in section IV. Results are presented in section V. Finally, conclusion is explained in Section VI.

II. RELATED WORK

A.Bechkaouiet. al. [1] presented a fault diagnosis method in order to detection the inter-turn short circuit fault in permanent magnet synchronous motor (PMSM) based on the comparative analysis of two types of controllers. This study consists in the sliding mode control (SMC) of the (PMSM) and the two controllers (fuzzy logic controller (FLC) and Adaptive fuzzy logic controller (AFLC) by taking account of the presence of inter-turn short circuit fault. This study aims to select the most robust controller against the stator faults, load torque variation and reversing rotation speed.

Mohamed Kadjoudjet. al. [2] presented that the objective of the model reference adaptive fuzzy control (MRAFC) is to change the rules definition in the direct fuzzy logic controller (FLC) and rule base table according to the comparison between the reference model output signal and system output. The MRAFC is composed by the fuzzy inverse model and a knowledge base modifier. Because of its improved algorithm, the MRAFC has fast learning features and good tracking characteristics even under severe variations of system parameters. The learning mechanism observes the plant outputs and adjusts the rules in a direct fuzzy controller, so that the overall system behaves like a reference model, which characterizes the desired behaviour. In the proposed scheme, the error and error change measured between the motor speed and output of the reference model are applied to the MRAFC.

Suneel K. Kommuriet. al. [3] investigated the problem of automatic speed tracking control of an electric vehicle (EV) which is powered by a permanent magnet synchronous motor (PMSM). A reconfiguration scheme, based on higherorder sliding mode (HOSM) observer, is proposed in the event of sensor faults/failures to maintain a good control performance. The corresponding controlled motor output torque drives EV to track the desired vehicle reference speed for providing uninterrupted vehicle safe operation. The effectiveness of the overall sensor fault-tolerant speed tracking control is highlighted when EV is subjected to disturbances like aerodynamic load force and road roughness using high-fidelity software package CarSim.

P. L. Xuet. al. [4] proposed a novel square-wave type carrier signal injection method using zero sequence voltage for sensor-less control of permanent magnet synchronous machine (PMSM) drives. Different from the conventional square-wave type injection methods employed in the stationary reference frame and estimated synchronous reference frame, the proposed square-wave injection is performed on the estimated reference frame, which rotates anticlockwise at twice estimated rotor electrical angular speed. Compared to the conventional square-wave methods with carrier current sensing, theproposed strategy using zero sequence voltage has two main advantages, (a) the amplitude of the resultant carrier response is not related to the injection frequency, and (b) the carrier response does not require differentiation calculation for rotor position estimation.

Zhiyong Zenget. al. [5] presented a three-phase four-switch (TPFS) inverters are generally applied as cost-reduction topologies for permanent magnetic synchronous motor (PMSM) drives because of their reduced number of switching devices. However, undesirable torque ripples are produced by the inverter-fed PMSMs due to the application of non-sinusoidal voltages. Because the torque ripples are strongly influenced by the employed PWM strategy, two commonly used switching sequences in TPFS inverter-fed PMSM drives are fully investigated based on the root mean square (RMS) value of the torque ripples, in which the effects of the different equivalent zero vectors on the torque ripples are presented.

Adeeb Ahmedet. al. [6] presented a Maximum torque per ampere (MTPA) control scheme for buried magnet permanent magnet synchronous motor (PMSM) or internal permanent magnet (IPM) machine. Proposed control scheme was developed based on measurement of only DC link quantities eliminating the necessity of 3-phase current feedback. The scheme employs an online search algorithm with initial condition computed from the a-priory system information. Hybridization of search based algorithm with

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pre-computed control coefficients ensures robustness against parameter variations while maintaining good dynamic performance.

Ying-Shieh Kunget. al. [7] presented a sensorless speed control IP (Intellectual Property) for PMSM (Permanent Magnet Synchronous Motor) drive. Firstly, the mathematical model of PMSM is derived, and the vector control is built up. Secondly, the rotor flux angle (FA) and rotor speed, which are estimated by using EKF estimator, is described. These estimated values are feed-backed to the current loop for vector control and to the speed loop for speed control. In additional, to cope with the uncertainty of system parameter variation, AFC is applied. The parameters of fuzzy rule will be adjusted according to the minimum performance index requirement which is based on the steepest descend method. Thirdly, the Very-High-Speed IC Hardware Description Language (VHDL) is adopted to describe the behaviour of the sensor less speed control IP which includes the current vector controller, EKF, AFC, etc.

III. DESCRIPTION OF PMSM DRIVE SYSTEM

Permanent magnet synchronous motors (PMSM) are typically used for high-performance and high-efficiency motor drives. High-performance motor control is characterized by smooth rotation over the entire speed range of the motor, full torque control at zero speed, and fast acceleration and deceleration. To achieve such control, vector control techniques are used for PM synchronous motors. The vector control techniques are usually also referred to as field-oriented control (FOC). The basic idea of the vector control algorithm is to decompose a stator current into a magnetic field-generating part and a torque generating part. Both components can be controlled separately after decomposition. Then, the structure of the motor controller (vector control controller) is almost the same as a separately excited DC motor, which simplifies the control of a permanent magnet synchronous motor.

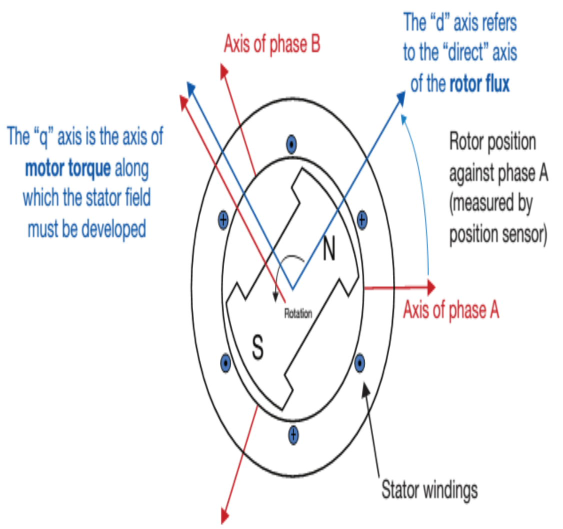

Figure 2: Field-Oriented Control Vector Explanation

1. Torque Generation

A reactance torque of PMSM is generated by an interaction of two magnetic fields (one on the stator and one on the rotor). The stator magnetic field is represented by the magnetic flux/stator current. The magnetic field of the rotor is represented by the magnetic flux of permanent magnets that is constant, except for the field weakening operation. We can imagine those two magnetic fields as two bar magnets, as we know a force, which tries to attract/repel those magnets, is maximal, when they are perpendicular to each other. It means that we want to control stator current in such a way that creates a stator vector perpendicular to rotor magnets. As the rotor spins we must update the stator currents to keep the stator flux vector at 90 degrees to rotor magnets at all times. The reactance torque of an interior PM type PMSM (IPMSM) is as follows, when stator and rotor magnetic fields are perpendicular.

$$Torque=32pp\lambda Iqs$$

2. DC Values/Angle Control

First, we need to know the rotor position. The position is typically related to phase A. We can use an absolute position sensor (e.g., resolver) or a relative position sensor (e.g., encoder) and process called alignment. DC motor control is simple because all controlled quantities are DC values in a steady state and current phase/angle is controlled by a mechanical commutator. During the alignment, the rotor is aligned with phase A and we know that phase A is aligned with the direct (flux producing) axis. In this state, the rotor position is set to zero (required voltage in d-axis and rotor position is set to zero, static voltage vector, which causes that rotor attracted by stator magnetic field and to align with them.

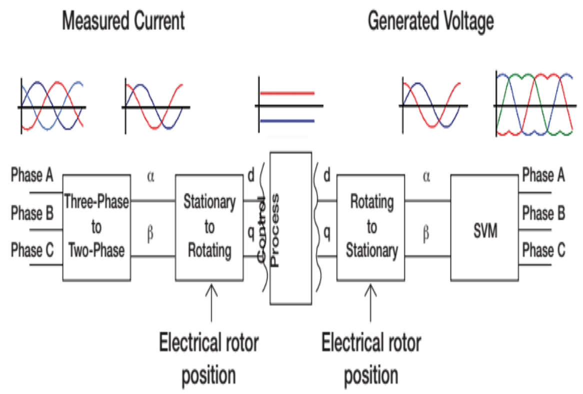

Figure 3: Principle of Field-Oriented Control

3. Sensorless Control

The rotor position information is needed to efficiently perform the control of the PMS motor, but a rotor position sensor on the shaft decreases the robustness and reliability of the overall system in some applications. Therefore, the aim is not to use this mechanical sensor to measure the position directly but instead to employ some indirect techniques to estimate the rotor position. These estimation

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techniques differ greatly in approach for estimating the position or the type of motor to which they can be applied.

IV. RESULTS & DISCUSSION

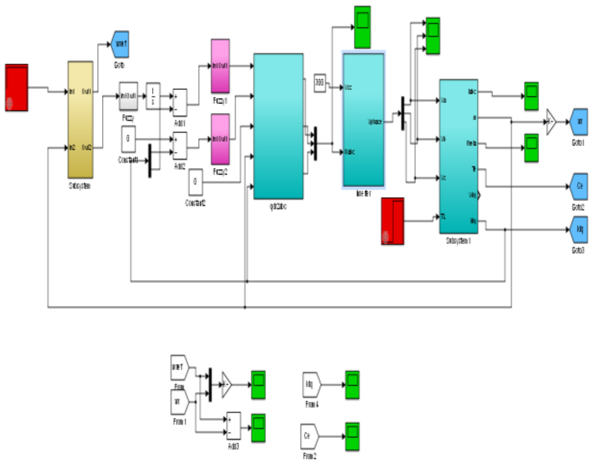

Figure 4: Proposed System Model

PMSM drive is largely maintenance free, which ensures the most efficient operation and it can be operated at improved power factor which can help in improving the overall system power factor and eliminating or reducing utility power factor penalties. From the research over PMSM until now it shows that, in future market PMSM drive could become an emerging competitor for the Induction motor drive in servo application and many industrial applications. So now there is a great challenge to improve the performance with accurate speed tracking and smooth torque output minimizing its ripple during transient as well as steady state condition such that it can meet the expectation of future market demand. Modelling and simulation is usually used in designing PM drives compared to building system prototypes because of the cost. Having selected all components, the simulation process can start to calculate steady state and dynamic performance and losses would have been obtained if the drive were actually constructed.

The most innovative feature of this PMSM is its double stator winding. That means, each phase winding has been divided in two equivalent parts . One part of the three phase windings (A, B and C) are called primary windings and the other (A‟,B‟ and C‟) are called secondary windings. Before explaining the operation of the motor it is necessary to understand the various torques terms that are associated with synchronous motors.

Motor develop maximum torque when its rotor lose its angle of 90^0 or we can say that, it has shifted backward by the distance that is equal to half of the distance b/w adjacent poles. Motor starts its operation when three phase winding of the synchronous motor is energized by three phase supply, then magnetic flux of the constant magnitude but rotating at synchronous speed is produced. The Squirrel cage winding in the rotor generates the Starting and Accelerating torque to catch up the motor speed.

Pulse-width modulation refers to the concept of delivering energy through rapidly pulsing rather than continuous varying analog signal. This method is commonly used in high precision motor control, heaters or lights in varying, intensities or speeds. By increasing or decreasing pulse width, the controller regulates the flow of energy to the motor shaft. The motor inductance plays a very vital role in this operation. It acts like a filter and store energy during the ’on’ cycle and release the energy corresponding to the input or the reference signal.

The dynamic responses of the PMSM motor transformed to the estimated rotor frame are nonlinear, thus the observer and observer error dynamics are nonlinear. The stability of control system is analyzed as a linearized error model. Nowadays, fuzzy logic is one of the well known methods, which is used to overcome the problem in many fields, and also in electrical machine control problems. The main idea to design the fuzzy logic is based on the exact behaviors of the machines. Therefore, fuzzy logic can perform very well with nonlinear system, e.g. AC machines. A Fuzzy control has been employed to control temperature. The error-count is used to trigger the fuzzy inference process.

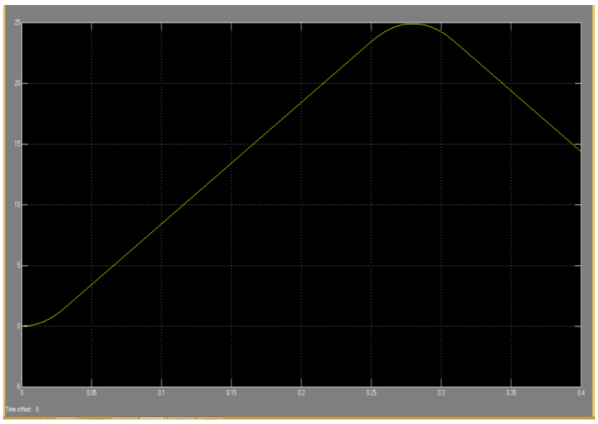

Figure 5: Angle Response of System

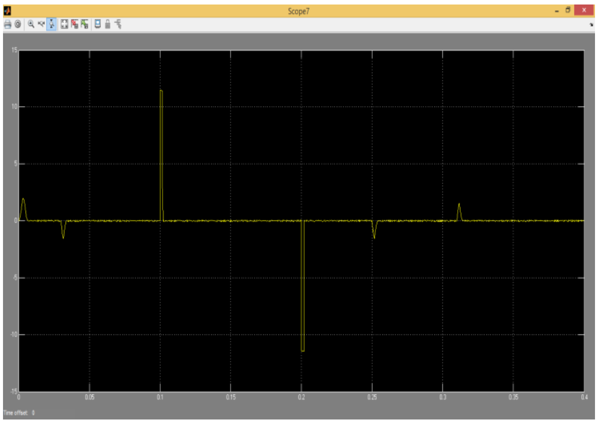

Figure 6: Speed Response using Fuzzy Controller

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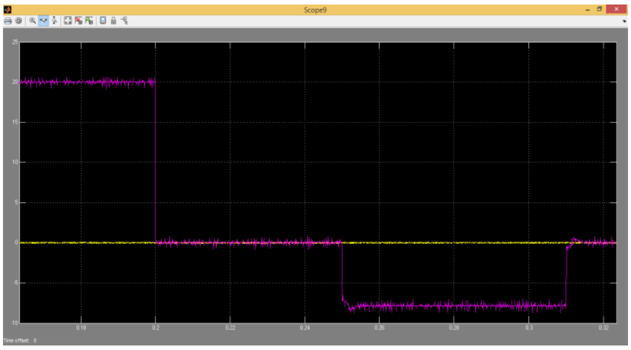

Figure 7: Proposed Stator Current Response

To evaluate the performance of the proposed methods, the model has been implemented in the Matlab / Simulink software. In this work, system is implemented and controlled by fuzzy controller to remove the error response.

The system performance was evaluated using two PI controllers in both the current and speed control loops. The current loop PI controller has been tuned up by PID Tuner. The obtained parameters are Kp for the proportional gain and Ki for the integral gain. The FLC has two inputs speed error e(k) and change in speed error ce(k) and one output u(k) which represents the change in quadrature reference current Iq*(k) . The FLC consists of three stages: the fuzzification, rule execution, and defuzzification. In the first stage, the crisp variables e(k) and ce(k) are converted into fuzzy variables E(k) and CE(k) using the triangular membership functions. In the second stage of the FLC, the fuzzy variables E and CE are processed by an inference engine that executes a set of control rules. The control rules are formulated using the knowledge of the PMSM behavior. The inference engine output variable is converted into a crisp value U FUZZY in the defuzzification stage.

VI. CONCLUSION

This work presents the results of a detailed comparative study on Fuzzy logic speed controller in Dual PMSM drives. The main goal of the control system is to determine the effectiveness of the 'case design' for high performance PMSM drive by comparing the speed response with 'standard design' obtained. A broad comparative simulation study is presented to assess the performance of the PMSM. First, a conventional PI controller was evaluated with the Fuzzy Controller with constant gain without using the observer. The comparative aspects were the speed response, the stator currents, and the electromagnetic torque. The experimental results show the demonstrated the utility of using the nonlinear control with a time-varying system. It found the conventional PI controller to suffer from some issues in the experimental results compared with the simulation results for the same controller; these issues such as degradation in the rise time; the sinusoidal fluctuation in the speed steady-state response; and, failure to track high frequency reference changes test and to compensate for load torque disturbance. In contrast, the Fuzzy controller exhibited super performance in simulated tests.

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