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Hybrid Pi-Fuzzy Speed Controller for Interior Permanent Magnet Synchrono

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Abstract

The AC machine drives are becoming more and more popular, specifically the Induction Motors and Permanent Magnet Synchronous Motor (PMSM), but the PMSM drives are meeting the requirements with a fast dynamic response, high power factor and wide operating speed range in high performance applications. Some of the PMSM advantages include high efficiency, small volume, high power density, fast dynamics, large torque to inertia ratio, and low maintenance costs. Their applications are found in machine tools, servo and robots, in textile machines, electric vehicle etc. In a permanent magnet synchronous motor, the dc field winding of the rotor has been replaced by a permanent magnet to produce the air-gap magnetic field. By putting the magnets on the rotor, some of the electrical losses due to the field windings get reduced and the absence of the field losses improve the thermal characteristics of the Permanent Magnet machines along with its efficiency. The lack of some mechanical components such as brushes and slip rings makes the motor much lighter, high power to weight ratio which assures a higher efficiency and reliability. The permanent magnet synchronous generator is a viable solution for wind turbine applications as well. PM machines also have some disadvantages, at high temperature, the magnet gets demagnetized, difficulties to manufacture and high cost of PM material.

Keywords: *Interior Permanent Magnet, PMSM, Hybrid Pi-Fuzzy.*

Introduction

Among the synchronous motor types the permanent magnet synchronous motor (PMSM) is one possible design of the three phase synchronous machines. The stator of a PMSM has conventional three phase windings. In the rotor, PM materials have the same function of the field winding in a conventional synchronous machine. Their development was possible by the introduction of new magnetic materials, like the rare earth materials. The use of a PM to generate substantial air gap magnetic flux makes it possible to design highly efficient PM motors. With fast and accurate speed responses, quick recovery of speed from load disturbances and insensitivity to parameter variation is the important criteria of high performance drive system. The conventional PI and proportional integral derivative controllers have been broadly used as speed controllers in PMSM drives.

Permanent Magnet Machines are such electromechanical devices which are using magnets to produce a magnetic flux in the air gap. There are two major classifications of ac motors. The first one is induction motors that are electrically connected to power source through electromagnetic coupling, the rotor and the stator fields interact, creating rotation without any other power source. The second is synchronous motors that have fixed stator windings that are electrically connected to the ac supply with a separate source of excitation connected to field windings when the motor is operating at synchronous speed.

The permanent magnet synchronous motor (PMSM) has a number of advantages over other machines used for ac servo drives. The stator current of an induction motor (IM) contains magnetizing as well as torque producing components. The use of the permanent magnet in the rotor of the PMSM makes it unnecessary to supply magnetizing current through the stator for constant air gap flux; the stator current need only to be torque-producing. Hence for the same output, the PMSM will operate at a higher power factor (because of the absence of magnetizing current) and will be more efficient than the IM. The conventional wound-rotor synchronous machine (SM), on the other hand, must have dc excitation on the motor, which is often supplied by brushes and slip rings. This means that the rotor losses and regular brush maintenance are less. The key reason for the development of the PMSM was to remove the foregoing disadvantages of the SM by replacing its field coil, dc power supply, and slip rings with a permanent magnet. The PMSM, therefore, has a sinusoidal induced EMF which requires sinusoidal currents to produce a constant torque just like the SM. Current research in the design of the PMSM indicates that it has a higher-torque-to-inertia ratio and power density when compared to the IM or the wound-rotor SM, which makes it preferable for certain high-performance applications like robotics and aerospace actuators. The PMSM which is smaller in size and lower in weight makes it preferable for high performance applications.

The model of PMSM is however non-linear. This paper applies the concept of vector control that has been extensively applied to derive a linear model of the PMSM for the controller design purposes. The speed and current controllers are then designed. The nonlinear equations of the PMSM, current and speed controller equations and real time model of the inverter switches and vector control are used in the simulation. The switches are assumed to be ideal.

Results and Discussion

The conventional and proposed MATLAB/Simulink models were developed for 100 kW PMSM and the rest system parameters values are tabulated. The motor is operated in constant torque mode. In the designed model for performance improvement of IPMSM drive system, two controllers have been integrated: One as outer speed controller and other as inner current controller. Here our main aim is to analyze and compare the performances of PI, Fuzzy and Hybrid PI-FLC as different speed controllers but before that we require to select an excellent current controller which can provide smooth and ripple free responses of current and torque developed. So for selection of current controller first we compares the responses of drive system using conventional hysteresis band current controller and based on their performance we choose the better current controller for required operation of PMSM drive system. For this purpose PI controller is used as speed controller tuning its constants as Kp= 5 & Ki= 100.

In this section, performance of drive system using PI, Fuzzy and Hybrid PI-FLC as different speed controller has been demonstrated at no-load, variable load & variable speed conditions. For all condition operation Adaptive hysteresis band current controller has been integrated as inner current controller. The MATLAB/Simulation is focused on minimization of the ripple contents of stator current, torque and improving the motor speed response under transient and steady state operating conditions.

For this case the gain constants are set as Kp= 5 & Ki= 100 and the reference speed to be track is 1350 rad/sec. Fig.4.2 shows the 3-phase stator current which does not contains any disturbances, smooth response of electromagnetic torque and rotor speed where the ripple contents of the rotor speed are 200 and settling time is 0.5 sec. The response of the PI controller is under No-load condition.

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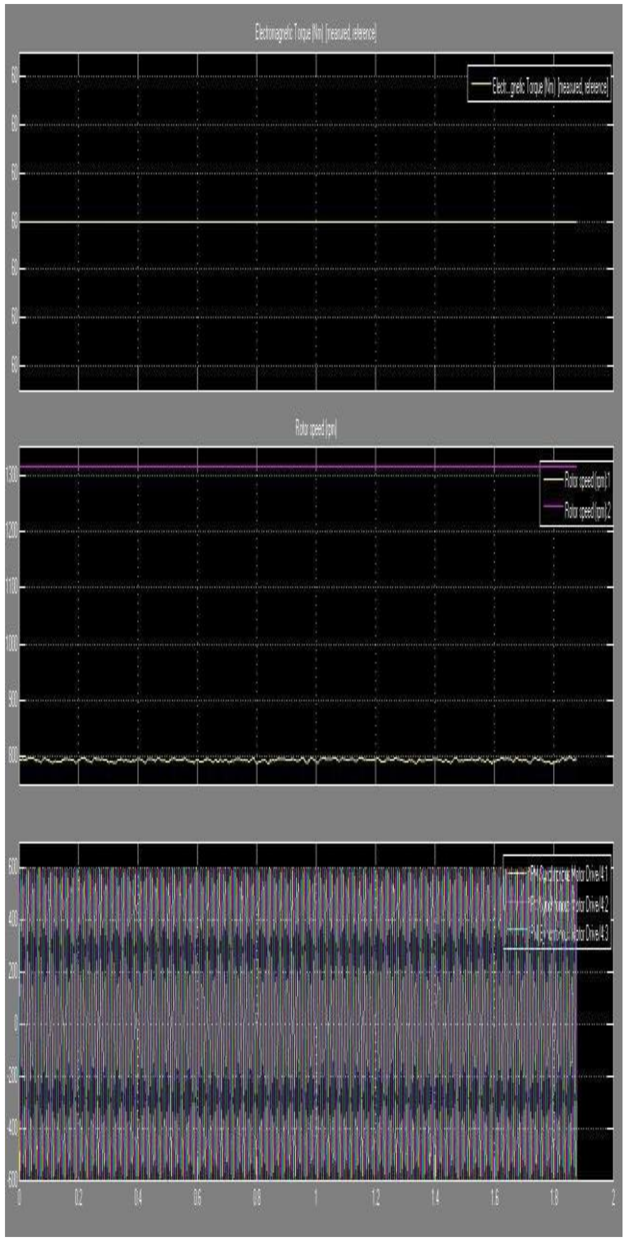

Figure 1: PI controller response under No Load condition

For this case a 5×5 triangular MF for both inputs as well as output variables of FLC, Fuzzy implication using Mamdani's **min** operators and Defuzzification using Centroid method has been implemented for designed FLC. Fig.5.3 shows the Fuzzy Logic Control Block diagram. Figure 5.4 shows the 3-phase stator current, shows response of electromagnetic torque and rotor speed where the ripple content is 200 and the rotor speed are 1350 rad/sec and settling time is 0.1 sec.

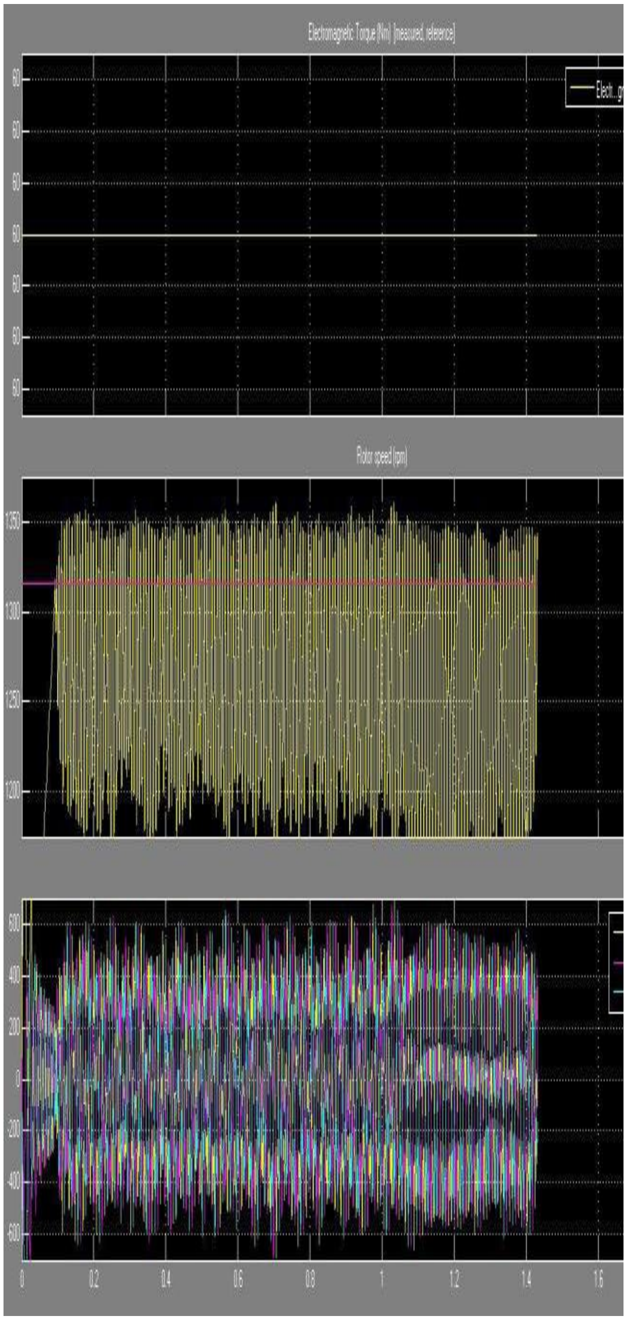

Figure 2: Electromagnetic Torque, Rotor speed and response of fuzzy logic controller

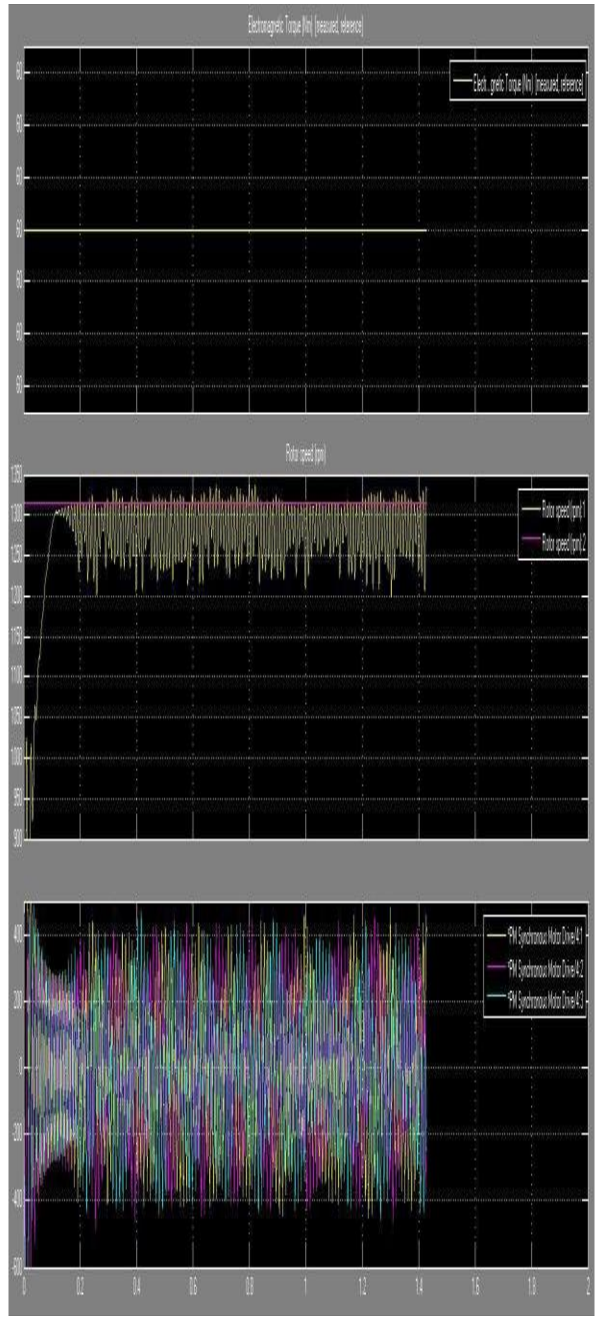

Figure 3: Hybrid Torque, Rotor Speed and ripple factor response at No Load

The figure shows the Hybrid model variable load fuzzy rule viewer. Fig.5.8 shows the 3-phase stator current, response at torque 60 Nm and 63 Nm, variable Load and rotor speed responses. Here also it can be observed that the notches in speed response get smaller than response using conventional PI controller and ripple contents in torque is 0.05 Nm.

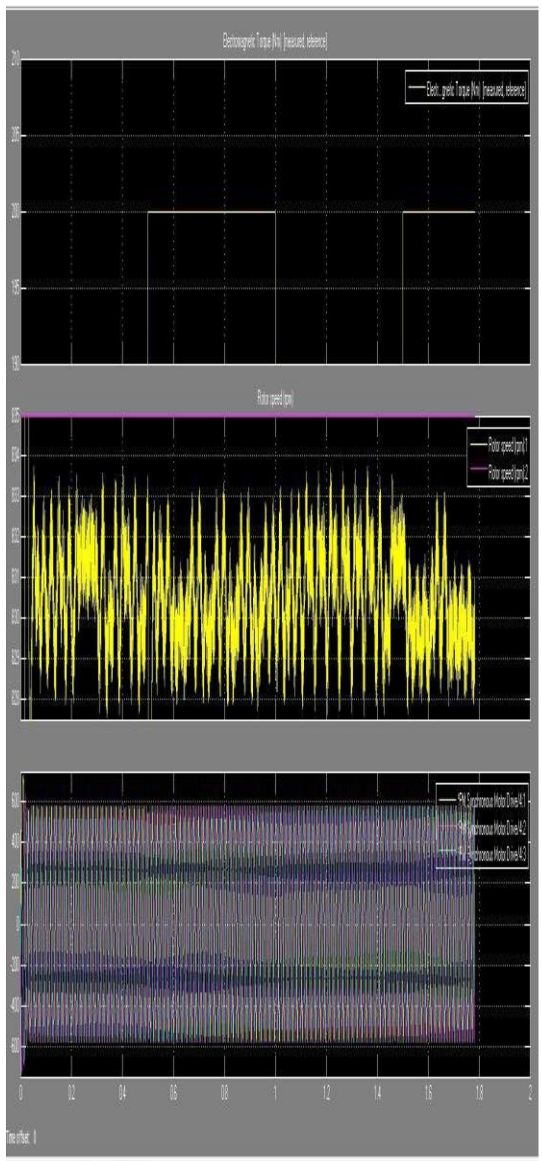

Figure 4: Results for variable load on Hybrid model

Fig. shows the Hybrid model variable speed fuzzy rule viewer and the figure shows the 3-phase stator current, response of electromagnetic torque and rotor speed responses with lesser ripple and notches in the stator current and torque response than the PI & FLC. The ripple content in torque under load condition is 0.05 Nm. So it can be revealed that the performance of IPMSM drive system gets improved using Hybrid PI-FLC model.

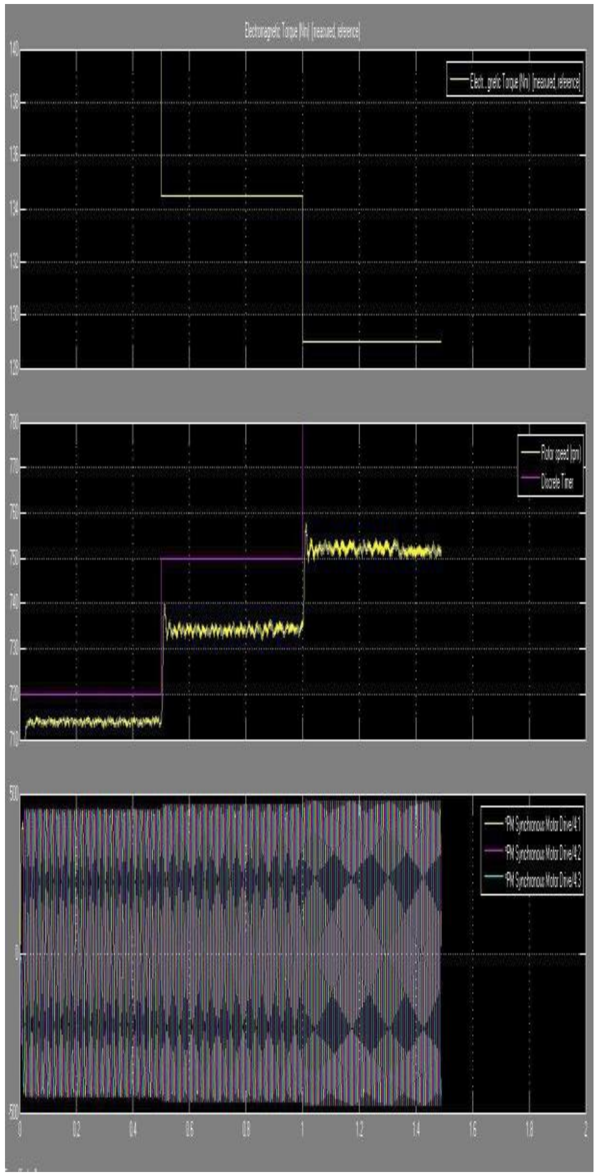

Figure 5: Hybrid model variable speed results

Discussion

In this chapter a comprehending results and responses of proposed IPMSM drive system using two integrated control strategy has been presented which is modeled and verified in the MATLAB/ Simulink environment. From the given responses of speed control of IPMSM drive system using a current controller and different speed controller techniques, we come to the conclusion that the hysteresis band current controller reduces the torque ripple, minimizes the current error and maintains the switching frequency. While among different speed controller, Hybrid PI-FLC is giving better response than others during both steady state and transient conditions.

Conclusion

This dissertation is mainly emphasized on the study of performance of IPMSM drive system using different current controllers in inner loop and speed controllers in outer loop. In order to run IPM motor at the desired speed, a closed loop with vector control IPMSM drive was successfully designed and operated in constant torque mode. The feasibility of the above mentioned integrated control strategy is modeled and verified in the MATLAB/Simulink environment for effectiveness of the study.

From the obtained results we observed that, during both steady-state and transient conditions hysteresis current controller reduces the torque ripple, minimize the current error and maintain the switching frequency. While comparing with the PI controller, the FLC and hybrid PI-FLC techniques, It is proved that PI-FLC controller has superior performance. The ripple contents of stator current, flux and torque are minimized considerably and the dynamic speed response is also improved with the proposed control technique under transient and steady state operating conditions. The simulation results are presented in forward motoring under no-load, load and sudden change in speed operating conditions.

So the proposed model with Hybrid PI-FLC as speed controller and fixed band hysteresis current controller has been used as a current controller which is providing smooth and improved performances as compared to other controllers that have been taken in consideration in this Thesis.

Future Scope

Here the focused has been made on the performance enhancement of IPMSM drives and simulation work has been done for its thorough analysis. However, due to equipment limitations these methods could not tested practically for all purposes. So in the future work the results obtained for proposed control techniques from simulation environment may be validated 43 with experimental results. In addition to that, the analysis of performance of PMSM drive implementing further advanced and intelligent controller like Adaptive fuzzy controller, Adaptive Hysteresis controller and implementation of such controller in both speed and current loop can be carried out. The analysis also can be extended to the above rated speed operation i.e. Flux weakening region also.

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