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Study to Improve the Performance of a PMSM Drive System by Achieving More Precise Speed Tracking and Smooth Torque Response

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Abstract: ***From the last three decades AC machine drives are becoming more and more popular, especially Induction Motor Drives (IMD) and Permanent Magnet Synchronous Motor (PMSM), but with some special features, the PMSM drives are ready to meet sophisticated requirements such as fast dynamic response, high power factor, and wide operating speed range like high performance applications, as a result, a gradual gain in the use of PMSM drives will surely be witness in the future market in low, mid and high power applications. Now in a permanent magnet synchronous machine, the dc field winding of the rotor is replaced by a permanent magnet to produce the air-gap magnetic field. Having the magnets on the rotor, some electrical losses due to field winding of the machine get reduced and the absence of the field losses improves the thermal characteristics of the PM machines particularly its efficiency. Also absence of mechanical components such as brushes and slip rings makes the motor lighter, high power-weight ratio which assures a higher efficiency and reliability. With the advantages described above, permanent magnet synchronous generator is an attractive solution for wind turbine applications also. 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 will be 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.***

Keywords: Induction Motor Drives, Permanent Magnet Synchronous Motor, dynamic response, power factor, efficiency, reliability etc

1. Introduction

PM electric machines are classified into two groups (i) PMDC machines and PMAC machines. The PMDC machines are similar with the DC commutator machines; the only difference is that the field winding is replaced by the permanent magnets while in case of PMAC the field is generated by the permanent magnets placed on the rotor and the slip rings, the brushes and the commutator does not exist in this machine type. For this reason the machine is simpler and more attractive to use instead of PM DC. PMAC can be classified depending on the type of the back electromotive force (EMF): Trapezoidal type and Sinusoidal type. Sinusoidal type PM machine can further be classified as Surface mounted PMSM and Interior PMSM. The trapezoidal PMAC machines also called Brushless DC motors (BLDC) has a trapezoidal-shaped back EMF and develop trapezoidal back EMF waveforms with following characteristics:

- Rectangular current waveform
- Rectangular distribution of magnet flux in the air gap
- Concentrated stator windings.

While the sinusoidal PMAC machines, called Permanent magnet synchronous machines (PMSM) has a sinusoidal-shaped back EMF and develop sinusoidal back EMF waveforms with following characteristics:

- Sinusoidal current waveforms.
- Sinusoidal distribution of magnet flux in the air gap
- Sinusoidal distribution of stator conductors.

2. Aims and Objectives

The main objective of this research is to improve the performance of an PMSM drive system by achieving more precise speed tracking and smooth torque response by implementing a Hybrid PI-FLC and an adaptive hysteresis band current controller respectively by employing their superior performance. The overall objectives to be achieved in this study are:

- To design the equivalent d-q model of PMSM for its vector control analysis and closed loop operation of drive system
- For the PMSM drive the model can be developed using d-q reference frame in this case vector control method will be used for purpose of predicting the motors dynamic performance.
- Analysis of conventional hysteresis current controller and hysteresis band current controller as inner current controller in MATLAB/Simulink environment to compare their performances so as to consider better controller for our system application.
- The electromagnetic torque, stator winding currents, rotor speed and winding voltage are stored for studying the dynamic responses of the drive. Hence, PWM current contrllers are going to be used for maintaining the winding currents in the vicinity of their reference values.
- Comparison of system performance using PI, PID, Fuzzy Logic , Hybrid PI-FLC and Hybrid PID-Fuzzy Logic speed controller etc. during steady state and transient condition in MATLAB/Simulink.

3. Surface Mounted Magnet Type (SPMSM)

In the case the magnets are mounted on the surface of the rotor. The magnets can be regarded as air because the permeability of the magnets is close to unity (μ=1) and the saliency is not present due to same width of the magnets. Therefore the inductances expressed in the quadrature coordinates are equal (Ld = Lq). In the case of SPMSM the saliency is not present, making this machine easier to design, becoming an attractive solution for wind turbine application.

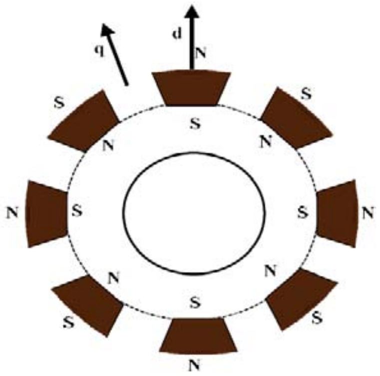

Figure 1: Surface PM (SPM) Synchronous Machine

4. Interior Magnet Type (IPMSM)

In this type the motor, the magnets are place inside the rotor. In this configuration saliency is available and the air gap of d-axis is greater compared with the q axis gap resulting that the q axis inductance has a different value than the d axis inductance. There is inductance variation for this type of rotor because the permanent magnet part is equivalent to air in the magnetic circuit calculation. These motors are considered to have saliency with q axis inductance greater than the d axis inductance (Lq>Ld). Due to saliency IPMSM is a good candidate for high-speed operation such as PCB manufacturing, spindle drives and hybrid electric vehicles (HEV) etc. Further, among Interior Permanent Magnet Synchronous Motor (IPMSM) and Surface Mounted Permanent Magnet Synchronous Motor (SMPMSM), IPMSM is preferably used for many applications due to its constructional features along with higher demagnetizing effect to enhance the speed above the base speed. Although IPMSM demand gradually increasing in various industrial applications with varaious speed control and fast dynamic response, there still exist a great challenge to control its speed.

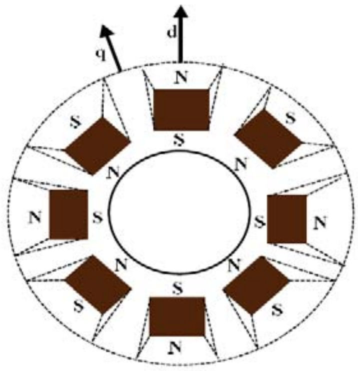

Figure 2: Interior PM (IPM) Synchronous Machine

5. Description of the PMSM Motor Drive System

The rotor speed ω_r is compared with the reference speed ω_r* and the speed error in motor speed is processed in the controller for each sampling interval. The output of this is considered to be the reference torque Te*.The quadrature-axis reference I_q^* is obtained by using the reference torque T_e* and the torque-constant K_t . For low-speed operation of PM motors, the flux weakening effect is not considered in this investigation; however, the effect of flux weakening is employed for high-speed operation of the PMSM drive. Hence in this investigation, the direct-axis reference current (i_d*) is considered to be zero for low- speed operation. The d-q axis reference currents i_d* and iq* are used to generate the reference currents i_a*, i_b* and i_c* in the reference current generator. The reference currents have the shape of the sinusoidal wave in phase with respective back-emfs to develop constant unidirectional torque. In PWM current regulating block, the motor winding currents ia and ic are compared with the reference current i_a*,i_b* and i_c* and the switching commands are generated for the inverter devices to drive the PMSM.

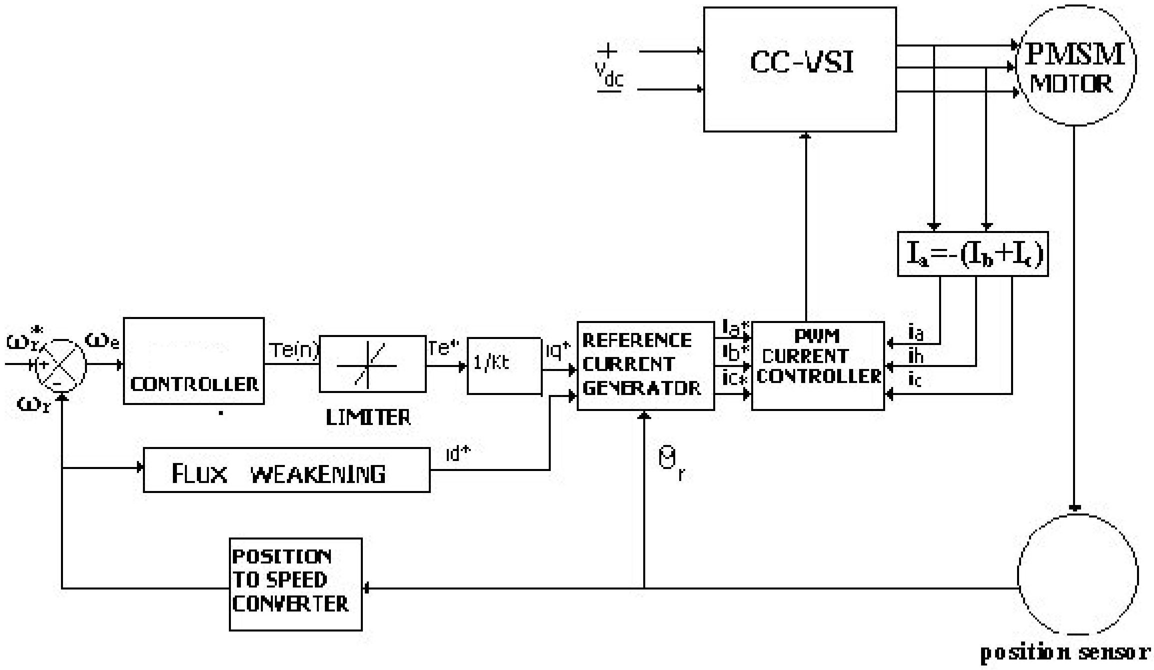

Figure 3: Schematic Block Diagram of PMSM Drive

6. Methodology

Vector control (or Field Oriented Control) principle makes the analysis and control of Permanent Magnet Synchronous Motor (PMSM) drives system simpler and provides better dynamic response. It is also widely applied in many areas where servo- like high performance plays a secondary role to reliability and energy savings. To achieve the field-oriented control of PMSM, knowledge of the rotor position is required. Usually the rotor position is measured by a shaft encoder, resolver, or hall sensors. In the PMSM, excitation flux is set-up by magnets; subsequently no magnetizing current is needed from the supply. This easily enables the application of the flux orientation mechanism by forcing the d-axis component of the stator current vector (i_d) to be zero. As a result, the electromagnetic torque will be directly proportional to the q-axis component of the stator current vector (iq), hence better dynamic performance will be obtained by controlling the electro-magnetic torque separately. The field oriented vector control scheme for permanent magnet synchronous motor (PMSM) drives, that regulates the speed of the PMSM, will provided by a quadrature axis current command developed by the speed controller. PI controller can be gradually used for outer speed control loop but because of its fixed proportional gain constant and integral time constant, the behavior of the PI controllers are affected by parameter variations, load disturbances and speed fluctuation. To overcome the problem of PI controller, here a Fuzzy logic controller will be included and finally taking the superior performances of PI and Fuzzy controller, a Hybrid PI-Fuzzy and hybrid PID-Fuzzy controller incorporated and compared among all the controller for smooth and uniform running of PMSM motor drive.

7. Conclusion

The conventional hysteresis band current controller has proven that, it is most suitable for current regulated VSI fed ac drives due to its simplicity and fast speed tracking. The proposed current control strategy will applied to the inner loop of the vector controlled permanent magnet synchronous motor (PMSM) drive system in order to reduce the torque ripple during load variation. Finally a performance comparison study of proposed model using PI, FLC and Hybrid PI-FLC separately as outer speed loop with adaptive hysteresis band current controller as inner current loop will be presented in terms of steady state and transient analysis with fixed step, variable step load and variable speed condition using MATLAB/Simulink environment. 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 will be 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.

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