ANALYSIS AND CONTROL OF PERMANENT MAGNET BRUSHLESS MOTOR DRIVES

by

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CERTIFICATE

This is to certify that the thesis entitled, **"Analysis and Control of Permanent Magnet Brushless Motor Drives"** being submitted by **Mr. Mukesh Kumar** for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him in the Electrical Engineering Department of Indian Institute of Technology, Delhi.

Mr. Mukesh Kumar worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard. The matter embodied in this thesis has not been submitted in part or in full to any other university or institute for the award of any degree.

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ABSTRACT

Permanent magnet brushless (PMBL) motors are finding wide applications in heating ventilation and air conditioning (HVAC), washing machines, adjustable speed pumps, refrigerator compressors, fans drives and electric vehicles due to their advantages of high efficiency, robust (brushless) construction, high power density, compact size etc. The use of these motors in place of conventional induction and DC motors results in a drive of lightweight, gives precise control, needs lower controller rating and above all it effects energy conservation. In view of these attractive features and scope of applications, the proposed research work makes an attempt to design, develop and implement improved controllers to give enhanced dynamic response, and facilitates the reduction in the sensors with a view to reducing the size and the cost of the drive. Moreover, these drives are fed from the AC-DC converter supplying current controlled voltage source inverter to obtain an effective control of the winding currents, the torque, speed and position of PMBL motors. It is also desired to improve the power quality at the AC mains using active and passive wave shaping techniques of AC-DC converter to meet the recently introduced harmonic standards and to reduce losses in AC distribution system by improving the overall power factor.

In this work two types of PMBL motors are considered for investigation with a view to select a suitable controller to give improved performance of the drive system. These motors, namely, PMBLDCM (Permanent magnet brushless DC motor) and PMSM (Permanent magnet synchronous motor) differ in their construction, waveform of back emf and thus their current control and sensor requirements etc. The PMBLDC motor has flux and emf close to trapezoidal waveform, thus requiring a quasi-square winding current to develop the unidirectional ripple free torque. However, PMSM has sinusoidal

flux distribution and back emf and it requires sinusoidal winding currents to produce the smooth torque.

The simulated response of both types of PMBL motor drive system have been obtained using standard d-q model for the PMSM and the phase variable model for the PMBLDC motor, respectively. The modeling of each component of the drive system is carried out and the set of modeling equations so obtained are combined together and solved by using Runge Kutta method. The response of the drive system is obtained for different operating conditions, such as, starting, load perturbation and speed reversal. The simulated results are validated using test results from the DSP based implementation. The scope of the investigation has been widen by putting emphasis on the closed loop speed control, sensorless control and power quality improvement aspects of the drive system.

A closed loop controlled motor drive system has speed and current control loops for its control. In such a drive system, the transient response is greatly affected by the structure of these controllers. Four different types of speed controllers namely, the proportional integral (PI) controller, sliding mode controller (SMC), fuzzy logic controller (FLC) and fuzzy pre-compensated PI (FPCPI) controller have been considered in this work, and their effectiveness have been examined with a view to selecting an appropriate controller for the given application. The experimental and simulated results given in this study show that the FPCPI speed controller results in an improved performance compared to PI, SMC and FLC speed controllers.

The closed loop control of a drive system can be practically implemented in two ways- using the dedicated hardware system or by a combination of hardware and software system. The latter has advantages such as reduced size and adaptability to advanced control algorithms. The digital signal processors (DSP), which have been especially

developed for power electronics applications are finding increasing applications in motion control because of their fast computational capabilities and high speed input-output interface. The investigations reported in this thesis deal with the implementation of PMBL motor drive system using a dedicated DSP developed by Texas Instruments (TI) namely TMS320F240.

The use of position and speed sensors has disadvantages such as increased number of connection, their sensitivity to environmental conditions (prohibiting the use of the motor in hazardous conditions) and increased complexity and cost of the drive system. The reliability of the drive system is also lowered due to the use of mechanical sensors. These limitations of sensors have led to research efforts for sensorless control of PMBL motors. In this study, a position and speed sensorless scheme of PMBLDC motor drive has been implemented using a digital signal processor. The position signal pulses are obtained by comparing the back emf signals. The speed is estimated from the position signals. The proposed (position sensorless) scheme has been implemented with a single current sensor in DC link. The test results with single current sensor and without using position and speed sensors have been presented to validate the working of the sensor reduction scheme.

Similarly, the mechanical sensorless control of PMSM using voltage and current model based sensorless control algorithms have been investigated and the simulated responses for both transient and steady state operating conditions show the effectiveness of sensorless control schemes of PMSM.

A three–phase current controlled voltage source inverter (VSI) is used to feed both PMBLDCM and PMSM drives. The DC link voltage for VSI is obtained from a single-phase diode-bridge rectifier. The power electronics (PE) converters (rectifier and VSI) draw highly distorted current from the AC mains, which is a potential cause of mal

operation of other loads. To reduce the impact of PE converter on the supply system, attempts are made to improve the power quality in terms of improved PF, reduced crest factor (CF) and total harmonic distortion (THD) of AC mains current. For this, both passive and active waveshaping techniques are investigated, which results in reduction in losses in supply system, interference with the neighbouring consumers and rating of the converters.

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