POWER QUALITY IMPROVEMENT AND SENSOR REDUCTION IN PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVES

by

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CERTIFICATE

Certified that the thesis entitled **"Power Quality Improvement and Sensor Reduction in Permanent Magnet Synchronous Motor Drive"** which is being submitted by **Mr. Sanjeet Kumar Dwivedi** for the award of the degree of **Doctor of Philosophy** in the Department of Electrical Engineering, Indian Institute of Technology Delhi, is a record of the student's own work carried out by him under our joint supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

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ABSTRACT

The availability of improved quality Permanent Magnet (PM) material has generated a lot of interest in the development of Permanent Magnet Brushless (PMBL) motors. This has gained further impetus from the development of high power low cost switching devices and high-speed digital signal processors. Together, they have made the drive system flexible, compact and the overall cost of the PMBL motor drive has been reduced considerably. These motors are, therefore becoming an attractive option for applications in Heating Ventilating and Air-conditioning (HVAC) systems, refrigerators, washing machines and many other cases. Considering these attractive features, the PMBL motor drive is selected for this study with a view to improving its performance and identifying therefrom some aspects of the problem worthy of further investigation.

PMBL motors have two types of flux distribution, the one with sinusoidal distribution is named as Permanent Magnet Synchronous Motor (PMSM), while the other with trapezoidal flux-distribution is named as Permanent Magnet Brushless DC Motor (PMBLDCM). In closed loop variable speed drive (VSD) applications, PMSMs utilize two types of controls, namely the Vector Control (VC) and the Direct Torque and Flux Control (DTC). These two control techniques are having their own inherent advantages and disadvantages, and depending upon the requirement of application either the vector control or the direct torque control technique is used for the control of PMSM drive. Both techniques have been considered in this work with a view to comparing their usefulness for PMSM drive used in small ratings domestic appliances such as, washing machines, air-conditioners and refrigerators.

The investigation reported in this thesis deals with the hardware development of vector controlled and direct torque controlled PMSM drives. This includes the development of power circuit, interfacing circuit and control circuit. The control algorithm alongwith the

generation of switching signals are developed in assembly language and are executed in a Digital Signal Processor (DSP), namely, ADMC401 developed by Analog Devices (AD). The experimental responses are obtained for different operating conditions, such as starting, speed reversal, load perturbation and steady-state conditions for both VC and DTC techniques. The simulated results are compared with test results obtained from the DSP based implementation of the system to validate the developed model of the PMSM drive systems. The results of vector controlled and direct torque controlled PMSM drives are compared to examine the usefulness of the control techniques.

The transient response of the drive system is greatly affected by the choice of speed controller. Four different types of speed controllers, namely the Proportional Integral (PI) controller, the sliding mode controller (SMC), the fuzzy pre-compensated PI (FPPI) controller and the hybrid fuzzy PI (HFPI) speed controller have been considered in this work and their effectiveness have been examined with a view to selecting an appropriate controller for a given application. These controllers for the PMSM drives are implemented in the assembly language and executed in DSP for both VC and DTC techniques.

Sensor reduction, both electrical and mechanical, has been one of the important aims of system designer with a view to enhancing the reliability of the drive and reducing its overall cost. Advances in digital signal processors have facilitated the development of mechanical sensorless control of ac drives. However, they still suffer from the degraded performance at low speeds owing to the difficulty in flux estimation without the sensing of speed. Methods based on standard motor model are affected by errors in sensing and are sensitive to stator resistance variation. In this work, the effectiveness of some of the existing schemes of sensorless control have been examined with a view to developing a suitable scheme for the operation of PMSM drive in sensorless mode. A stator terminal based sensing technique has been investigated for speed estimation without using a mechanical sensor. The mechanical sensorless control scheme developed for PMSM drive is implemented on DSP and the test results are compared with simulated results to validate the algorithm.

In both, the vector and direct torque controlled PMSM drives, the ac mains experiences poor power quality due to the presence of diode bridge rectifier, which is utilized for feeding power to the voltage source inverter of the PMSM drive. The diode bridge rectifier has a low operating power factor, in addition to causing distortion in input supply current and harmonics injection into the ac mains. Therefore, the necessity of power quality improvement in PMSM drive has led to the development of improved power quality ac-dc converters by using different passive and /or active waveshaping topologies. For improving the power quality of input ac mains, different types of passive waveshaping topologies are investigated for feeding power to the single-phase diode bridge rectifier of the PMSM drive. These filters are designed and mathematically modeled to study their effectiveness. The dynamic as well as the steady state performances of the drive are simulated in MATLAB environment with PSB/Simulink toolboxes. The developed prototypes of these topologies for feeding power to PMSM drives are tested to validate the design and to obtain the corresponding simulated performance.

The passive waveshaping topologies are not capable to regulate the dc-link voltage of VSI of PMSM drive. For regulation of dc-link voltage as well as to achieve the improved power quality performance, the boost power factor correction (PFC) converter topologies both in unidirectional and bi-directional modes of power flow are used. In this investigation, three unidirectional power flow active waveshaping converter topologies, namely, the single switch boost PFC converter, two switch asymmetrical and symmetrical boost PFC converters along with one bi-directional power flow converter topology, namely, the voltage source converter have been designed and analysed. The performance simulation of different topologies has been carried out using the MATLAB along with its toolboxes. The corresponding hardware implementation of these topologies includes development of power circuit, interfacing circuit, the control circuit for single switch boost PFC converter, and symmetrical two-switch boost PFC converter respectively. The control algorithm alongwith the generation of PWM switching signals are developed in assembly language and executed in DSP with a view to reducing the hardware. The PMSM drive system using one or the other of these waveshapers is analysed and the resulting improvement in the power quality is compared under varying loads.

While using these topologies with active waveshaping techniques the isolation between ac and dc is not possible which is desired in a number of applications, and also they require voltage and current sensors for their control. The use of high frequency transformer in isolated topologies of ac-dc converters in discontinuous conduction mode requires only the dc link voltage feedback for improving the power quality at the ac mains. Due to the isolation of the input and output, these converters prove to be a better alternative among the front end PFC converters in the small rating drives used in the domestic appliances, medical equipments and many other applications. In this investigation, different topologies of high frequency transformer isolated ac-dc converters are modeled in the PSIM software. The hardware developments of isolated active waveshaping ac-dc converter topologies include development of buck-boost converter in discontinuous conduction mode of operation with reduced sensor requirement and improved power quality features. The performance of the PMSM drive system with varying loads is compared and analysed for the improvement in power quality.

TABLE OF CONTENTS