Experimental Investigation of Acoustic Noise and Vibration of High Performance PMSM Drive

Thesis submitted in partial fulfilment of

the requirements for the degree of

Doctor of Philosophy

by

Rajesh M. Pindoriya

Enrollment No. D15041

Under the supervision of

Dr. Bharat Singh Rajpurohit

and

Dr. Rajeev Kumar

School of Computing and Electrical Engineering

Indian Institute of Technology Mandi

Mandi, Himachal Pradesh-175075

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DEDICATED TO MY FAMILY

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Declaration by the Research Scholar

I hereby declare that the entire work embodied in this Thesis is the result of investigations carried out by me in the **School of Computing and Electrical Engineering,** Indian Institute of Technology Mandi, under the supervisions of **Dr. Bharat Singh Rajpurohit,** and **Dr. Rajeev Kumar** and that it has not been submitted elsewhere for any degree or diploma. In keeping with the general practice, due acknowledgements have been made wherever the work described is based on finding of other investigators.

Place: IIT Mandi
Date: September 2020

Signature:
Name: Rajesh M. Pindoriya

Declaration by the Research Advisor

I hereby certify that the entire work in this Thesis has been carried out by **Rajesh M. Pindoriya,** under my supervision in the **School of Computing and Electrical Engineering**, Indian Institute of Technology Mandi, and that no part of it has been submitted elsewhere for any Degree or Diploma.

Signature:
Name of the Guide: Dr. Bharat Singh Rajpurohit
Name of the Co-Guide: Dr. Rajeev Kumar

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Rajesh M. Pindoriya

Abstract

Electrical machines are the most mainstream machines in regular life and their number of types increments with improvements in designing, science, and innovation. Electric motor drives are utilized in a wide power range from MWs to GWs. Over the most recent three decades, numerous new electric motor drives have been created and a few are in cutting edge model stage incorporating motors with superconducting field excitations. Progress in electric motor drives innovation is animated among others by the approach of quick and dispersed preparing facilities, new materials, modern applications, and new methodologies to control, the impact of power electronics technologies.

Adjustable Speed Drives (ASDs) have become an essential commodity in today's industrial world. Applications of ASDs are as following, manufacturing processes, robotics, electric and hybrid vehicles, Heating, Ventilating, and Air Conditioning (HVAC) systems, washing machines, etc. Since the last two centuries industries have used Induction Motors (IM) and Direct Current (DC) motors as ASDs in domestic and industrial applications. However, due to the latest technology, trends, and several advantages, ASDs switching over from IM and DC motors to Special Electrical Motors (SEMs). Some of the advantages of SEMs are as following, high torque to inertia ratio, high efficiency, high power density, good dynamic speed response, compact size, etc. The SEMs are classified into three categories such as brushless permanent magnet, switched reluctance, and stepper motors.

This work is focused on brushless Permanent Magnet Synchronous Motor (PMSM) drives. For the operation of PMSM drive, the rotor position information is mandatory. Normally, rotor position information is sensed by hall effect sensors, encoders, and proximity sensors. But these types of sensors have certain disadvantages like reduced reliability, increased weight & complexity, cost, and size of the ASDs. Higher Acoustic Noise and Vibration (ANV) are the other important challenges with PMSM drive. Hence, this work is focused on the reduction of ANV and the development of rotor position sensorless operation, of PMSM drive.

The ANV of electric motor drives relies upon the kind of the machines, its structure, size, geography, development, materials, fabricating, rotation speed, input power supply, mechanical support, mounting, bearings, load, coupling, etc. In addition, ANV of electric drives is predominantly dependent upon supply from converter-interfacing which is rich in harmonics. Therefore, ANV of PMSM drive can be reduced in two ways, i.e. changing motors design and novel algorithms for control of power electronics converter & modulation techniques. This work focuses only on control techniques of power electronics converters for the reduction of ANV in PMSM drives.

The Random Pulse Width Modulation (RPWM) techniques have been implemented by several researchers to reduce the ANV of IM based electric drives. To validate the effectiveness of proposed RPWM techniques, a small-scale laboratory experimental set-up has been developed in a lab. for validation of results. The RPWM techniques can be classified into three modulation strategies, i.e. first is randomized switching frequency, second is randomized pulse position and third is random switching operation of a three-phase inverter. This work focuses on two modulation techniques, first is randomized switching frequency i.e. Pseudorandom

Triangular Pulse Width Modulation (PTPWM) and second is randomized pulse position i.e. Random Pulse Position Modulation (RPWM).

For testing ANV level of PMSM drive free-field enclosure is required. A low-cost acoustic chamber has been designed and developed in a lab. for testing ANV of PMSM drive. The detailed design procedure of the low-cost acoustic chamber has been reported in this thesis. The ISO and IEEE standards stipulate the procedures for conducting acoustic measurements. The standards are being followed for reliable and reproducible results with a specified level of accuracy in this work.

The specific necessity in control of PMSM drive is the synchronization of the AC excitation frequency with the rotational speed. A shaft mounted rotor position sensor is required for accomplishing this. This shaft mounted rotor position sensors expands the expense and decreases the consistency in the drive framework. This makes it unwanted for industrial and residential applications. Henceforth, this research develops a rotor position sensorless control algorithm for the operation of PMSM drive. In this work, two sensorless control algorithms are implemented, first is current slope detection and second is based on measuring the stator voltages and phase currents of PMSM drive.

The proposed research work has been implemented using MATLAB/Simulink software and further, experimentally validated over a small scale-laboratory set-up of rating 1.07 kW PMSM drive.

The main objectives behind the present work have been the following:

1. To design a vector control algorithm for position sensor based high-performance PMSM drive.
2. Design and development of an experimental set-up for analysis of ANV of PMSM drive.
3. To design novel control algorithms for the reduction of ANV of high-performance PMSM drive.
4. To design a control algorithm for position sensorless operation of high-performance PMSM drive.

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