

MINIMIZATION OF TORQUE RIPPLES IN PERMANENT MAGNET SYNCHRONOUS MOTOR-OVERVIEW

R.SUJA¹, P.MELBA MARY²,

¹ PET Engineering College, ANNA University, Tamil Nadu, India

² V.V.Colleg of Engineering, Principal, ANNA University, Tamil Nadu, India

Abstract: This paper deals with torque ripples, Permanent magnet synchronous motors are widely used in high performance applications. This paper reviews a controller based design techniques. Controller based techniques for minimizing torque ripples involve the use of algorithms. Finally, successful suppression of pulsating torque relies on the systems approach to all aspects of the PMSM.

Keywords: PMSM, Torque ripples, Controllers

1. Introduction

Permanent magnet synchronous motors are very attractive machine which is used in machine tools and robotics. Torque ripple exist in PMSMs due to non sinusoidal flux density distribution around the air gap and variable magnetic reluctance in the air gap due to stator slots. Torque smoothness is essential requirement in a wide range of high performance control applications.

Analysis of torque pulsations:

1. Cogging torque: Pulsating torque components generated by the interactions of the rotor magnetic flux and angular variations in the stator magnetic reluctance. Stator excitation is not involved in cogging torque.
2. Torque ripple: Pulsating torque components generated by the interactions of the stator current magneto motive forces and rotor electromagnetic properties, which can take two forms.
 - (a) Mutual or Alignment torque: It results from the interactions of the current mmfs with the rotor magnet flux distribution. This is the dominant torque in most of the permanent magnet machines
 - (b) Reluctance torque: It results from the interactions of the current mmfs with the angular variations in the rotor magnetic reluctance.
- © Pulsating torque: This is the sum of the cogging and ripple torque.

B .Pulsating torque minimization overview:

Many techniques have been adopted during past 25 years for minimizing the generation of pulsating torque components. These techniques has two major categories. First one is to adjust the machine design and the second category is based on active control

schemes which modify the excitation to correct for any of the non ideal characteristics of the machines. Soft computing techniques are also implemented for minimizing torque ripples.

2. Motor design

From the motor design viewpoint skewing the stator lamination stacks or rotor magnets, arranging proper winding distribution reduce cogging torque to a certain limit but do not completely eliminated. Moreover, special machine design processes additionally increase the complexity in the production process and also increase the machine cost.[1]. Recursive least square (RLS) estimation algorithm is used to calculate parameters of inductances for Interior Permanent Magnet Synchronous Motor (IPMSM). This control method can minimize torque ripple of IPMSM because of keeping linearity of inverter output. [2]

A flux estimation technique is used to estimate the rotor position of the slot less PMSM that takes advantage of the slot less machine's characteristically low inductance to limit flux estimation error. The rotor position is estimated using a reference model and the measured phase currents and voltages. The proposed sinusoidal control method reduces the torque pulsations present when Hall sensor position feedback alone is used and eliminates the need for high-resolution rotor angle sensors. [3]

A merit of this system is that it doesn't need to know the internal motor mechanical structure specifications, the torque ripples are reduced by 91%. So the haptic designers have the ability to use motor with high torque to volume ratio and low-cost motor without taking into consideration the cogging problem. [4]

Permanent magnet torque ripple depends on the choice of the permanent magnet width and the slot opening width. The torque ripple tends to have a minimum for one or two different permanent magnet width, depending on the number of slots per pole per phase. This method minimizes the third harmonics of air gap flux density. [5]

3. Controller design

Several controllers have been used to minimize the ripples. Sliding-mode control is one of the controllers and is based on a generic mathematical model of the motor. The estimation is based on the differentiation of measured signals using the ideas of robust

exact differentiator (RED). This is implemented on an industrial servo drive. [6]

This proposed method using two PI controllers to suppress the harmonics, torque ripples, noise and electromagnetic interference. Invert switching frequency is affected by PI controllers also reduces the cogging torque. PMSM gives smooth operation owing to smooth waveform of current and torque. [7]

In most of the research, the source of the energy is electrical energy. But this method uses the source of energy supply is the fuel cells. A fuel cell feeding a boost converter which further feeds a three phase tri-state CSI gives rise to minimized torque ripple, which has been proved in Hybrid Electric Vehicle.[8]

Direct Torque Control (DTC) algorithm is also used to minimize the torque ripple. The electromagnetic torque in a PMSM is proportional to the angle between the stator and rotor flux linkages. Direct Torque Control (DTC) provides better dynamic response and its main advantage of DTC is its structure simplicity. An improved PMSM DTC scheme by using an active-null vector modulation strategy based on an rms torque-ripple equation minimization. The proposed strategy improves the performances of DTC by combining low torque ripple characteristics in steady state with the faster torque dynamics. [9].The application of tooth shape optimization method cogging torque can be reduced in permanent magnet motors. An optimum tooth shape has been achieved by the implemented algorithms, starting from three basis shapes. [10]

With the proposed method, the torque ripple caused by the magnetic saturation could be effectively reduced at the rated torque. In this method an effective real time inductance measurement method using the DFT was presented to obtain the inductance distribution according to the rotor position. The magnetic saturation of the PMSM was proved by this measurement method. Moreover, the saturation effect was analyzed by a nonlinear analysis, and a simple active cancellation strategy to minimize the torque ripple at each electric angle was proposed. [11]

The sensor less control of the interior-magnet motor is based on a speed-adaptive observer augmented with a pulsating high-frequency signal injection technique at low speeds. The method proposed for torque ripple reduction is suitable for sensor less PMSM drives. Both flux harmonics and inductance harmonics are taken into account, and a harmonic in the torque estimate is suppressed using a torque ripple compensator based on three additional motor parameters. [12]

The offset error and scaling error causes torque ripples. These ripples deteriorate the performance of speed control. A compensation technique is being used to obtain precise torque control and eliminate ripples in speed. Basic analysis has been shown that the offset current causes the torque error oscillating at the frequency and the scaling error current causes the torque error oscillating at the frequency. By proposing this method ripples are reduced. [13]

An adaptive-filter-based torque-ripple minimization of a fuzzy-logic controller for speed control an reduction of torque ripples of an interior permanent magnet motor drive. The gain of the filter is adapted online based on the magnitude of the torque ripple. The optimal position of the filter in the complete drive is also determined for effective Torque ripple minimization [14]

A DTFC space vector based PWM technique is proposed to reduce the ripple in torque, flux and current in the steady state. A new approach for speed control of PMSM servo system using fuzzy logic technique. Without changing the motor parameters and load a fuzzy logic based DTC methodology is used for an efficient control of the torque and flux. [15]

An adaptive controller when compared with other controllers shows great success in torque ripples reduction, enabling speed tracking while minimizing the torque ripple.[16]

A hybrid filter topology is proposed to reduce torque pulsation switching voltage harmonics and EMI noises in PMSM with direct torque hysteresis controllers. The AF is characterized by detecting the harmonics in the motor phase voltages and uses hysteresis voltage control method to provide almost sinusoidal voltage to the motor windings. The simulation results of this combined control structure show considerable torque ripple or pulsation reduction in steady state range and adequate dynamic torque performance as well as considerable harmonics and EMI noise reduction.[17]

An iterative learning control scheme implemented in time domain to reduce periodic torque pulsations. However, this limited the extent to which torque pulsations can be suppressed. In order to eliminate this limitation, a modified ILC (Iterative Learning control) scheme was implemented.Both proposed schemes are carried out on a DSP-controlled PMSM drive platform. [18]

4. Soft computing design

The torque ripples in PMSM are minimized by soft computing techniques .Neural controller is used for torque ripple minimization of this type of motors. Two methods of neural controller design are used. The first method is based on current controller and speed controller. The second method is based on estimation of torque constant and stator resistance in PMSM. The q-axis inductance is modeled off-line according to q-axis stator current. Weights are initially taken as small random value and those weights are adjusted according to the model reference control algorithm. [19]

A novel compensation method for permanent magnet synchronous motor (PMSM) direct torque controlled (DTC) drive based on neuro-fuzzy observer is proposed. Instead of conventional hysteresis controller two Fuzzy logic controllers are used This method presents the implementation of a voltage distortion observer based on the artificial neural network (ANN) and produce a ripple less torque. [20]

In recent years, direct torque control along with soft computing techniques has been used to minimize the torque ripples. The application of vector control and direct torque control (DTC) with neural network to reduce the ripples. [21]

A DTFC space vector based PWM technique is proposed to reduce the ripple in torque, flux and current in the steady state. A new approach for speed control of PMSM servo system using fuzzy logic technique. Without changing the motor parameters and load a fuzzy logic based DTC methodology is used for an efficient control of the torque and flux. [22]

Non-dominated Sorting Genetic Algorithm (NSGA) is used to reduce cogging torque in PMSM. NSGA is a Multiple Objective Optimization algorithm. The goal of algorithm is to minimize the peak value of cogging torque while the average air gap flux density remains unchanged. Also the algorithm tries to minimize the area of the magnets. In each iteration of GA, Finite Element Method (FEM) is used to calculate the cogging torque and to obtain the air gap flux density in this study. The results show that the cogging torque is reduced by more than 10 times using proposed method. [23]

5. Conclusion

This paper has presented the techniques applied for minimizing the torque ripples in PMSM. For minimizing torque ripples other advanced control techniques could apply, depending on the information of machine parameters. PMSM are widely used in many applications with smooth operation. This paper addresses the issue of torque ripples associated to machine control and drives that could be minimized through different control techniques. Suppression of the ripples basically depends on the controller part of the drive system and the techniques that can be used necessitate a variety of configurations to be arranged. Some techniques require hardware modification or add-on stages, whereas other schemes are algorithm-based techniques.

6. REFERENCES

- [1] C.Studer,A.Keyhani,T.Sebastine and S.K.Murthy "Study of cogging torque in permanent magnet machine 'Proc. IEEE 32nd,Ind.App.Soc(IAS)Vol.1,NewOrleans,LA,Oct1997,PP.4 2-49.
- [2] Torque Ripple Improvement for Interior Permanent Magnet Synchronous Motor Considering Parameters With Magnetic SaturationW. Seung-Joo Kim, Hyung-Woo Lee , Kwang-Soo Kim , Jae-Nam Bae , Jong-Bin Im , Cherl-Jin Kim
- [3] Slotless Permanent Magnet Synchronous Motor Operation without a High Resolution Rotor Angle Sensor. Todd D. Batzel and Kwang Y. lee, transactions on energy conversion, vol. 15, no. 4, december 2000
- [4]]Torque ripple of permanent machines with concentrated windings.Pia Salminen and Prof.Juha Pyrhönen Lic.Sc. Florence Libert and D.Sc.Juliette Soulard 2005-XII International Symposium on Electromagnetic Fields in Mechatronics.
- [5] Identification and compensation of Torque ripples of PMSM in a Haptic context Z. Jabhour,G. Champions.
- [6] Sliding-Mode control of Permanent Magnet synchronous motor with Uncertainty Estimation Markus Reichhartinger and Martin Horn. International Journal of Mechanical and Materials Engineering 1:2 2010
- [7] Torque ripple minimization,suppress harmonics, and noise of brushless pm synchronous motors derived by field oriented control Hamdy Mohamed Soliman, & S. M. Hakim. IJRAS,September 2012 Vol12Issue3
- [8] Simple Method of Torque Ripple Minimization and performance Characteristics Enhancement of Fuel Cell based PMSM Drives . International Journal of Computer Applications (0975 – 8887) Volume 19– No.2, April 2011
- [9] Torque Ripple Reduction in a PMSM driven by Direct Torque Control. L. Romeral, A. Fabrega, J. Cusido, A. Garcia, J.A. Ortega IEEE Transactions 2008.
- [10] Torque Ripple Minimization in PM Synchronous Motors Using Tooth Shape Optimization Ali Jabbari Majlesi Journal of Mechanical Engineering, Vol. 3/ No. 2/ Winter-2010
- [11] Active Cancellation of PMSM Torque Ripple Caused by Magnetic Saturation for EPS Applications Geun-Ho Lee Journal of Power Electronics, Vol. 10, No. 2, March 2010.\
- [12] Torque Ripple Reduction in Sensorless PMSM DrivesAntti Piippo and Jorma Luomi In Proceedings of The 32nd Annual Conference of the IEEE Industrial Electronics Society (IECON'06), pp. 920–925, Paris, France
- [13] Analysis and Compensation of Current Measurement Error in Vector-Controlled AC Motor DrivesDae-Woong Chung,Student Member, IEEE, and Seung-Ki Sul, Member, IEEE.. IEEE Transaction on Industry Applications, VOL. 34, NO. 2, MARCH/APRIL 1998
- [14] An Adaptive-Filter-Based Torque-Ripple Minimization of a Fuzzy-Logic Controllerfor Speed Control of IPM Motor Drive M. Nasir Uddin,Senior Member, IEEE transactions on industry applications, vol. 47, no. 1, january/february2011
- [15] Digital Simulation of Direct Torque Fuzzy Control of PMSM Servo System Jagadish H Pujar , S.F. Kodad International Journal of Recent Trends in Engineering, Vol 2, No. 2, November 2009
- [16] Adaptive Control for Torque Ripple Minimization in PM Synchronous Motors Mahmoud M. Saafan, Amira Y. Haikal, Sabry F. Saraya, Fayez F.G. Areed International Journal of Computer Applications (0975 – 8887)Volume 37– No.5, January 2012.
- [17] Reduction of torque pulsation and noises in PMSM with hybrid filter topology, Simulation Modeling Practice and Theory,Volume19,Issue1,Pages350-361,Ali Ahmed Adam, Kayhan Gulez.
- [18] W. Qian and S. K. Panda,]Torque Ripple Minimization in PM Synchronous Motors Using Iterative LearningControll IEEE Trans, VOL. 19, NO. 2, MARCH 2004
- [19] Artificial Neural Network Control of Permanent Magnet Synchronous Motor. Mahmoud M. Saafan, Amira Y. Haikal, Sabry F. Saraya, Fayez F.G. Areed. International Journal of Computer Applications (0975 – 8887)Volume 37– No.5, January 2012
- [20] An Implementation of Neural Network and Multi-Fuzzy Controller for Permanent Magnet Synchronous Motor Direct Torque Controlled Drive XianqingCao and LipingFan Jinxia Huang International Conference on Automation and Logistics Qingdao, China September 2008.
- [21] Neuro Direct torque control of permanent magnet synchronous motor with Genetic Algorithm speed controller.A. ELJanati el idrissi,N.Zzahid M. Jedra (2)
- [22] An Adaptive-Filter-Based Torque-Ripple Minimization of a Fuzzy-Logic Controller for Speed Control of IPM Motor Drive M. Nasir Uddin,Senior Member, IEEE transactions on industry applications, vol. 47, no. 1, January/february2011
- [23] A practical approach to cogging torque reduction in a Permanent Magnet Synchronous Motor using Non-dominated Sorting Genetic Algorithm