Simulation Modelling Practice and Theory 19 (2011) 350–361

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

Reduction of torque pulsation and noises in PMSM with hybrid filter topology

Ali Ahmed Adam [a], Kayhan Gulez [b,*]

[a] Fatih University, Engineering Faculty, Electrical-Electronics Eng. Dept., Istanbul, Turkey
[b] Yildiz Technical University, Electrical-Electronics Eng. Faculty, Control and Automation Eng. Dept., Istanbul, Turkey

ARTICLE INFO

Article history:
Received 16 February 2010
Received in revised form 5 July 2010
Accepted 15 July 2010
Available online 24 July 2010

Keywords:
Active power filter
Direct torque control
Hybrid filters
Permanent magnet synchronous motor
Passive filters
Torque ripple
Torque pulsation
Harmonics

ABSTRACT

In this paper, a hybrid filter topology is proposed to reduce torque pulsation, switching voltage harmonics and EMI noises in PMSM with direct torque hysteresis controllers. The filter topology consists of IGBT-based active filter (AF), LC filter in the main inverter output and trap filter in the motor side. The coupling of the AF-compensated voltage and the motor main voltage is achieved through series transformer. 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 active filter uses hysteresis voltage controller while the motor main circuit uses hysteresis direct torque control. 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.

1. Introduction

Hysteresis direct torque control (HDTC) of permanent magnet synchronous motor (PMSM) involves direct control of stator flux linkages and generated electromagnetic torque by applying optimum voltage switching vectors to the inverter supplying the motor. Although HDTC compared with rotor field oriented control has many advantages such as elimination of the *d*–*q* axis current controllers, elimination of rotor position required for transformation and fast torque response [1], it has many disadvantages such as large switching harmonics and voltage harmonics supplied by the power inverter which constitute the major source of harmonics in PMSM. These harmonics cause many unwanted phenomena such as electromagnetic interference “EMI” and torque ripple and the associated mechanical vibration and acoustic noise. These drawbacks are especially high when the sampling period is greater than 40 μs [1–3].

In the HDTC the switching of the inverter is updated only when the outputs of the hysteresis controllers change states, which result in variable switching frequency and associated large harmonic range and high current ripples which affect passive filter to be properly designed.

Recently, many research efforts have been carried out [4–12] to reduce the torque ripples in PMSM derived with HDTC with different degree of success. Tan et al. [4] and Martins et al. [5] have used complicated multilevel inverters to reduce torque ripples and fixing switching frequency. Tang et al. [6] have used space vector modulation techniques; however it reported that the operation at low speed is not stable. In [7], a modification of the switching table by insertion of zero vectors has been

* Corresponding author. Tel.: +90 212 3832454; fax: +90 212 3832507.
E-mail addresses: aliadam999@yahoo.com (A.A. Adam), gulez@yildiz.edu.tr (K. Gulez).

1569-190X/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.simpat.2010.07.008

considered, but there is no significant change in results has been observed. Degober et al. [8] have proposed an approach to minimize the torque ripple of the Surface-mounted PMSM caused by back-EMF harmonics. The approach used self-tuning multiple-frequency resonant controllers in the Concordia reference frame with good results however, the coefficients of the resonant controller should be re-evaluated according to the rotor speed while the motor operates and the excitation current waveforms should be predetermined according to the commanded torque and rotor position. Stamenkovic et al. [9] have provided a model that can identify the torque ripple experienced with PMSM based on measurement performed on a typical PMSM. They provided results suitable for designing active and passive torque ripple compensation. Gasc et al. [10] have proposed an approach to reduce ripple torque without position sensor. The scheme utilizes reduced order torque observer and Kalman filter. The scheme provided good results however, accurate speed, currents and line voltages are necessary to define position and load torque for the observers operations. Yun et al. [11] have proposed a variable step-size normalized iterative learning control scheme to reduce periodic torque ripples. This technique was combined to existing PI current controller to minimize the mean square torque error. The provided simulation results show some improvements in minimizing torque ripples. In [12] an iterative learning control algorithm has been used to decrease the pulsating torque. It has been shown that the torque pulsation amplitude varies under different operating conditions and in general is larger with lower speed and higher load torque. However, simulation and experimental results were shown for very small load (0.4 N m compared to the rated (7.6 N m)) so, it is not clear whether the pulsating is actually decreasing at rated load.

In [13], Gulez et al. have provided a technique which depends on evaluations of torque error and flux error to provide switching time for the selected vectors according to the torque magnitude error, good results have been achieved, however at a very low speed, though the required torque is always achieved, the operation is not stable.

In this paper, a new hybrid filter topology is proposed to reduce torque ripples, voltage harmonics and EMI noises in PMSM with direct torque hysteresis controllers. The filter topology consists of IGBT active filter (AF), high frequency LC filter in the inverter output and trap filter in the motor side. The coupling of the compensated AF voltage and the inverter main voltage is achieved through series transformer. 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 active filter uses hysteresis voltage control algorithm while the motor main circuit uses hysteresis direct torque control algorithm. The trap passive filter is connected to the secondary of the coupling transformer to capture the high and intermediate frequency voltage components due to the active filter and the main filter switching.

2. The proposed system topology

Fig. 1 shows the proposed hybrid filter topology together with the motor drive system. The main inverter control system is hysteresis direct torque control utilizing hysteresis controllers with switching table [1].

The PMSM equations in rotor reference frame are given as:

$$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \begin{bmatrix} R + pL_{sd} & -P\omega_r L_{sq} \\ P\omega_r L_{sd} & R + pL_{sq} \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + \begin{bmatrix} 0 \\ P\omega_r \psi_F \end{bmatrix} \quad (1)$$

$$T_e = \frac{3}{2} P(\psi_F i_{sq} + (L_{sd} - L_{sq}) i_{sd} i_{sq})) \quad (2)$$

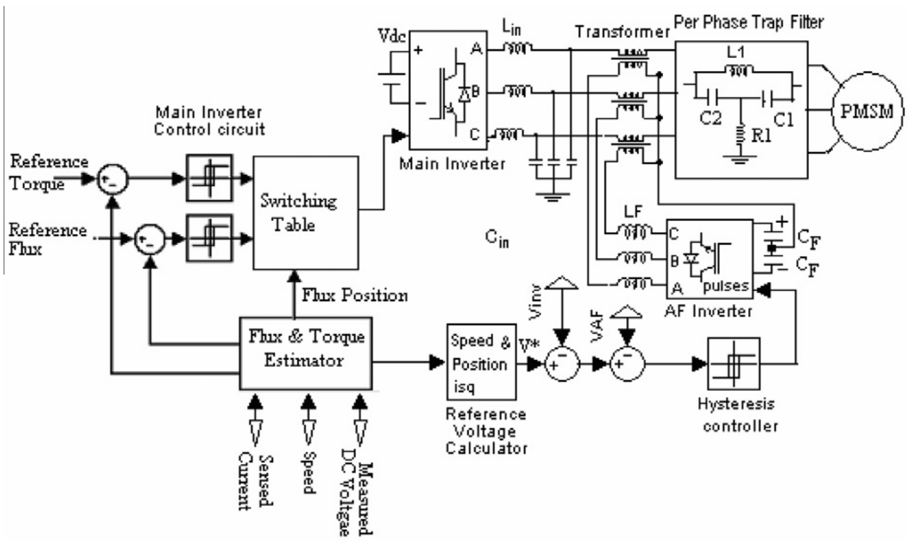

Fig. 1. The basic structure of Hybrid Filter with PMSM control circuit.