Contributions to optimize the control of Permanent Magnet Synchronous Machine Drives

Yuanlin Wang

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1. Prof. Dr.-Ing. Dieter Gerling
2. Prof. Dr.-Ing. Manfeng Dou

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Abstract

In order to optimize the control performance of IPMSM, four topics are researched in this thesis, including inverter nonlinearity compensation, model predictive torque control, position sensorless control and online electrical parameters estimation.

1) Inverter nonlinearity compensation

Voltage-fed PWM inverter is widely used in industrial applications. However, due to the non-ideal characteristics, the output voltage is distorted with respect to the reference value. The voltage error results in serious problems, such as current waveform distortion and control performance deterioration.

In this thesis, the voltage distortion principles of MOSFET inverter and IGBT inverter are analyzed and compared. A graphical solution of compensating inverter voltage error is proposed, which is easy to implement and efficient. The effectiveness of the proposed method is verified by experiment.

2) Model predictive torque control

As it is well-known, due to many advantages, Finite Control Set-Model Predictive Torque Control (PTC) is widely researched and successfully applied to a wide range of applications.

However, there are also some challenges for conventional PTC method. As all voltage vectors are enumerated, the computational burden is enormous and sampling period is long. Meanwhile, only one voltage vector is employed in one sampling period, so the torque ripple is high.

This thesis proposes an alternative strategy of conventional PTC strategy to reduce the torque ripple and computational burden. In order to reduce the torque ripple, in each sampling period, an improved Discrete Space Vector Modulation (DSVM) technique is utilized to synthesize a large number of virtual voltage vectors. Deadbeat (DB) technique is used to optimize the voltage vector selection process, avoid enumerating all the available voltage vectors. With this proposed method, only three voltage vectors are tested in each predictive step. Based on the improved DSVM method, the three candidate voltage vectors are calculated out by using a novel algebraic way.

This new strategy has the benefits of both MPTC method and DB method. The performance of this approach is compared with MPTC method and Deadbeat Torque and Flux Control (DB-DTFC) method by experiment.

3) Position sensorless control

As well known, rotor position is required in close loop control of PMSM, which is usually obtained by using an external dedicated sensor. However, the position sensor may increase cost, weight, volume, complexity and reduces the reliability. Meanwhile, the application area is limited. To avoid the defects of PMSM with a position sensor, a kind of rotor position sensorless strategy is proposed in this thesis.

A full order discrete mode of IPMSM in $\alpha\beta$ coordinate frame is built, and a new Sliding Mode Observer (SMO) is developed. Pole placement technique is used to design the switching surfaces, and Free Hierarchical law is adopted as switching scheme. Reaching law is used to solve the sliding mode trajectory and control inputs. Rotor position and speed are achieved by using a quadrature locked loop. The performance of the proposed position sensorless control strategy is evaluated by experiment.

4) Online electrical parameters estimation

Electrical parameters of PMSM are of great importance for machine evaluation, optimize control and condition monitoring. When motor operates, these parameters are time-varying. Therefore, in this thesis, an online parameters estimation strategy is proposed.

In order to estimate all four electrical parameters in real time, a full rank estimation model is built, and its identifiability is analyzed by using Jacobian matrix. The autocorrelation of Recursive Least Square (RLS) estimation error is analyzed by using Durbin-Watson (DW) test. As the estimation residuals of RLS are positively correlated, an improved strategy-Recursive Generalized Least Square (RGLS) with forgetting factor is used in this thesis to estimate the motor electrical parameters.

5) Experiments

The performances of the four proposed strategies are validated by using two independent experimental test benches. One test bench is low power IPMSM with MOSFET inverter, and the other test bench is high power IPMSM with IGBT inverter.

Keywords: Inverter nonlinearity compensation, Permanent Magnet Synchronous Machine (PMSM), Finite Control Set-Model Predictive Torque Control (PTC), position sensorless control, online electrical parameters estimation.

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