Chapter 1

Introduction

BLDC motors are widely used in human's daily life. The introduction to the motor application and its research background will be presented in section 1.1. Next, the recent development of sensorless control methods will be depicted in section 1.2. Finally, the organization of this thesis will be proposed in section 1.3.

1.1 Research background

Motors with the function of transforming the electrical power to mechanical power have played an important role in human's life, frequently applied in public transit systems, hybrid vehicles, compressors, generators, compact disks, micro devices and etc. In light of the divergent functions in its application, motors can be further categorized into DC brush machines and brushless motors. The diagram of motor categorization is represented in Figure 1.

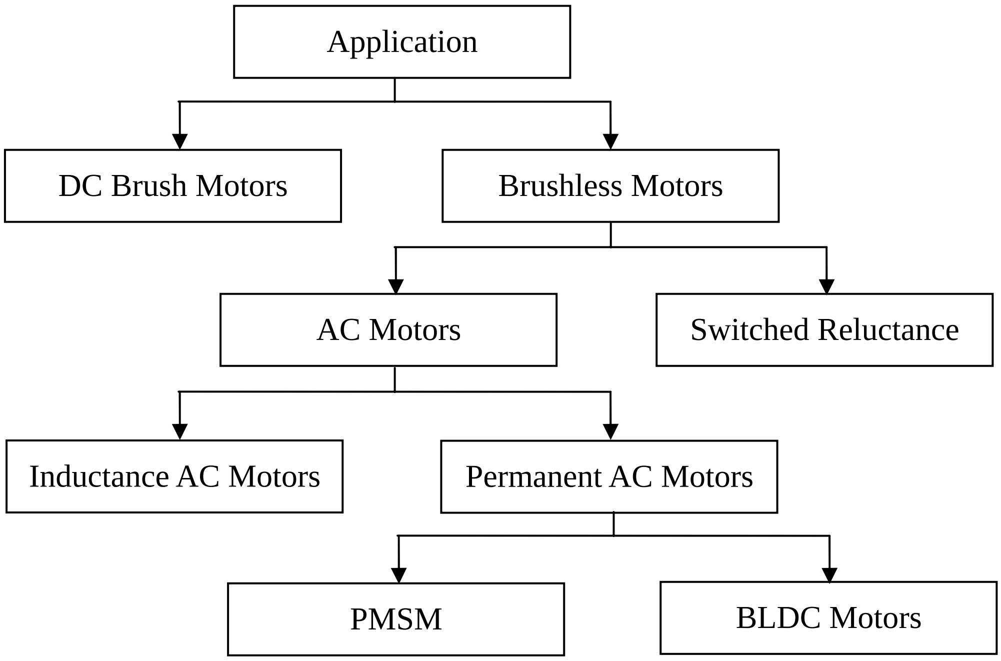

Figure. 1.1 The motor selection procedure.

Among the classification of the motor, the permanent magnet AC (PMAC) motor is the most popular due to its reliability and efficiency. The PMAC motor is equipped with the features of high efficiency, high torque to inertia ratio, high torque to volume ratio, high air gap flux density, high power to inertia ratio, high power to volume ratio, and compact structure. Furthermore, the PMAC motor is mainly divided into permanent magnet synchronous motor (PMSM) and brushless DC (BLDC) motor. They both have a permanent magnet (PM) on the rotor and require alternating stator currents to produce constant torque. The only difference between these two machines is that the PMSM has sinusoidal back-EMFs distribution while the BLDC has trapezoidal one. More description and comparison between the PMSM and BLDC motor are discussed in [1].

In this thesis, the 3-phase brushless DC axial-flux wheel motor is used. It is a low speed and high torque direct-drive motor.

1.2 Recent development

Currents feedback control, electrical angular velocity feedback control and electrical rotating angle feedback control are three typical types of PMAC motor control. The following is a brief introduction to the three motor controls. First, the current feedback control aims to decide the rotating reference frame's currents in which i_d is equal to zero and i_q is identical to reference q-axis current i_q^*. These currents in the rotating reference frame are measured from three phase current by current sensors. Second, the electrical angular velocity feedback control attempts to rotor velocity sensed by inside motor's encoder. The last control, electrical rotating angle feedback control, is planned to be located somewhere and the rotor position can be detected by three Hall-effect sensors posited on the surface of the stator.

Among the three motor controls, the three Hall-effect sensors and encoder have several disadvantages in their applications, such as system cost, size and reliability. In addition, the sensors may be sensitive to the motor temperature inside. Therefore, recent research has paid more and more attention to sensorless control methods which do not use any Hall-effect sensors or encoder. Many sensorless methods have been focused on several categories [2]: back-EMFs sensing method [3], third-harmonic back-EMFs sensing [4], back-EMFs integrating method [5], freewheeling diode conduction method [6], observer-based method and etc. The common point of the first three categories is the detection of the back-EMFs which should be measured at the instant of the unexcited phase. The fourth method, freewheeling diode conduction method, uses indirect sensing of the zero-crossing of the back-EMFs to obtain the switching instants of the BLDC motors. Regardless of using any method above, the back-EMFs proportional to the rotating angular velocity should be recognized directly or indirectly. Nevertheless, there exists a shared drawback, that is, the back-EMFs are difficult to measure at start-up or low rotating angular velocity. Besides, the fifth method, observer-based method, can be further categorized into the extended Kalman filter [7],[8], non-linear reduced [9], [10], and sliding mode [11], [12] observers.

The extended Kalman filter (EKF) is a stochastic observer in the least-square sense for estimating the states of dynamic non-linear systems and it is a viable for the on-line determination of the rotor position and velocity of a PMSM. However, the drawbacks of the EKF application to sensorless drives are listed as follows. First, the detail dynamic model including initial position is not available. Second, it is not available for formulating EKF model in closed loop. Third, the initial position and velocity convergence problems are exited.

The non-linear reduced observer is based on the model of the motor represented in the stationary reference frame. Then, the sufficient conditions for convergence as well as convergence velocity are established. The results of the non-linear reduced observer show that low sensitivity to torque disturbance and variation of the motor parameters.

The sliding mode observer is based on the linear model of a BLDC motor, so its stability is easy to be discussed. Furthermore, the pole assignment problem is easier to be solved because the order of the observer's error equation is reduced when the sliding mode occurs. Using the pole assignment, the position estimator is more robust against velocity estimation errors. In addition, the observer is also robust other parameter deviations.

The present research starts from the estimated-based method. The sliding mode estimator for BLDC motor's angular velocity will be presented. Its main advantage is that only the phase current should be measured rather than detecting the back-EMFs. In particular, the back-EMFs can be obtained by filtering equivalent control gains. Then, the estimator for back-EMFs and electrical angular velocity are simultaneously designed. Finally, the convergence of the stability will be proved by using Lyapunov function. These processes will be simulated by the software, Matlab®–Simulink® and hardware experiments set up by Real-Time WorkShop® (RTW) of Matlab®.

1.3 Thesis organization

The thesis is organized as follows. The fundamental and the mathematical modeling of the BLDC motor are introduced in chapter 2, including the coordinate transformation process, stationary and rotating reference frame.

In chapter 3, some sensorless control methods will be proposed. A sliding mode estimator for electrical angular velocity and back-EMFs are designed to estimate the rotating speed and rotor position by detecting three phase currents only. Note that the estimations are robust to parameter variations. Consequently, the stability of the convergence is proved by Lyapunov function.

In chapter 4, the simulation of the BLDC motor model and the sensorless control method, sliding mode estimator for motor’s electrical angular velocity are implemented by Matlab®–Simulink®. This toolbox can help designer establish them easily and directly. Besides, a hardware experiment is prepared for testing and verifying the method of this thesis.

In chapter 5, the simulation and experimental results will be shown. Finally, the discussions and conclusions will be proposed in chapter 6.