Introduction

This chapter introduces the background of the project. An overview of the conventional sensorless control schemes for permanent magnet synchronous motors is presented, and based on the complexity level and some limitations related to the individual schemes, the objective of the thesis is derived.

Permanent Magnet Synchronous Motor (PMSM) drives are being replacing classical DC and Induction Machine (IM) drives in some industrial applications such as machine tools and robots. Advantages of PMSMs include high torque to inertia ratio, high power density and high efficiency. Additional features such as robustness, reliability and ease of control allow this machine to be the focus of many industrial applications in the nearest future.

Industrial applications are based on variable speed drive systems. Therefore, the control of PMSMs requires shaft position sensor or rotational transducer, in order to provide maximum (or optimum) starting torque. This is achieved by keeping appropriate space angle between the stator and the rotor magnetic fields, based on signals received from the sensor.

However, the afore-mentioned machine advantages could appear to be ineffective due to the drawbacks encountered with the use of sensors or rotational transducers, especially for small drive systems. Some of these drawbacks are:

- the significant drive cost
- the substantial reduction of the drive ruggedness
- the increased complexity and maintenance
- the imparity between robustness and reliability of the drive system.

In order to solve the problem related to the use of sensor, many researches suggested an approach to control AC machines without sensors, thereby opening doors to the so called sensorless drive systems.

However, there is no absolute solution for any scientific problem; new approaches appear with their own limitations, hence the sensorless approach limitations, encountered especially with the Surface mounted Permanent Magnet Motor (SMPMSM).

1.1 Sensorless schemes for PMSM

In sensorless control techniques, speed sensor is not used to give position information. Instead, the position is estimated based on machine variables such as phase current or stator voltage [1-2].

There are basically two types of sensorless position estimation schemes for PMSM based on the back electromotive force (EMF) and the machine saliency.

1.1.1 Back EMF approach

In this approach, the position is estimated using voltage models, flux observer or kalman filters [3-4]. Good results are achieved in middle and high operating speed regions. However, since the amplitude of the back EMF is proportional to the rotor speed, the performance of this approach is worse in lower operating speed region.

1.1.2 Magnetic saliency based approach

This scheme utilizes the machine magnetic saliency [5] and is known as signal injection based approach. Voltage or current signals are used to estimate the rotor position.

-voltage signal injection

Extra voltage signals are injected in to the motor to estimate the rotor position by detecting machine inductances in a very short time.
Since this approach is based on inductance detection, it might suffer from parameter variation or measurement noise. Alternatively, current signals injection can be used to estimate the rotor position.

-fluctuating high frequency voltage signal injection

The basic idea of this method is to detect the small fluctuation of the back EMF voltage by injecting a high frequency test voltage to the machine at stand still. This approach shows good performance at low and zero speed regions under loaded condition [3], and is suitable for Interior mounted Permanent Magnet Synchronous Machines (IMPMSM).

-Rotating high frequency voltage signal injection

This scheme utilizes rotating high frequency voltage signal combined with tracking algorithm.

Generally, the back EMF sensorless scheme suffers from poor performance at zero or low speed range, meanwhile the scheme based on machine saliency could be problematic when it is applied for machines with few saliencies such as SMPMSM.
SMPMSM has smaller magnetic saliency compared to IMPMSM and the axis representing the higher impedance can easily saturate according to the load level. Therefore, the magnetic saliency will be

decreased or vanished. This leads to the failure of the applied sensorless control strategy.

The description presented so far shows different conventional ways of applying sensorless control technique for permanent magnet motor. A focus in order to select which control scheme will be applied in this project is convenient to define the objective of the project.

The back EMF scheme requires voltage model, kalman filters or flux observer (as stated previously).
Kalman filters could be difficult to implement due to parameter drift over temperature. Therefore, this will not be considered in this project.

From previous experiences, the implementation of flux observer could be difficult in achieving optimal accuracy of the observer in real operating conditions. So the approach based on flux observer will not be a focus of this project as well. Then, the back EMF scheme based on **voltage model** will be considered.

The fluctuating high frequency voltage signal injection provides good performance at zero and low speeds under loaded condition, but this approach is suitable for IMPMSM [3]. This scheme will not be considered in this project since the motor used in this project is a SMPMSM.

Rotating high frequency voltage signal injection could be an alternative way of dealing with the sensorless control of SMPMSM, but this scheme suffers from narrow limits of the dynamic characteristic [6] and will not be considered in this project.
Then, amount the control strategies based on the machine magnetic saliency, **the voltage signal injection** will be considered in this project, though it might suffer from parameter variations due to temperature increases.

Objectives

The goal of this project is to investigate sensorless control schemes for surface mounted permanent magnet motor, taking in consideration the zero and low speed issue, which is still one of the crucial problems in industrial drive systems. Therefore, the focus will be on the starting procedure(s) providing maximum torque level and accurate position information when applying sensorless control schemes for SMPMSM.

The selected approaches will be first implemented in Simulink. Then based on the simulation results, a chosen scheme will be implemented in DSPACE laboratory (if sufficient time space available), in order to bring an insight in the real operating condition of a surface mounted permanent magnet motor in open loop control strategy.
After a brief overview of the sensorless control schemes for PM motor presented in this chapter, an analysis of the basic operations needed to model a sensorless control scheme for PM machines is presented in chapter 2. Afterwards in chapter 4, a controller design for the intended sensorless schemes is derived. Chapter 5 presents the sensorless control approach based on the back EMF calculation (just for reviewing the principle, since this is known as the traditional approach, though it does not work at zero and low speeds).
In chapters 6 and 7, two sensorless control algorithms are proposed, including the simulation results and the results discussion. Finally, conclusion and future prospects are the aim in chapter 9, followed by the appendix.

1.2 Project limitations

Following are the limitations in this project:

- the inverter non linearity has not been considered
- only a linear machine model has been assumed and used

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