

Chapter 1 – Introduction

This chapter presents an introduction and overview on basic machine technology and construction. Furthermore the problem statement, the issues that need to be addressed to solve the problem and the methodology that will be used to address and solve the problem are also introduced. A chapter overview of the dissertation is listed at the end.

1.1 Background

Since its invention in the 19th century, electric machines have played a key part in both industry and science. One can even say that electrical machines are the backbone of the modern world.

Electrical machine technology may have improved significantly since it was first introduced, but the basic operating principle has stayed the same. With this statement kept in mind, electrical machines can be classified according to the stator field excitation: alternating current (ac) or direct current (dc). As the technology improved the classification levels expanded, but the two main classifications are still the same. The focus of this will be on ac machines and more specifically a hybrid design between an induction motor (IM) and permanent magnet synchronous machine (PMSM) known as a line-start PMSM (LS PMSM).

LS PMSMs are not a new concept or idea as this motor technology is similar to synchronous motors with a damper cage. The damper cage produces torque at start up to provide the machine with line-starting capabilities, in the absence of an excited winding in the rotor. In the past, IM was favoured above synchronous machines because of its robust design, low maintenance and lower cost of ownership. Thus the industry demand for line-start synchronous machines was low.

Since the year 2000, an increase in research publications can be seen on LS PMSM related topics. This may be due to several influencing factors, one of which may be the increased demand by the industry due to stricter efficiency regulations on machines. As a PMSM/LS PMSM have almost rotor losses a PMSM will be more efficient than even the most efficient IM with regards to energy efficiency. Thus the biggest advantage an LS PMSM has over an IM is the increased efficiency and cost of ownership.

1.1.1 Classification of electrical motors

The literary survey for the project will be on polyphase induction machines and sinewave permanent magnet (PM) machines as an LS PMSM is a combination of an IM and PMSM. Figure 1.1 shows a clarification of AC electrical machines.

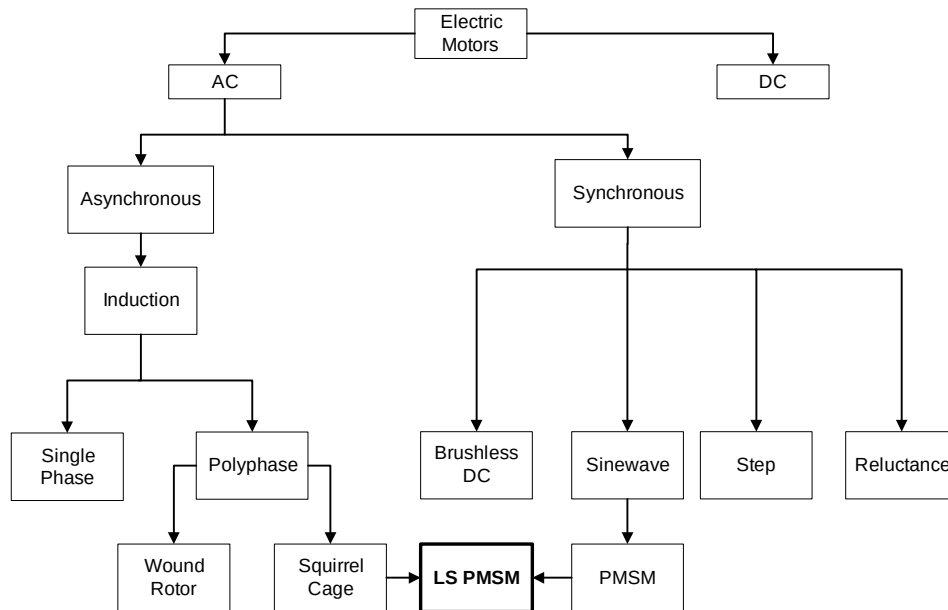


Figure 1.1: Motor classification [1, 2]

Figure 1.1 indicated that AC machines are divided into two types, asynchronous machines and synchronous machines. Due to the unique design of an LS PMSM the motor cannot be categorised into only one of the two operating methods. Thus an LS PMSM falls under both categories.

1.1.2 Motor topology

Electrical machines come in different shapes and sizes. Figure 1.2 provides a basic overview of the four main machine topologies.

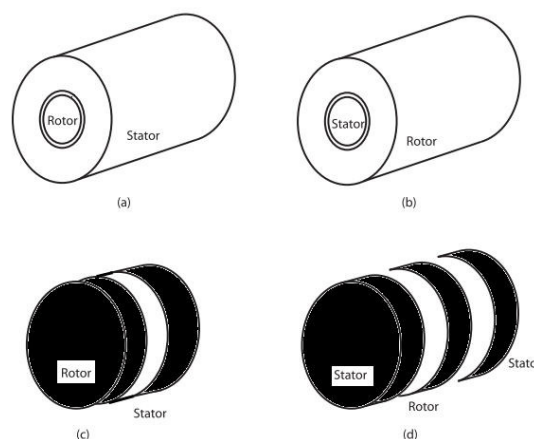


Figure 1.2: Machines construction possibilities: (a) internal rotor, radial flux; (b) external rotor, radial flux; (c) external rotor, axial flux; (d) internal rotor, axial flux [5]

All the above machines are cylindrical shaped machines. Figure 2 (a) is the most commonly found electrical machine on industrial plants and in house hold appliances. Designs (b) - (d) are used only in

specialised applications, like traction motor, wind generators or energy storage systems. Design (a) will be the focus topology for the LS PMSM prototype design.

1.1.3 Line-start permanent magnet synchronous machines

As stated earlier, LS PMSM is a hybrid or combination design between an IM and a PMSM. By combining the two different rotor designs into a single rotor, the negative aspects of both designs are eliminated and a better, more efficient machine can be produced in theory.

The basic operating concept behind an LS PMSM is easily explained: during start-up, the motor operates as an induction machine and acceleration torque is created by the rotor cage. This torque will accelerate the machine close to the synchronous speed. Once the rotor is synchronized with the stator, the motor operates as a PMSM and the rotor cage has no effect on torque production. The cage will act as a stabilization component in the event of a sudden load change.

The basic design of an LS PMSM is also very simple. Figure 1.3 below is a cross sectional view of a four-pole embedded magnet LS PMSM machine. As both an IM and PMSM can operate with the same stator design, the LS PMSM can also operate with the same stator designed. The rotor components of an LS PMSM are the IM's squirrel cage, the permanent magnets of the PMSM and laminated electrical steel core. The design complications of this machine are the interaction, topology and size of the two machines (IM and PMSM) as they may negatively influence each other during different stages of operation.

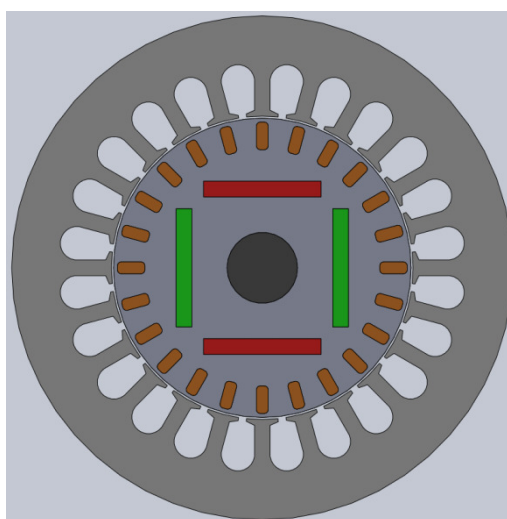


Figure 1.3: Cross section view of an LS PMSM with embedded PM

In Figure 1.3, the copper bars represent the IM's squirrel cage and the green and red represents the PMSM's permanent magnets. The grey material represents the magnetic laminations of both the stator and rotor. As with a synchronous machine, ideally an LS PMSM must have equal amount of pole pairs in both the stator and rotor, this is to ensure maximum torque development.

Current commercially available and research developed LS PMSM machines and the operation of the machine will be discussed in depth in Chapter 3.

1.2 Problem statement

The purpose of this research is to develop an LS PMSM prototype. The performance criteria of the LS PMSM must be similar to that of an IM of the same power rating and design application. The LS PMSM prototype motor has three key points that have to be considered during the research and design process, namely: operating requirements, transient operation and steady state operation.

1.2.1 Operating requirements

The prototype motor will be designed to the following specifications:

Power rating:	7.5 kW
Operating voltage:	525 V three phase @ 50 Hz
Machine poles:	4 poles
Topology:	Radial flux machine

1.2.2 Transient operation

The transient period of the LS PMSM is from start-up to synchronisation. During this period, the motor will act primarily as an IM that must to produce adequate torque to accelerate the machine and its connected load up to synchronous speed. Furthermore the start-up current may not be greater than 10 times the rated current of the motor. This is due to protection systems in the network that have been designed for this type of behaviour during motor start-up and as this prototype motor will function as an IM replacement.

1.2.3 Steady state operation

Steady state operation is once the rotor reaches synchronization. At this point the developed torque must be equal to that of an IM of the same rated power at maximum speed. Furthermore, at synchronous speed the method used during start-up must not influence the motor operation negatively.

1.3 Issues to be addressed

When developing any type of motor there are certain key areas that need to be addressed in order to produce a working prototype. By keeping the operating requirements as well as the application of this motor in mind, the three main issues that need to be addressed are: the motor's frame size, the stator and rotor design.

1.3.1 Rotor design

In this project the rotor design will be the main focus. As the LS PMSM operation relies on two different techniques of producing in a single rotor, the issues unique to an LS PMSM need to be addressed. These issues are:

- The interaction between the components (PMSM and IM) in the rotor during different stages.
- The PM and squirrel cage topology.
- The required PM volume to produce the needed air gap flux.
- Torque production and independent torque producing components to form a torque vs. speed curve.
- Transient and steady state operation of the design.
- The mechanical construction of the rotor.

By addressing the above mentioned issues, a functioning LS PMSM rotor design can be derived to overcome some of the current limitation of an LS PMSM as stated in Chapter 3.

1.3.2 Stator design

The biggest concern with the stator design is efficiency and the interaction between the rotor and stator. The stator efficiency and rotor interaction is dependant in the following:

- Stator sizing (inside and outside diameters, active length).
- Wiring configuration.
- Slot shape.
- Lamination material.
- Material saturation.
- Manufacturing options (laser cutting vs. pressed lamination, welded vs. cleating the stack)

1.3.3 Fitting

For this project an existing industrial standard radial flux motor frame will be used to house the machine. this is done to reduce the manufacturing cost of the motor and ensuring that the mechanical design and operation is of high standard. The mechanical design and optimization is not part of the project scope. The selected frame may be smaller than a same rating IM which will result in the mounting brackets/holes differing. Ideally the prototype must be the same size as an IM of the same power rating.

1.4 Research methodology

The research methodology entitles the process to develop and manufacture the LS PMSM prototype. Firstly a general machine and LS PMSM knowledge need to be in place. From this, the design concept is formulated after which the machine is designed, manufactured and tested.

1.4.1 Literature survey

The literature survey will focus on current LS PMSM technology and the applications for this type of machine. The goal behind investigating current technology is to determine the unique properties, disadvantages of existing machines and previous research. This survey will also determine previous techniques used that may aid the design. From the knowledge gained in the literature review the current design problems can be highlighted which will aid in the conceptual design.

The literature survey will also focus on IM and PMSM operation. This will aid in the concept design for the LS PMSM. The different components of the machine will be divided into sub-design sections. The methods used to design the machine will be handled in the appropriate section and not in the literature survey.

1.4.2 Design of an LS PMSM

In this section the components will be designed with the aid of literature and verified with Finite Element Method (FEM) simulations techniques. Once the simulations are done, the original design will be adapted and the design must be verified again against the analytical values that were selected and calculated during the design. This process will be repeated several times until the design is finalised after which manufacturing will start. Figure 1.4 contains a flow diagram of the design process.

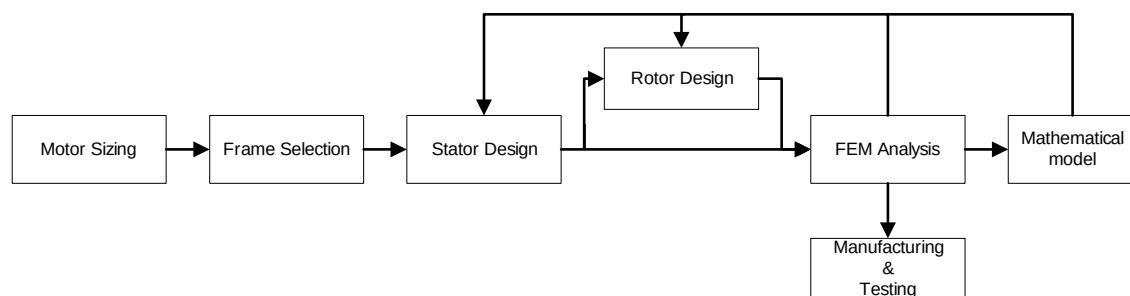


Figure 1.4: Proposed LS PMSM design process

1.4.3 Mathematical modelling of an LS PMSM

Upon completion of the design, a mathematical model of the LS PMSM prototype needs to be derived. This will aid in simulating the motor in real-time operations and help to investigate the motor's

characteristics under different conditions and transient response. Information gained from the model will be used to adapt the design and change the mathematical model.

1.5 Dissertation overview

Chapter 2 – Literature Review on LS PMSM technology: In this chapter the different components that form part of an LS PMSM are briefly discussed and currently available LS PMSM. Focus is also placed on past research done where prototypes were developed to gain a better understanding of the machine and to incorporate unique design features that were successfully used.

Chapter 3 – Machine Design: This chapter contains the entire design of the prototype. A high level design breakdown is also listed in this chapter. The design is divided into two main parts namely the stator and rotor design. The stator design includes the sizing of the machine, winding layout comparison and verification of the design using FEM. The rotor design is divided into three parts namely the PMSM, IM en LS PMSM rotor design.

Chapter 4 – Performance prediction: In this chapter the torque production profile of the prototype is constructed for both steady state and transient operation. The design in Chapter 3 is compared to FEM packages to verify the machine design.

Chapter 5 – Manufacturing Processes: This chapter focuses on the method used and steps taken in the manufacturing of the prototype. Any deviations from the design in Chapter 3 are also provided in this chapter along with the cost of manufacturing and manufacturers used.

Chapter 6 – Test & Evaluation: This chapter provides the test results of the prototype along with a discussion and conclusion on the performance and operation of the machine against the predictions made.

Chapter 7 – Conclusion and recommendations: This chapter summarises the work done during the project and provides relevant conclusions regarding the prototype operation and deviations in performance. Several unresolved or possible areas for future work are also provided.

This chapter provides an introduction into electrical machines and more specifically, LS PMSM. The problem statement for the project is defined from which the issues that need to be addressed are formulated. The research methodology in the design of the machine is given along with the project breakdown.