Performance Analysis of a PMSM for Traction Applications in Electric Vehicles with Hairpin Winding Technology

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***Abstract*—This paper presents the performance analysis of an interior permanent magnet synchronous motor (IPMSM) for electric vehicle application based on hairpin winding technology. Firstly, the vehicle dynamic was modelled and analysed to determine an appropriately rated motor for the drive system, and a suitable IPMSM via finite element analysis (FEA) using hairpin winding in the stator. Four different layers of hairpin winding – 2-layer, 4-layer, 6-layer and 8-layer were considered. The performance analysis show that the 8-layer has the lowest mechanical losses, and thus most suitable for application in electric vehicles design.**

***Keywords* — IPMSM; hairpin winding technology, electric vehicle; finite element analysis**

I. Introduction

Fossil fuel-based vehicles are a major source of air pollution in the environment. Furthermore, combustion engine vehicles are not suitable for the environment. Electric vehicles (EV) have become viable alternatives in recent years. An electric motor is one of the significant design modules of the electric vehicle. However, two major challenges to EV are minimal power requirements for propulsion and energy utilization. Thus, optimum selection of electric motor with less ripple torque, lighter weight, less noise, and high efficiency can result in less periodic maintenance and increase in vehicular life span. Permanent magnet synchronous motors (PMSM) are considered owing to high efficiency; torque density and good performance in the field-weakening section[1][2]. However, the rotating portion of the PMSM which is made up of permanent magnet (PM) materials can be demagnetized suddenly due to high remnant flux density and high operating temperature during operation. This can be overcome by the application of hairpin winding with suitable conductor bars.

The demand for highly efficient electric traction motors is set to rise as the forecast reaches a 30% market share in 2030 of the increasing number of electric vehicles [3]. Recent research works have focused on electric proportion due to the need to decarbonize the society. Electric motor and its component play a vital role in this respect. The EV traction with hairpin winding technology in the stator is gaining attention among researchers due to the associated intrinsically high slot fill factor, good thermal indulgence and short end-winding length which makes the winding a good candidate for traction applications. However, the major drawback is high losses at high-frequency operation due to skin and proximity effects. The winding consists of pre-shaped copper bars that are modelled into a hairpin shape which are subsequently inserted into the stator slot.

Hairpin windings have generated tremendous interest in high torque density electric vehicle applications [4], [5]. However, compared to the conventional round conductors, dc copper loss due to the shortened end-winding and a higher fill factor leads to high current density, peak torque, and a fully automated manufacturing process that eventually reduces associated costs [6]. Studies on ripple torque reduction [7], and reduction of AC winding losses at high frequency by varying the number of conductor layers from four to six, and the effect of skin and proximity effects were decreased. [8].

This study focuses on the performance analysis of an IPMSM for vehicle traction application with hairpin winding using different conductor bar of the layer is considered. In this design approach, the performance of the IPMSM is considered by analyzing the AC losses at high frequency.

II. METHODOLOGY

A. Electric Vehicle Dynamic Analysis

The dynamic analysis of the vehicle is persistent by the consequential forces adoptive on the vehicle as given in (1). The tractive energy as of the wheel depends on the motor torque, gear ratio, and the motor's efficiency. Therefore, tractive force ought to stunned the total force applied on the vehicle when moving, which depending on the motor power together with gear ratio and the wheel radius [9]–[11].

$$M_v a_v = F - \sum F_r \quad (1)$$

Where M_v is mass of the vehicle, a_v is vehicle acceleration, F is the tractive force or the road load of the electric vehicle and F_r is the resistive force.

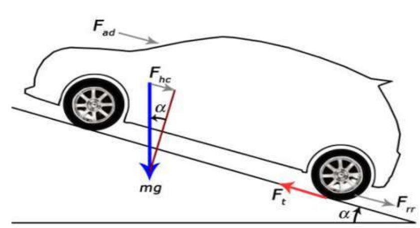

Fig. 1: Tractive forces acting on the vehicle on a slope

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