Coupling between an Analytical Tool and Stator Current Sheet to Test the Inherent Impact of Armature Winding Distribution using FEM

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The study of the inherent impact of different winding distributions using FEM can be complicated when taking into account the stator slots as it introduces both constraint and reluctance variation of the air gap. To avoid this fact, a ‘current’ sheet spread all around the inner stator surface can be used while being coupled with an analytical tool that supplies it by the given MMF values.

Index Terms—analytical tool, current sheet, electrical machine, finite element analysis, stator modelling.

I. INTRODUCTION

The harmonic content of a given winding distribution, and then the one of the corresponding Magneto Motive Force (MMF), can quickly be obtained through analytical approaches [1]. Their accurate impact on the magnetic flux density in the air gap requires numerical modelling in order to take into account the real geometry and the magnetic behaviour of the materials. However, in this case, the stator slots have also to be account for and then the harmonic content of the magnetic flux density also results from the interaction with the latter. Furthermore, in case of different winding tests, the geometry of the slots and then their sizes should be modified which induces new meshes. One solution to avoid this fact and to be able to analyse the only effect of a given winding distribution on the magnetic flux density consists in using a current sheet, located all around the inner surface of an equivalent slotless stator. This current sheet will model the total stator MMF thus replacing the real conductors supplied by their currents. The idea of substituting the supplied armature windings by a current sheet has featured in [2] but without any further development.

The present paper deals with the use of such current sheet and its coupling to an external tool which can lead to test different winding without any slot constraint. It is organised as follows. The second part is devoted to explain the current sheet model and its coupling with the analytical tool that determines the harmonic content of a given MMF. To validate the proposed approach, results obtained from a squirrel cage induction test machine are compared to the ones given by the proposed approach in terms of local (magnetic flux density in the airgap) and global (induced currents in rotor bars) quantities.

II. COUPLING BETWEEN AN ANALYTICAL TOOL AND A FINITE ELEMENT COMPUTATION SOFTWARE

A. Principle

Stator of an electrical machine is generally modelled as shown in Fig. 1. The number of the slots and their sizes are directly linked to the design of the machine by means of pole pairs, conductor number and RMS current supply. Recently, several works have sought to determine new distribution of windings in order to optimize different criteria [3]. To test their inherent effect on a realistic machine while taking into account the real rotor characteristics would be complicated as it needs to modify the stator geometry for each case. The simplest way to avoid such problem is to replace the MMF of the real windings by a current sheet of a limited thickness in the air gap spread all around the inner surface of the same stator with no slots. This sheet is composed of elementary areas, of the same small surface, regularly located in the air gap as shown in Fig. 2. Each elementary surface is considered as a conductor which is supplied by a ‘current’ obtained from the MMF of the supplied armature windings to test. Moreover, only the thickness of the stator yoke (h) is considered in the proposed approach in order to reach the same magnetic saturation level.

![Fig. 1. Classical modelling of a stator electrical machine](image1)

![Fig. 2. Stator modelling by a current sheet](image2)
obtained from the total MMF of the stator winding with respect to its position in the air gap. The expression of this current is given below (1).

\[
MMF_i(t, \theta) = \sum_{j=1}^{m} \sum_{k=1}^{\frac{Nc}{m}} A_h \sin \left( h p \theta_i - \frac{2\pi}{mp} (j - 1) \right) \times I_m \sin \left( \omega t - \frac{2\pi}{m} (j - 1) \right)
\]

(1)

Where \( i \) the index of conductor, \( Nc \) the number of conductor, \( m \) the number of phase, \( h \) the harmonic rank, \( A_h \) the harmonic amplitude, \( p \) the number of pole pairs, \( \theta_i \) the angular position of conductor \( i \).

III. RESULTS

In order to validate the proposed approach, simulations results obtained from a squirrel cage induction machine of 48 slots, 4 poles modelled with its real stator and using the current sheet coupled with the analytical tool are compared.

First calculations are conducted, at standstill, in the case of a simplified rotor without no slots and no bars. The results, in terms of magnetic flux density per unit area are shown in Fig. 3. Fig. 3a presents the waveform of this quantity vs position and Fig. 3b shows its harmonic content. As expected, results from the proposed approach are free from stator slot effects and then, except the harmonics linked to these slots, which are then mitigated, the harmonic contents in both cases are close. The magnitude of the first harmonic is logically higher because of the absence of the reluctance of the stator slots.

IV. CONCLUSION

In this paper, the use of a current sheet to substitute the armature supply while avoiding stator slots modelling is proposed. This sheet is coupled an analytical tool which calculates the stator MMF harmonic content to supply each of its areas. The proposed approach is validated through the study of induction machine at standstill. In the extended version, the approach will be more detailed and other results will be given and analysed.

REFERENCES


