ELSEVIER

Journal of Materials Processing Technology 161 (2005) 288–293

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Design of skewed mounted permanent magnet synchronous generators based on 2D and 3D finite element techniques

Themistoklis Kefalas, George Kalokiris*, Antonios Kladas, John Tegopoulos

Laboratory of Electrical Machines, Electric Power Division, Faculty of Electrical and Computer Engineering, National Technical University of Athens, 9 Heroon Polytechneiou Street, Athens 15780, Greece

Abstract

This paper investigates the effects of rotor skew on the performance of permanent magnet synchronous generators. The main effects are concerning reduction of the electromotive force induced, stator current harmonics and torque ripple. The analysis performed is based on various 2D and 3D finite element techniques. Simulation results are compared to measurements.

Keywords: Finite element techniques; Harmonic frequencies; Permanent magnets; Skewed rotors

1. Introduction

The distortion of voltage waveforms due to electromotive force harmonics of permanent magnet machines can affect the network power quality [1,2]. In this paper, the effects of rotor skew on electromotive force harmonics in synchronous permanent magnet generators are investigated [3–5]. The analysis is based on models involving 2D and 3D finite element techniques. The computed results are compared to measurements on a prototype.

2. Finite element modeling

The method of finite elements, is based on a discretisation of the solution domain into small regions. In magnetostatic problems, the unknown quantity is usually the magnetic vector potential A, and is approximated by means of polynomial shape functions. In two-dimensional cases triangular elements can easily be adapted to complex configurations and first order elements exhibit advantages in iron saturation representation. The size of elements must be small enough to provide sufficient accuracy [6]. In this way, the differential equations of the continuous problem can be transformed into a system of algebraic equations for the discrete problem. The practical problems necessitate usually several tenths of thousands of unknowns. However, appropriate numerical techniques have been developed, enabling to obtain the solution of such systems within reasonable time, even when personal computers are used. It should be mentioned that the 3D problems require considerably higher computational resources than the 2D ones. In the present paper, the 2D finite element model adopted involves vector potential formulation, while the magnetic flux Φ_{m} per pole can be calculated as follows:

$$\Phi_{\mathrm{m}} = \iint_{S1} B \times \mathrm{d}S = \oint_{C_1} A \times \mathrm{d}l \cong (2A_{\mathrm{gap}})l_0 \tag{1}$$

where l_0 is the length of the magnetic circuit (m), A the magnetic vector potential, A_{gap} the vector potential value in the middle of the air-gap, B the flux density (Tesla), S_1 the cross-sectional area normal to the direction of flux flow (m^2) and C_1 the contour surrounding the surface S_1 (m). The electromotive force at no load can be calculated as follows:

$$E = -\frac{\mathrm{d}\Phi \mathrm{m}}{\mathrm{d}t} \tag{2}$$

* Corresponding author.
E-mail address: gkalok@mail.ntua.gr (G. Kalokiris).

0924-0136/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmatprotec.2004.07.038

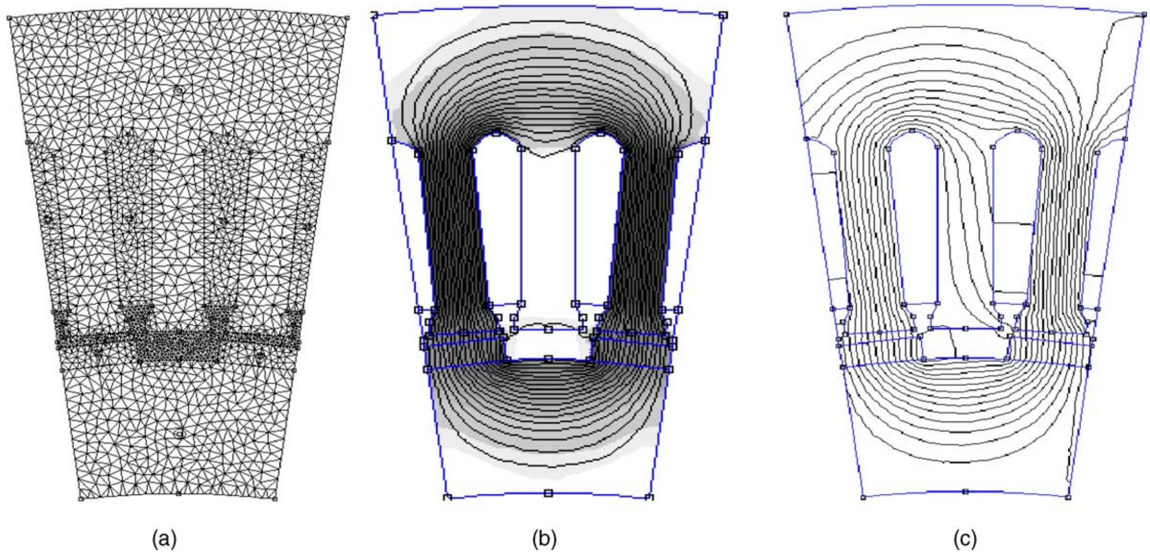

Fig. 1. One pole part of the permanent magnet machine constructed (unskewed rotor): (a) employed triangular mesh; (b) field distribution at no load; (c) magnetic field distribution at full load.

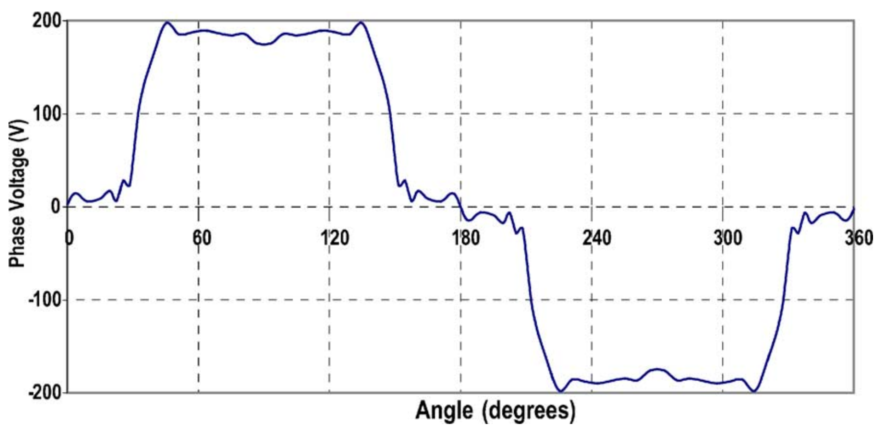

Fig. 2. No load voltage of permanent magnet generator without rotor skew (2D fem simulation).

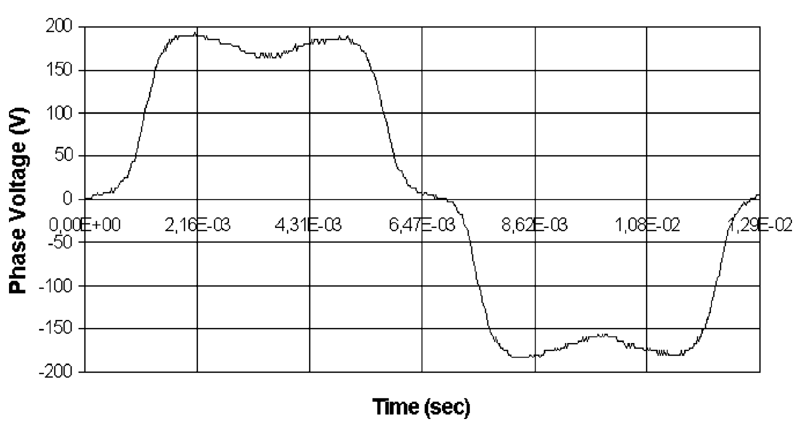

Fig. 3. No load voltage of permanent magnet generator without rotor skew (experiment).