Calculation of Magnetizing Inductance of Self Excited Induction Generator Using Finite Element Method

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Abstract

This work deals with a novel method of magnetizing inductance investigation using field-circuit type finite element of dynamic regimes of the three-phase Self-Excited Induction Generator (SEIG) used in the isolated small wind power conversion systems. Proposed method uses normal component of the flux density in the air gap to calculate the magnetizing inductance. the value of the stator leakage inductance of the machine has calculated in this paper with reasonable accuracy using finite element method.

Since the magnetizing inductance is the main factor of the voltage build-up and stabilization of the generated voltage for different conditions, so an accurate calculation of the magnetizing inductance based on the magnetizing current is crucial for a realistic representation of the voltage build-up. The results of the proposed method compared with the experimental test and theoretical value of the inductance calculated from a manufacturer's proprietary design program. Experimental approach uses a synchronous test. It can be concluded that the results of the simulation using the proposed method is much closer to the manufacturer's proprietary design program than the experimental test and it can better simulate the dynamic behavior of the machine.

Keyword—Finite Element Method, Magnetizing Inductance, Self-Excited Induction Generator, Induction Machines.

I. INTRODUCTION

Three-phase squirrel cage induction generators used in the wind energy conversion systems may be connected in parallel with the grid, when the required reactive power is absorbed from the grid, in other cases, they might be isolated from the grid when the needed reactive power is ensured by a suitable capacitor Bank, parallel connected to the stator windings [1]-[4]. When the induction generators are used in isolated from the grid, they are called Self-Excited Induction Generators (SEIG).

Self-excited induction generators (SEIG) have some characteristics that make them useful. these are: no need for brushes (squirrel-cage rotor), reduced size, absence of DC power supply for excitation , reduced maintenance costs, good performance when changing the speed, protected against short circuit, no need for synchronization and better transient performance. The SEIGs have an important place as AC generators in the developing countries[5]- [7].

Variation of magnetizing inductance is the main factor of the voltage buildup and stabilization of the generated voltage for different conditions of the SEIG, thus a particular attention should be paid to its correct determination [8].

Recently, researchers used dc excitation in order to obtain the magnetizing inductance of induction machines. The iron loss in the machine are considerably reduced and minimally influenced the measurement when compared to the traditional 60-Hz no-load test. Magnetizing Inductance has been measured using a static dc excitation technique which can be employed whenever the neutral of the machine is accessible[9]. This approach is not applicable when the neutral point of the machine is inaccessible. In this approach, since the induced voltage at low currents is difficult to measure, so it may give inaccurate results.

More recently, another method of Magnetizing Inductance calculation using comparison between data from no load test and adequate data from dynamic simulation has been proposed[10]. Both of these techniques [9] , [10] are used for measuring magnetizing inductance of a self-excited induction machine if the complex measurement cannot be done or if machine dimensions are not known and consequently, the finite element method analysis cannot be carried out .

Because the detailed geometry and physical characteristics of the machine is considered in the calculations, so the proposed method has more exact results than other techniques discussed in previous papers. It should be noted that this paper takes into account some of the most important parameters like the skin effect in the rotor bars, teeth harmonics etc.

2. Modeling of the SEIG using 2D FEM coupled with the electrical circuit

In order to study an electromagnetic device, we have to solve Maxwell's equations. These equations in two dimensions can be written as:

$$\frac{\partial}{\partial x}(\nu\frac{\partial A}{\partial x})+\frac{\partial}{\partial y}(\nu\frac{\partial A}{\partial y}) = -J_0+\sigma(\frac{\partial A}{\partial x}+\frac{\Delta V}{l}) \quad (1)$$

Where σ represents the conductivity, J_0 the current density, A the magnetic vector potential, l the active length and ΔV the electric scalar potential difference and ν the reluctivity.

If we rewrite (1) using FEM, we will have following equation:

$$[S][A]+[H_C][\Delta V]+[T][\frac{dA}{dt}] = [F] \quad (2)$$

Where [S] and [T] represent the stiffness and diffusion matrices respectively and [F] represents the source term. [H_C] is a matrix which comes from the electric scalar potential.

Since we are going to simulate the induction machine, an extra equation will be needed to express the stator voltages as a function of the currents and fluxes as follows:

$$[U_S]= [R_S][I]+[\frac{d\varphi}{dt}] \quad (3)$$

Where [ϕ] represents the flux linkage and [U_S], [I] and [R_S] are voltage vectors, armature current and stator winding resistance respectively.

To couple the magnetic field and electric scalar equations, we have to express the current density J_0 in terms of the armature current and the flux linkage in terms of the vector potential [10]. In the two dimensional case, since we have short circuited ring, the voltage ΔV should be equal to zero. By combining (2) and (3) we have following equation:

$$\begin{bmatrix} S & -D \\ 0 & R_S \end{bmatrix}\begin{bmatrix} A \\ I \end{bmatrix} + \begin{bmatrix} T & 0 \\ G & L_{ed} \end{bmatrix}\frac{d}{dt}\begin{bmatrix} A \\ I \end{bmatrix} = \begin{bmatrix} 0 \\ U_S \end{bmatrix} \quad (4)$$

Where G and D represent coupling matrices [11] and [L_{ed}] represents stator end coil inductance matrix related to the machine studied. The value of L_{ed} can be calculated using usual analytical equations [12].

The short circuit ring of the rotor bars can be modeled by introducing the coupling between the rotor bars like fig. 1 where r_g and l_g represent the short circuit ring resistance and inductance between rotor bars respectively. Because the l_g is not considerable with regard to r_g, we don't take it into *account.*

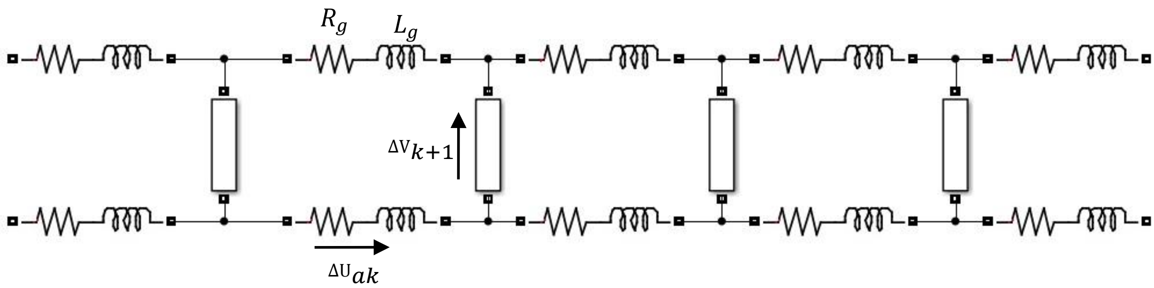

Fig. 1. Short circuit ring of the rotor bars

By neglecting the short circuit ring inductance, relationship between the rotor bars and the short circuit ring can be expressed like the following:

$$[\Delta U_a] = \frac{1}{2}[K]^t[\Delta V] \quad (5)$$