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FINITE ELEMENT SIMULATION OF A SYNCHRONOUS WIND GENERATOR WITH SOFT MAGNETIC MATERIAL ROTOR

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Abstract:This work presents a study of the use of finite elements for the simulation of synchronous generators with soft magnetic composite core (SMC). For this, the analysis of the magnetic flux variation in the air gap is used in this technique, through the simulation by the finite element method (FEM), through Ansys Maxwell software. In the study, scenarios of mapping and capture of flow results are proposed, in order to observe the effects and later contour conditions in the machine operating parameters. The applicability of (SMC) materials in generation projects is then discussed. In addition, design and performance are dependent on machine output parameters, in direct application scenarios, for the proper conditions to which it is proposed.
Keywords: Soft magnetic materials; Finite element analysis; Renewable energy sources; Wind energy generation; Electric machines.

INTRODUCTION

The group of soft magnetic metals has fostered numerous studies to include materials of characteristic behavior, and its development linked to performance in the area of frequency, either medium or low, yet has significantly improved properties compared to technology currently commercially performed of non-oriented grain laminates [1]. The notorious property that mediates the great development in research is its particular magnetic-isotropy in the three basic dimensions (XYZ) [2]. In general, the design of an electric machine is determined according to its topology of use, thus, it follows in the choice of materials necessary for the design conditions, followed by the decision of sizes in various sections calculated via software, thus, based on the power and conjugate requirements, the verifications of a varied range of performance equations are calculated [3]. Machine design boils down to the application of synthetic knowledge, machine theory and manufacturing experience, so many parameters and certain dimensions influenced the final design results.

A transient dynamic analysis is proposed in the calculation methodology, together with an optimized design, where modification of conditions is required during rotation due to rotor/stator combined angle dependent variations [4].

THEORETICAL REFERENCES

In powder metallurgy (M/P), there is the particulate of powder that has a high electrical resistivity, and during the manufacturing process, this material is wrapped and pressed under a matrix to which the final shape is desired, and then heat treated. in order to anneal and cure their bonds, thus, in a small way, there is a geometry wrapped in the (M/P) process [5].

By analyzing the rotor of a generator, while the final form of the core constitutes a complex geometry, in constructive terms, the powder metallurgy (M/P) process allows its production to be economically viable, and this feature becomes the combination of factors such as its windings is simplified, thus, the (SMC)-based machine is more "powerful" and, even easier to manufacture, compares with current electric steel technology [6].

Among the challenges, there is a crucial issue, in which, to build the model for wind generation it is necessary to form a reinforced core packed with grooves and the like, for this purpose it is a fact that solid steel cannot be used given the classic Foucault losses, in which case, if the common electric steel is chosen, the lamination must be adopted, together with this, there must be a spiral winding to form the assembly [3]. At low speeds, wind systems have demonstrated their satisfactory performance, and as main characteristics we have the high efficiency and high conjugate/

volume ratio [7].

In a discretized analysis, during (2D) flow distribution, it is first forced radially into the rotor before it occurs axially, while what is allowed on an (SMC) rotor is that the path goes in the shortest directions, ending the option is to have a more compact rotor, which reduces its mass, whose magnetization changes during rotation, in the same way, where the flux is able to spread tangential/radial, after entering the rotor, the density the average flow rate becomes smaller on the SMC rotor, therefore, these effects reduce overall rotor losses [6].

As a result, the nature of powders tends to benefit the efficiency of electric machines, however, crucial features agglomerate the challenges in their design, and as indicators of this one has the permeability that is weak, the flow density of saturation that is reduced, hysterical loss, material structure, which depends on the accommodation between particles/“binder”, which makes the material somewhat “fragile”, also the porosity, which requires considerations in terms of corrosion and these are the points that should be guiding the new design concepts, promoting differentiated solutions, which should be sought to obtain the ideal result [3].

For reliable analysis, the finite element method (FEM) is chosen, and it has the convergence characteristics of a solution to any problem that has characteristics to be discretized in a finite range of derivatives (partial/spatial), appropriate initial boundary conditions [8]. In the application of (FEM), when solving physical problems a number of defined elements must be started in the representation of the volume, in addition to field discretization, because for a finite set of values, “unknown” at first sight, it becomes if it is possible to substitute the (derived) energy equation for matrix equations, these approximations are involved with the use of non-infinitesimal elements [9]. In general, these elements have characteristics of flat-faceted, and in some cases curvilinear Lipschitz polyhedra. Also, given the matrix, there are a small number of negative eigenvalues, so the resulting matrix tends to limit Helmholtz values [10].

The perception of these differential geometries indicates a way for the discretization of Maxwell’s equations, and for these differential forms it must be ensured that the essential electromagnetic properties are indisputably preserved, even if they are arranged in discretized environments [10]. The resultant of the vector fields are the first order edge element representations and the second order scalar for the unknown nodal [8].

In the representation of Hilbert spaces, we have the proper determination for fields, which include the contributions of magnetic-electric energy [10]. These field equations are coupled in the circuit to the conductors, given that in the case of applied voltage sources, the values of injected currents are unknown [8]. In electromagnetic problems there is still the manipulation of degrees of freedom based on the vertices of mesh geometries, and this result can be composed of discontinuities, which are the particular cases in the simulation, given the numerical condition of Vlasov [10].

MATERIALS AND METHODS

For the simulation that follows in this study, we start from the data found in Figure 1, related to magnetization, which indicates in the navy blue curve, the general behavior of a (SMC).

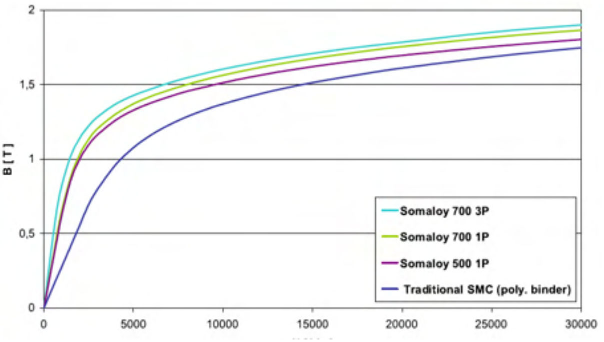

Figure 1. Flow/Field curves, magnetization. Adapted from [11].

As indicated, we opted for the Traditional SMC (poly, binder), which would represent an approximate general behavior, within the market availability, and, the following data composition guides the triphase generation model:

Parameter	Value
Ø outer	120 mm
Ø inner	50 mm
Length	65 mm
Number of Poles	4 units
Number of slots	24 units
Material	SMC(poly+binder)
Density	74,5 Kg/m³

Table I. Rotor Parameters.

Parameter	Value
Ø outer	180 mm
Ø inner	121 mm
Length	65 mm
Number of Poles	4 units
Number of slots	30 units
Material	Electric steel
Density	78,2 Kg/m³

Table I. Stator Parameters.

In a computational construction analysis, we have that, three-phase synchronous generators constitute one of the main sources of electricity for commercial use, in general, their operation constitutes receiving mechanical energy in its axis, and turning it into electrical, from an analytical perspective. constructive, the rotor is equipped with a multipolar winding, it is excited by an AC source, and the stator is equipped with a three-phase winding, which has a sinusoidal spatial distribution, which produces a rotating magnetic field, so the machine is capable to produce active/reactive power as required by the load connected to the stator phasors [8].

The model in Figure 2 offers advantages such as variable speed operation and four-quadrant active/reactive power capabilities, yet such a system results in lower conversion costs and lower energy losses compared to fully powered synchronous generation system with full converter [12]. This can also be seen as an induction generator with non-zero rotor voltage [13].

Comparing the structures of a synchronous motor to a generator, we have that they are practically the same, however, their phasor relations and calculation methods are slightly different, the same is true of the output characteristics data, which, serve for both air spaces, whether uniform or not, the Schwarz-Christopher transformation is adopted in the resolution of the air gap magnetic field distribution, thus, in the finite analysis, for the interior of the region of interest, the function f (ζ) maps the direction of the real axis to the extremes, and if the polygon has internal angles a, b e g [8], this mapping is given by the following equation:

$$f(\zeta) = \int^{\zeta} \frac{K}{(w-a)^{[1-(\alpha/\pi)]} + (w-b)^{[1-(\beta/\pi)]} + (w-c)^{[1-(\gamma/\pi)]} \ldots} dw \quad (1)$$

Thus, K is composed of a constant, and, a ≤ b ≤ c, are values along the real axis of the plane ζ, in doing so, the main factor of the formula also becomes constant, and, is absorbed by the constant K, one should also keep in mind that the infinity point in the method would be mapped to the vertex with angle a. In general, there is the detailing of the windings with the meshes illustrating the composition of predeterminations adopted for solution of the machine to which the study addresses, in Figure 2.

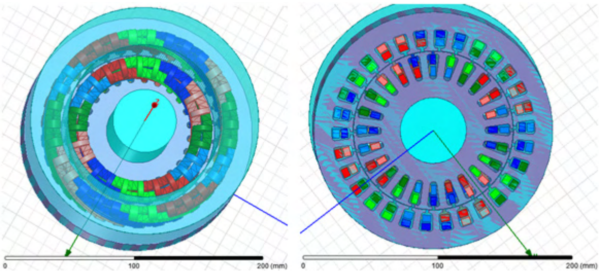

Figure 2. Front view and perspective view of the wind turbine. [Author].

In their design, stator and rotor should have the same number of poles (p), so as to produce terminal voltages at the desired frequency (f), the stator winding should be excited by balanced polyphase currents, which can be resolved through of an AC-DC-AC converter. Potential analysis can be defined as a function of the position analyzed, this condition is used to specify the potential of limits, and can also be used to define interfaces, called Dirichlet boundary conditions.

In numerical model analysis, advanced methodologies such as FEM, magnetic flux density (B) and magnetic field (H) can be defined using response surfaces using Taylor series approximations. In the finite simulation results this series is used in the loop to determine the gradients, so the harmonic solver is based on the assumption that all electromagnetic fields pulse with equal frequency, and have quantities and initial phase with angles. calculated by Maxwell's equations [8].

For nonlinear materials, the dependence between fields (H) and (B) is nonlinear, and occurs in soft materials with negligible hysteresis, while Maxwell requires the (B/H) curves for the main directions, and from these, the energy dependence is extracted for each of the main directions of the material and is used in the process of obtaining the nonlinear permeability tensor (μ) used in the iterative Newton-Raphson solution, where is the magnetic scalar potential, where it becomes a particular built solution [8].

$$\bar{\mu} = \begin{vmatrix} \mu'_1.[1 - j.\tan(\delta 1)] & 0 & 0 \\ 0 & \mu'_2.[1 - j.\tan(\delta 2)] & 0 \\ 0 & 0 & \mu'_3.[1 - j.\tan(\delta 3)] \end{vmatrix} \quad (2)$$

In the calculation of magnetic field energy, for the solution of eddy currents, one has that, the energy density in the general case includes the magnetic and electric energy densities, so the energy of the magnetic field in AC is given as follows:

$$U = \frac{1}{4}.\iiint Re[B.H^{*}(E.D^{*})] \quad (3)$$

Such that, (B) is the magnetic flux density, (H) is the magnetic field, (Re) is the actual operation, and, the envelope (*) indicates the complex conjugate. And this is the average energy over time, being the factor of ¼ explained by peak values for excitations.

DISCUSSION OF RESULTS

In the proposed work was created in the simulation environment a way to test the (SMC) material, and from the informed data, a careful analysis regarding its use in wind turbines. First, according to the method, the control loop was arranged to perform the accessory analyzes, as shown in Figure 3.

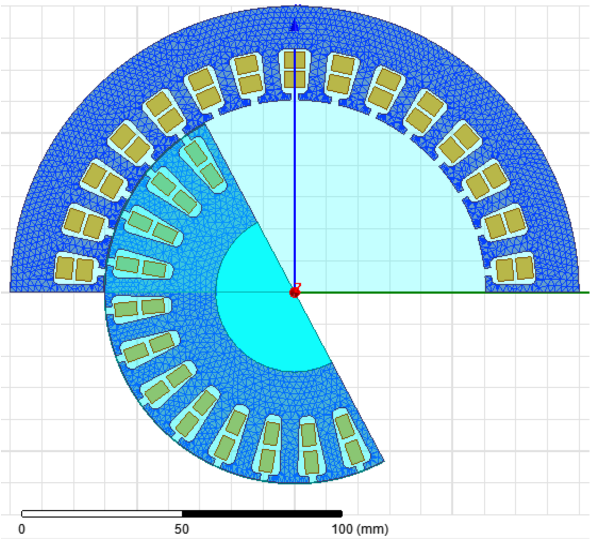

Figure 3. Front view / half section of the calculation mesh. [Author].

It should be noted beforehand that in the given quadripole wind system, when compared to the rotor speed, where it was lower than the synchronous speed, the currents of the same will have the same phase sequence as the stator currents, and the winding of the stator. The rotor thus receives power from a converter, however when the rotor speed is higher, the phase sequence of the rotor currents is different as soon as the rotor winding generates power to the converter while maintaining system stability as a whole [14]. Thereafter, a constant value of torque was applied and, given an excitation in the rotor windings, we analyzed the fluxes that, when crossing the turns, produced the magnetic phenomena, of which the behaviors are recorded, as follows in the Figures 4 , 5 and 6.

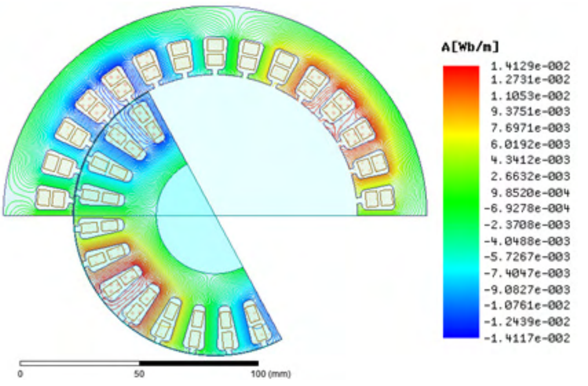

Figure 4. Magnetic flux. [Author].

In magnetic flux, Figure 4, in general terms, quantified the value in which the magnetic field "occupies", and this is generated by the movement of electric charges in the rotor windings, which, derives from the flux across the surface, which, will be mostly limited to direct excitation coils. While in the magnetic flux density, Figure 5, one can see the direct concentration measurement, so that it follows in the coils, wrapped around the (SMC) material, and, from the moment the current flows, a magnetic field circulates around it generating the transient distribution.

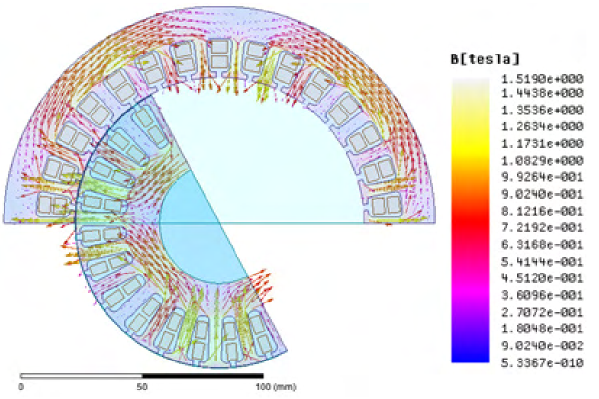

Figure 5. Density of magnetic flux. [Author].

Also, in the analyzed magnetic field, Figure 6, we see the concentration of magnetism that was created around the rotor, given the air gap, there is the generation of the electromagnet, which creates the photonic phenomenon.

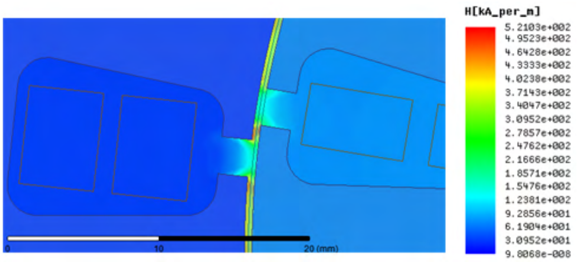

Figure 6. Magnetic field. [Author].

In these semi-stationary magnetic states of behavior proposed above, fields with pulsed-induced eddy currents may have a solution that has turbulent effects, and yet this is a solution that includes electromagnetic radiation effects.

During its operation, it must be indicated that the control of the "electromagnet executed" in the rotor is the responsibility of external circuits, and the injection of voltage and current in the rotor will occur in parallel analogy to the capture of wind data in real time, so that you get maximum performance from the set. As can be seen from Figures 7 and 8, given that the available torque situation on the shaft is "constant", the voltage and current waveforms provided are sinusoidal and shape analogous to each other. Similarly, given Figures 9 and 10, the indicated output, based on torque and stator-induced data, should be noted that the current behavior is not analogous to that of the voltage, so that the same be interfere only in the power factor of the electric machine, justifying the yield identified in Figure 11.

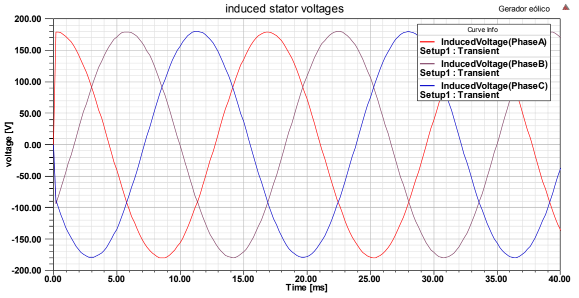

Figure 7. Induced stator voltages. [Author].

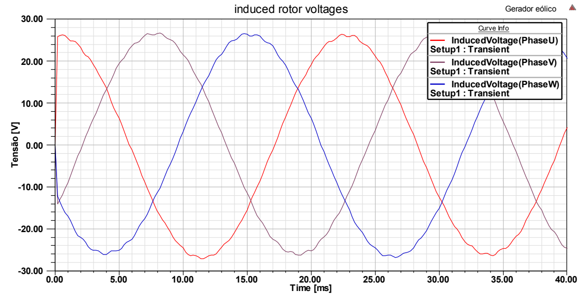

Figure 8. Induced stator voltages. [Author].

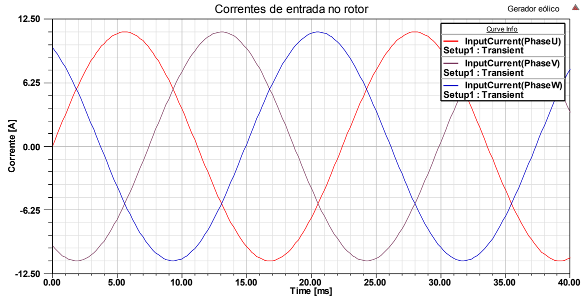

Figure 9. Rotor Input Currents. [Author].

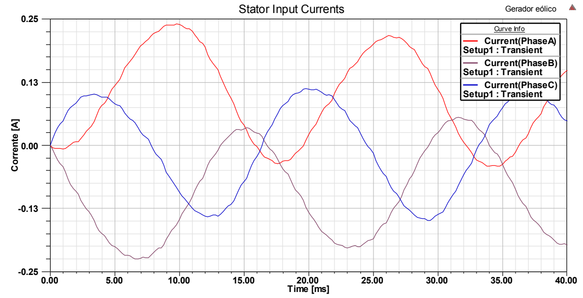

Figure 10. Stator Input Currents. [Author].

Thus, for the performance analysis of the model, during its work development, in speed, for generation, we have to reach, for optimal conditions, a range of 90.40%, which is justified before its losses, both constructive and functional, but still, this parameter is considered satisfactory for the study.

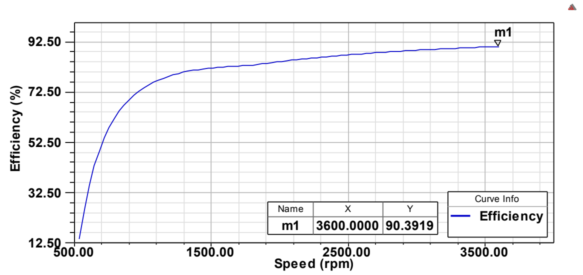

Figure 11. Model efficiency. [Author].

CONCLUSIONS

For this study, we analyzed the electromagnetic properties of the SMC material, before its use in wind turbine rotors, and through the development of this work, the characteristics of the soft magnetic composites could be analyzed, in order to make possible their choice in the use of the large area of alternative energy.

The analysis began with the collection of intrinsic physical/magnetic properties, provided by studies already developed, being inserted in the simulation environment and their electromagnetic behaviors found in 3D flux design, which, it was visualized, increased to magnetic field intensity, which resulted in a considerable increase in magnetic flux, surpassing this characteristic compared to the rolled steels.

In short the worked model has focus to be used in order to understand the internal dynamism of the energy converter, and the simulation is based on the assumption that the converter frequency is ideal, and thus has as simulated fixed parameter the controllable voltage.

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