INTEGRATED SYSTEM OF PRODUCTION AND ADJUSTMENT OF AC ELECTRIC ENERGY PARAMETERS FOR LOW POWER ISOLATED SITES THAT USE WIND ENERGY AS PRIMARY ENERGY

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Abstract – **This paper presents research results regarding the realization as unit block of the system made from a single-phase permanent magnet synchronous generator and a single-phase transformer. The proposed synchronous generator has double-gap, with high moment of inertia and axial magnetic field distribution. Built-in electrical transformer has toroidal core (effectively, the empty cylinder is made of electrical steel sheets) where are placed concentrated windings. The structure chosen for low power synchronous generator - with multiple air-gaps, axial magnetic field distribution and high moment of inertia - is particularly useful in conversion systems of wind energy in electricity because it allows the removal of mechanical gearbox for adjustment of aerogenerator output parameters at the input parameters of the electric generator (mechanical gateway). To envision some of the functional particularities, generated by constructive features of such an integrated system, in this paper was accomplished with PDE-ase software, an analysis of magnetic field distribution within the structure.**

In order to allow an overview regarding forces distribution in this integrated system, the maximum specific energies, existing in the structure were also determined, which along with Lagrangian formalism, were measured developed specific forces.

In conclusion, the realization of such an integrated system is possible and recommended for remote sites where electricity is to be maintained parameters - obtained from wind energy - a certain level, without the intervention of power electronics.

Keywords: *axial flux electrical machines, FEM analysis, renouwables sources*

1. INTRODUCTION

Use of low power synchronous generators excited with permanent magnets to convert wind power to electric power is a wide spread solution, nowadays, in remote areas [1], [2], [7].

Compared to using asynchronous generators, use of synchronous generators has the following advantages:

- decrease of generator volume, and therefore of all conversion system, an advantage for any remote area [7];
- increase of reliability and of conversion system life cycle [7];
- investment to implement the conversion system, a good feature for low power systems.

Although the mechanic-electric subsystem becomes simpler and more reliable and therefore cheaper through the use of synchronous generators with permanent magnets, the investment value is not considerably reduced as consumers requirements claim both a force development in order to adapt power parameters delivered by the generator to user (voltage value, intensity value, etc.) and automation development (power electronics and microelectronics) necessary to maintain the parameters in the imposed limits, regardless the mechanical (primary drive) or electric (load) disturbances that may occur.

Besides, power electronics generates great disadvantages that may put remote consumers in difficult situations, such as: high harmonic waves content, low performance of mechanic-electric conversion for the entire system, etc. [3], [4].

That is why adjustment of electric power parameters to user requirements should be done using a force electromagnetic device that is an electrical transformer as in classical systems of production, transport and distribution of electric power.

In order to maintain the advantages of the use of synchronous generators with permanent magnets for remote areas it is necessary to set up an integrated mechanic-electric conversion system and to adjust the parameters to consumer force system requirements.

This work is showing such an integrated system generator-transformer to the level of analysis of magnetic field distributions and of specific loads developed within the structure.

The additional advantage of such an integrated system relies in the flexibility granted to the potential user. The integrated transformer, both through adjustment of power parameters in the conversion system and galvanic separation granted, allows easy use for remote loads and network connection.

Then again, as most consumers use AC power and are going to use it for a long time, bringing the power source to the values required of the potential loads in the renewable conversion power systems would represent a great goal in wide-spreading use of such conversion systems.

2. STRUCTURAL FEATURES OF THE INTEGRATED SYSTEM SUGGESTED

The generator is axial flow type as such a structure gives a small axial length and a big diameter (high moment of inertia), making it suitable for wind power conversion systems. Also, the suggested integrated system comprises at the level of stator the electric transformer block (the primary winding is the synchronous generator stator winding, appearing as concentrated coils and the secondary winding, put on the same stator core, is the real output of the integrated conversion system). The structural features of the integrated system are much like those of classic synchronous generator, excited with permanent NdFeB magnets, with axial flow and double air gap, but without ferromagnetic core, which was made previously in the Laboratory of Electromechanical Converters and which represents the ***reference synchronous generator*** in this paper (Figure 1).

Figure 1: Synchronous machine with axial magnetic field, with double air gap (disk topology) made in the Laboratory of Electromechanical Converters (UDJG)

The features of the reference generator are as follows:

- lack of stator ferromagnetic core (lack of flow concentrator);
- stator concentrated winding (two by two coils concentrated per phase, the machine is tri-phased);
- resin embedding of stator winding (for purposes of mechanic fixing and galvanic isolation);
- permanent magnets located on both sides of rotor (many poles which means low synchronism speed);
- low rate $\frac{l_i}{D}$ that is (1:8), hence high moment of inertia;
- super-positioning of functional principles (electromagnetic induction + shape anisotropy);
- framework without an active role in magnetic flow transmission (used for protection only);
- high dispersion flow (low useful flows, hence low potentiality of the machine).

The following features are to be characteristic to achievement of the integrated system suggested (synchronous generator and transformer in a single block):

- achievement of a stator flow concentrator (lower dispersion, considerable useful effect);
- concentrated winding, but single-phase (four concentrated coils, connected in closed circuit);
- high moment of inertia, to damp down the waves given by the auto-generator;
- high number of rotor poles, hence low synchronism speed, same as in reference generator;
- the framework plays an active role in electromagnetic flow transmission.

In order to obtain a considerable useful effect it is necessary that the stator core is properly sized, thus avoiding saturation even in the case of a considerable overload, and the stator winding can offer a great surface to the magnetic field of permanent magnets (necessary to obtain a considerable magnetic flow). The stator winding of the synchronous generator will be set up as a closed global winding, thus becoming the residence of some induced electromotive voltages and thus of some induced currents. The induced currents will generate a new magnetic field which would close through the stator ferromagnetic core, intermixing with the helix of the secondary winding, winding closed on a load. The current flow through this winding has to be in such a manner that the magnetization of the ferromagnetic shared core is made in the same direction with the current in the primary winding (stator winding of the synchronous generator). The direction of the axial magnetic flow will be given by the permanent magnets, which, for this application are anisotropic. Using the principle of galet windings (as in power transformers), there will be placed the concentrated coils one by one on core which would form the secondary winding, properly sized that it could satisfy the user requirements (Figure 7). These features of the system will be seen in the comparative analysis with the reference generator and shown as follows.

3. DETERMINATION OF MAGNETIC FIELD DISTRIBUTION IN THE ANALYZED CONVERSION SYSTEMS

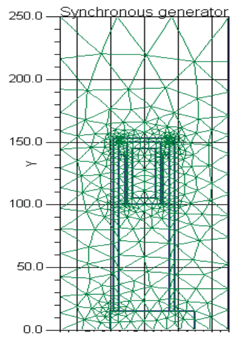
The finite element method has been used to solve the magnetic field problem. The mathematical model used is given by the system (1) [7].

$$\begin{cases} rot\left[\frac{1}{\mu}\cdot\left(rot\overline{A}-\overline{I}\right)\right]=0 & \\ \overline{A}(P)=0 & P\in Fr_1(D) \\ \frac{\partial\overline{A}(P)}{\partial\overline{n}}=0 & P\in Fr_2(D) \end{cases} \quad (1)$$

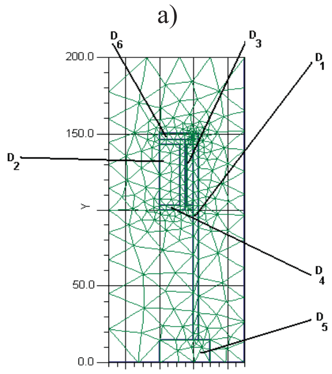
where: $\overline{A}$ - is the magnetic vector potential; $\overline{I}$ - is the internal magnetic induction (within the permanent magnet); μ - is the environment absolute magnetic permeability.

For symmetry reasons, the integration domain, in the case of the reference generator, considered in the analysis, is shown in Figure 2, b (a quarter of the machine), where:

D_1 – flange; D_2 – stator coil; D_3 – permanent magnet; D_4 – resin; D_5 – shaft; D_6 – framework.



a)



b)

Figure 2: The integration domain for determination of magnetic field distribution of the synchronous generator with double air gap (reference generator)
a) – for a half of the machine; b) for a quarter of the machine.

For the reference generator, the magnetic field current distributions, respectively of magnetic induction are shown in Figures 3-6, for two cases considered:

- idle operation of the generator ($\overline{J} = 0$);
- load operation of the generator ($\overline{J} \neq 0$).

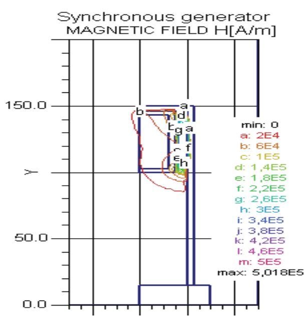


Figure 3: Distribution of magnetic field intensity $\overline{H}$ – in the case of the reference generator for - $\overline{J} = 0$

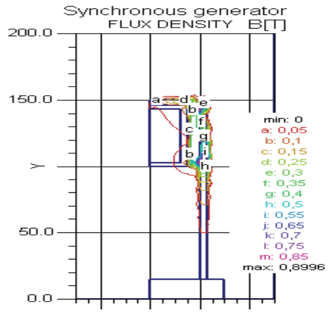


Figure 4: Distribution of magnetic induction $\overline{B}$ -in the case of the reference generator – for $\overline{J} = 0$

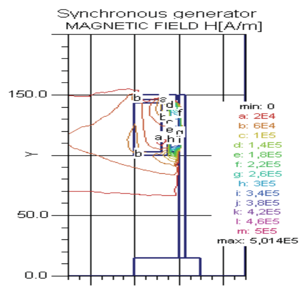


Figure 5: Distribution of magnetic field intensity $\overline{H}$ - in the case of the reference generator - for $J = 10[A/mm^2]$

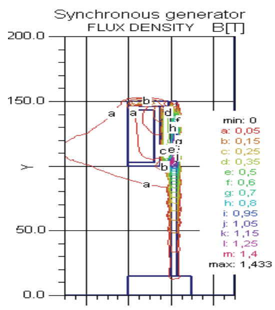


Figure 6: Distribution of magnetic induction $\overline{B}$ - in the case of the reference generator for - $J = 10[A/mm^2]$

In the case of the suggested integrated system, the integration domain used to determine the magnetic field distributions is shown in Figure 7.

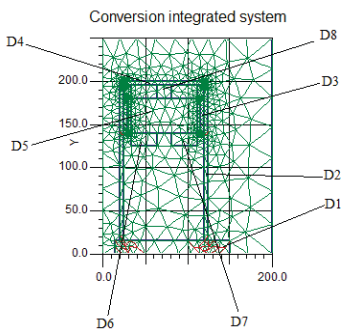


Figure 7: The integration domain used to determine the magnetic field distribution of the synchronous generator with double air gap and block transformer (integrated conversion system)

where:
D1 – shaft; D2 – flange; D3 – permanent magnet; D4 – framework; D5 – stator ferromagnetic core; D6 – stator coil (generator), respectively primary coil (transformer); D7 – secondary coil (transformer); D8 – Aluminium part used to fasten the stator ferromagnetic core.

The distributions of magnetic field intensity, respectively of magnetic induction in the case $\overline{J}_1 \neq 0$ (the current density in the stator winding of the generator and in the primary of the transformer) and $\overline{J}_2 = 0$ (the current density in the secondary winding of the transformer, characteristic to idle operation of the integrated system) are shown in Figure 9 and Figure 10.

Figure 8 shows the magnetic induction distribution (values field) in the case $\overline{J}_2 = 0$, to be able to notice the particular way of removing end effect based on little polar parts, located at the ends of stator ferromagnetic core, in the case of the integrated system.

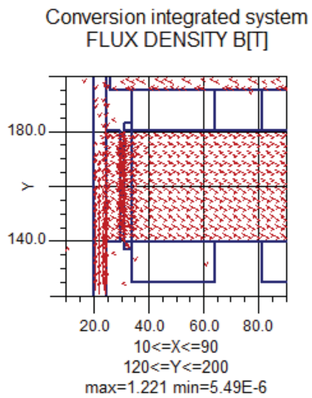


Figure 8: Distribution of magnetic induction $\overline{B}$ (vector field) - in the case of the integrated system - for $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 0$

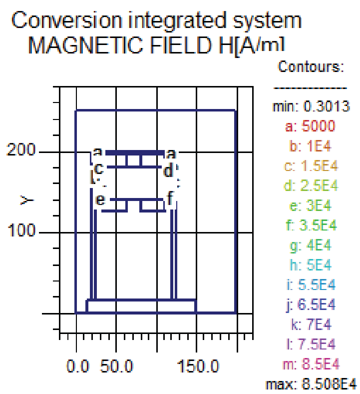


Figure 9: Distribution of magnetic field intensity $\overline{H}$ - in the case of the integrated system for - $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 0$

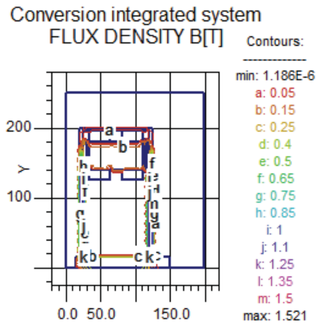


Figure 10: Distribution of magnetic induction $\overline{B}$ - in the case of the integrated system - for $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 0$

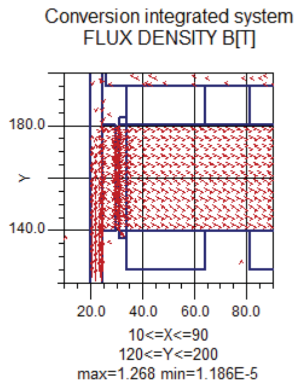


Figure 11: Distribution of magnetic induction $\overline{B}$ (vector field) - in the case of the integrated system - for $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 50[A/mm^2]$

In case the secondary of the transformer is closed on a load ($\overline{J}_2 \neq 0$) the distributions of magnetic field intensity, respectively, of magnetic induction are shown in Figure 12 and in Figure 13.

In the Figure 11 is shown, again, the vector distribution of the magnetic induction in the case of load operation of the integrated conversion system ($\overline{J}_2 \neq 0$).

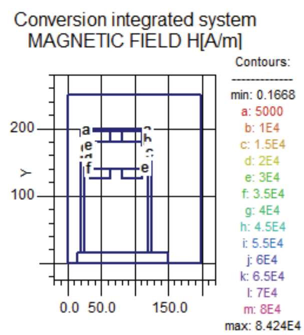


Figure 12: Distribution of magnetic field intensity $\overline{H}$ - in the case of the integrated system - for $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 50[A/mm^2]$

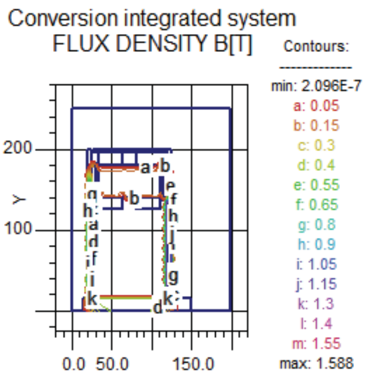


Figure 13: Distribution of magnetic induction $\overline{B}$ - in the case of the integrated system - for $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 50[A/mm^2]$

The shape anisotropy of the permanent magnets (magnetization along the axis of the machine) and a good choice regarding the magnetic features for the structure chosen (very close to the reference existent in the laboratory) allows a good operation (for the magnetic field) of the suggested integrated system (without reaching saturation of ferromagnetic parts of the structure).

4. DETERMINATION OF SPECIFIC ENERGIES AND OF THE FORCES DEVELOPPED IN THE CONVERSION SYSTEMS ANALYZED

An additional confirmation of the functionality of the suggested structure has been obtained through viewing specific energies, developed inside it, respectively of the forces generated.
The specific forces have been determined based on Lagrangian formalism (W_m - is the magnetic energy):

$$f_x = -\frac{\partial W_m}{\partial x}, \qquad f_y = -\frac{\partial W_m}{\partial y} \qquad (2)$$

Specific force modulus is calculated using the relation:

$$f = \sqrt{f_x^2 + f_y^2}\ . \qquad (3)$$

Figure 14 shows the spatial distribution of specific energy (per volume unit) for the suggested integrated system in the case of $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 0$ (idle operation).
Fig. 15 shows the spatial distribution of specific energies in the case of load operation of the suggested integrated system.
Spatial variation of specific forces developed inside the structure for the two operation cases analyzed (idle and load) are shown in Figure 16 and Figure 17.

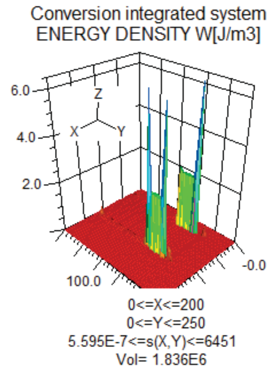


Figure 14: Spatial distribution of specific energy in the case of the integrated system for $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 0$ (idle operation)

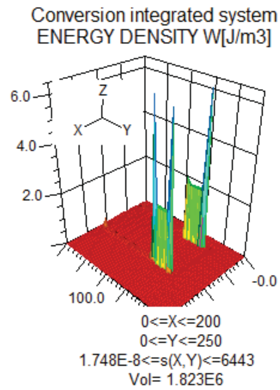


Figure 15: Spatial distribution of specific energies - in the case of the integrated system - $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 50[A/mm^2]$ (load operation)

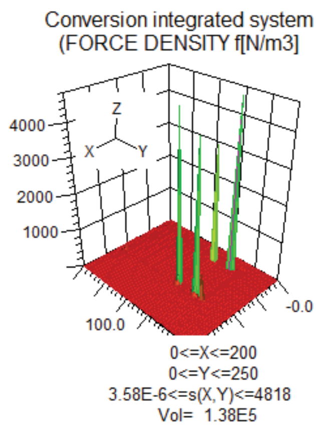


Figure 16: Spatial distribution of specific force modulus - in the case of the integrated system - for $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 0$ (idle operation)

The specific energies developed inside the structure have the greatest values at permanent magnets level, magnets located on the moving fitting. The peaks of energy occur at the separation surfaces of two media with different magnetic permeability (ferromagnetic core and air). The same effect occurs for the specific forces at the separation surfaces.

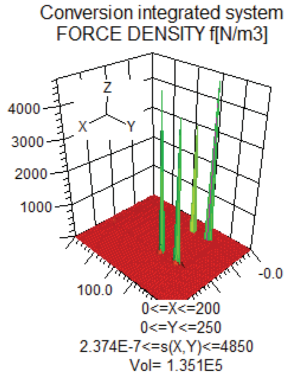


Figure 17: Spatial distribution of specific force modulus - in the case of the integrated system - for $\overline{J}_1 = 10[A/mm^2]$ and $\overline{J}_2 = 50[A/mm^2]$ (load operation)

5. RESULTS AND DISCUTIONS

Keeping close size of the integrated compared to the referential one (synchronous generator with double air gap without stator ferromagnetic core) and same loading of primary winding ($\overline{J}_1 = 10[A/mm^2]$),the characteristics of the new structure have been pointed out: heavy load of secondary winding of the integrated transformer (coil in air, effectively), a heavy decrease of permanent magnets characteristics (internal induction twice smaller compared to reference: $I_{ref} = 0.4[T]$, $I_{cis} = 0.2[T]$) to avoid saturation of thin ferromagnetic areas an Aluminium part is used between the framework and the stator ferromagnetic core (to give a turning back way to the magnetic field lines only in ferromagnetic areas) and thus, change the role of the framework from passive (reference) into active (integrated system).
The structure of the conversion integrated system sized this way and analyzed from the point of view of the magnetic field distribution is less stressed and can stand additional electric and magnetic loads.

6. CONCLUSIONS

A comparative analysis between the structure of a generator with multiple air gap and axial magnetic field and another potential structure that could be developed for remote areas has been performed in this work. The suggested structure comprises a synchronous generator and a transformer in a single block.
Consequent to the analysis performed, the following results arise: such a solution may be used successfully making necessary a proper sizing due to constructive features (existence of air gaps good for generator structure, but inadequate to the transformer), in order to obtain the utility required by a large amount of remote users.

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