The influence of ambient temperature on the potentiality of integrated systems for wind energy conversion into electricity

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***Abstract* - The main purpose of this paper is to view the influence of ambient temperature on the magnetic vector potential of a particular data structure, and thus the magnetic field distribution within the structure. The secondary purpose of this paper is to develop user awareness conversion electro-mechanic economic structures, while the electrical generators may use permanent magnets that require no thermal stabilization work at high temperatures (and therefore high prices). This paper presents an analysis of the influence of ambient temperature on the potentiality of an integrated conversion system (permanent magnet synchronous generator plus power transformer, the proposed solution to adjust the parameters of AC power, even in the structure of such damage). The analysis is carried out for two extreme values of ambient temperature, values found during winter seasons, respectively hot summers. During analysis, we considered distributions of both magnetic field and temperature in the proposed structure, which is a low-power one, suitable for wind energy conversion for energy production. For the study we used the PDE programming environment from Macsyma (two-dimensional software that allows solving problems involving partial differential equations through the finite element method). The results show that the wide range variation in ambient temperature influences the potentiality of these electromagnetic systems, but the constructive features of the proposed integrated system strongly reduces these effects, which is particularly important for potential users of such structures.**

Keywords - *FEM analysis, integrated conversion systems, environment – machine interaction*

I. INTRODUCTION

Due to the diversity of applications, a large number of electrical machines work in hostile environments in terms of the range of variation of ambient temperature. Even in temperate continental climate, there are large differences between ambient temperatures encountered in winter season (-30°C) and the same ambient temperature encountered in hot summers (+40°C). As a result, besides the electromagnetic requirements, electrical machines also have to bear - as structures - the tensions caused by temperature gradients in the environment. The issues caused by these additional tensions are even more serious in the integrated structures encountered in the case of wind to electricity energy conversion systems which, running at medium and high power, are placed not only in enclosures located practically at ambient temperature but also at a certain altitude (sometimes this can be an aggravating factor). Nacelles in which these structures are placed (particularly, electrical generator) can offer, in many cases, a certain level of protection against the tension of the environment. The situation is worse for structures used for small power systems wind to electricity energy conversion, where permanent magnet synchronous generators are generally used. Both properties of conductor materials and properties of ferromagnetic materials (either temporary magnetism or permanent magnetism) varies with temperature, and in the case of variations - in a wide range of ambient temperature - the balance between the two areas (internal electric machine and external represented by environment) is always different [2], [4]. With the particular conditions described in this paper, we took into account the temperature variation only for the electrical resistivity of the construction material of the conductor windings (that of other materials has been overlooked).

In the work [3] has been proposed a new structure for an electrical machine (an integrated system consisting of a permanent magnet synchronous generator and a transformer). The new system has been subjected to a comparative analysis in relation to a simple structure (an axial permanent magnet synchronous generator, double air gap without ferromagnetic stator core [5]) in terms of magnetic field distribution and specific forces developed.

The proposed integrated system has proved viable and able to meet the requirements of users in isolated sites that can be used successfully so as to convert wind power into electricity. This paper attempts to visualize the behavior of the proposed conversion integrated in a strenuous environment (ambient temperature variations in a wide range) specific to particular isolated sites. In order to resolve the proposed problem the PDE-ase software was used, which allows solving - by finite element - problems of both, electromagnetic or thermal field.

The primary goal of the new analysis is to indicate how changes in ambient temperature in a wide range affects the potentiality of the proposed integrated system, and its functional characteristics (dependent on the characteristics of constituent materials), respectively.

II. MATHEMATICAL MODELING OF THE INTEGRATED SYSTEM IN TERMS OF ENVIRONMENTAL TEMPERATURE VARIATION

The mathematical model requires the connection of two problems that have the same cause: the electric current passes through coils placed on ferromagnetic stator core (Fig. 1) [1].

The system of equations (1) [7], [8] groups the equations that model the two processes: the first equation models the magnetic field developed within the structure while the second equation models the thermal field developed in it. For each of these two problems boundary conditions have been imposed as shown in Fig. 1 - due to symmetry, the design takes half of the proposed structure.

$$\begin{cases} rot\left[\dfrac{1}{\mu}\cdot\left(rot\overline{A}-\overline{I}\right)\right]=\overline{J} \\ div(-k\cdot grad(T))=p_d \end{cases} \qquad (1)$$

$$p_d=\rho J^2 \qquad (2)$$

$$\begin{cases} \overline{A}(P)=0 & P\in Fr_1(D) \\ \overline{n}\times\overline{H}(P)=0 & P\in Fr_2(D) \end{cases} \qquad (3)$$

$$T(P)=T_0 \qquad P\in Fr_1(D) \qquad (4)$$

where the first equation within system (1) is Ampere law and the second represents thermal conduction law (Fourier law). We used the following notation:

$\overline{A}$ - the magnetic potential vector;

$\overline{I}$ - the magnetic polarization vector;

$\overline{J}$ - the current density vector;

$\overline{H}$ - the magnetic field vector;

μ - the magnetic permeability;

$$\mu=\mu_0\mu_r \qquad (5)$$

$\mu_0=4\pi\cdot10^{-7}[H/m]$ is the absolute magnetic permeability; μ_r is the relative magnetic permeability;

k - the thermal transmissivity (thermal conductivity) of the various materials structure;

T - the developed temperature;

T_0 - ambient temperature in the two analyzed cases;

p_d - power developed density of the structure;

ρ - the electrical resistivity;

$Fr_1(D)$ - the boundary on which the Dirichlet condition is applied; this is the external boundary for the integration domain of figure 1, both in the case of the magnetic field, and in that of the temperature range;

$Fr_2(D)$ - the boundary on which the Galerkin condition is applied; this boundary separates environments with varying degrees of permeability within the considered structure.

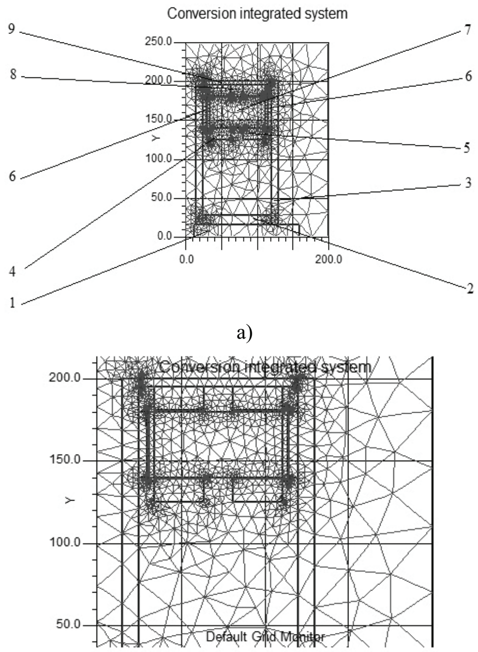
The ferromagnetic core relative magnetic permeability was considered $\mu_{rcore}=5000$. For the flanges sustaining the permanent magnets it was used $\mu_{rSteel}=2000$, and for the permanent magnets of NdFeB it was used the value $\mu_{rNdFeB}=1{,}05$ [2], [6], [8].

For the thermal conductivity (thermal transmissivity) of materials in the structure, the following values were used:

- air gap (air): $k_{air}=0{,}024[W/m^0C]$;
- rotor shaft (with lateral flanges and framework): $k_{shaft}=45[W/m^0C]$;
- ferromagnetic core: $k_{core}=1{,}2[W/m^0C]$;
- permanent magnets: $k_{NdFeB}=1{,}25[W/m^0C]$;
- bearing part of aluminum: $k_{Al}=207[W/m^0C]$;
- winding (cooper): $k_{Co}=378[W/m^0C]$.

The electric resistivity of copper has been chosen as $\rho_{Co}=2{,}35\cdot10^{-8}[\Omega m]$, which correlates with a conventional temperature of 115^0C, which is specific to the materials in the F isolation class.

Since there is a great amount of air in the integrated system suggested and the windings are placed in the air (not in the notches), the current densities used in simulations is the same as that of the classical electric machines ($J_1=6[A/mm^2]$ - for the primary of the transformer, and respectively $J_2=3[A/mm^2]$ - for the secondary of the transformer incorporated in the structure). As sources of the power developed density, p_d (2), were considered the Joule losses in the windings (neglecting the losses in the ferromagnetic cores).



a)

b)

Fig.1 Domain of integration for the proposed integrated system: a) general; b) details (zoom).

The following notations were used in Fig. 1: 1 - rotor shaft; 2 - inner iron core; 3 – flange; 4 - reaction winding of the generator (respectively, the primary winding of the transformer); 5 - transformer secondary winding; 6 - permanent magnet of NdFeB (synchronous generator excitation); 7 - iron core (stator synchronous machine + transformer); 8 - piece aluminum fixing stator core; 9 - box (with an active role).

It is worth noting that (simplifying assumptions used in the mathematical model):

- Although the coils are isolated from the core, the insulation was not noted in Fig. 1 and was not accounted for by its properties in the model;

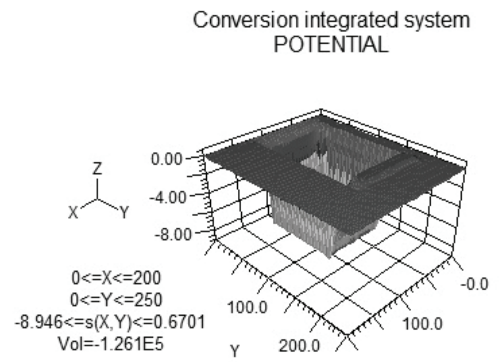
- In order to maintain the core coils, but also so as to exclude the end cap effect (swelling of magnetic field lines crossing the middle of the air gap) polar pieces were used (a change in the ferromagnetic core section from the air gap). They are not listed in Fig. 1, but different section (enlarged) of air gap around the ferromagnetic core were taken into account, in the model;

- The permanent magnets used were considered anisotropic, their magnetization being axial. For the utilized NdFeB magnets, the value of the magnetic polarization is $I_x = 0{,}4[T]$.

- The size of the air gap (also unlisted in Fig. 1) was considered constant in the entire pole piece and acceptable value of mechanical point of view (g=1[mm]).

III. RESULTS. DISCUSSION

The simulations carried out - based on the mathematical model - for the two extremes of ambient temperature (-30°C - in winter season respectively +40°C in summer season) are presented below. Fig. 2 shows the spatial variation of magnetic vector potential - for the system examined - when the operation occurs in the winter (Fig. 2, a) and in the summer (Fig. 2, b), respectively. Potential variations are very small for this wide range of variation in ambient temperature, and this is because variations with temperature of the characteristics of permanent magnets and the electrical resistivity of insulation of both coils placed on ferromagnetic core (outer stator) have been neglected.



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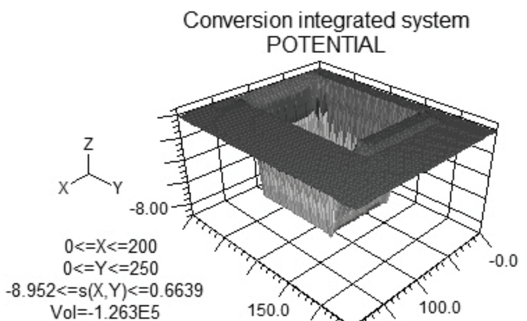


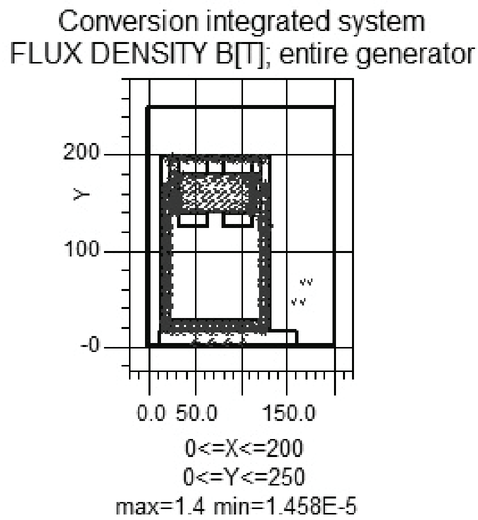
b)

Fig. 2 Spatial variation of the magnetic vector potential - in the proposed integrated system - for extreme values of ambient temperature considered: a) -30^{0}C (winter); b) +40^{0}C (summer).

The disregard for the above mentioned issues may be accepted in the first instance, and practice, taking into account the fact that the electric machine has a special construction (there is more air inside the proposed integrated system). Nevertheless, a rigorous analysis must take into account the variation with temperature of the intrinsic properties of the constituent materials of the structure.

Fig. 3, with the multiple simplifying assumptions taken, presents the distribution of the flux density vector in the proposed integrated structure at ambient temperature of -30°C (winter), while Fig. 4 presents the same distribution for an ambient temperature of +40°C (summer).

The main goal of this comparative analysis is to demonstrate that the proposed structure - with its constructive particularities - has a low sensitivity to thermal influences of the environment and major parts of the this structure - responsible for the development of forces - are little perturbed by variations thermal environment. Due to the fact temperature can create chaos within a structure, it was considered that the best analysis of this influence can be achieved by visualizing vector fields (in particular, the magnetic flux density).



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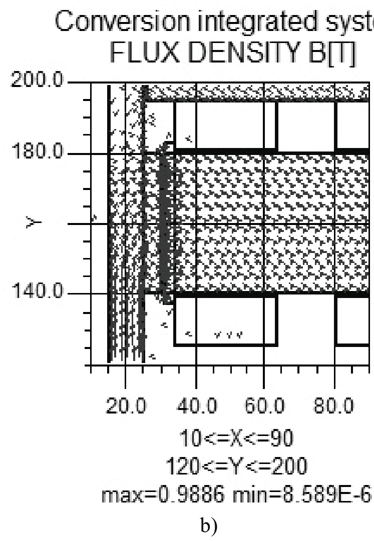

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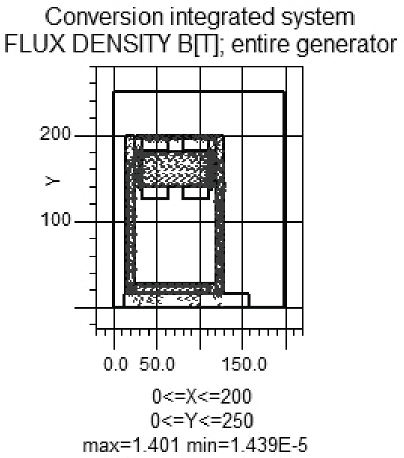
Fig. 3 Distribution of the flux density vector of integrated system proposed for ambient temperature -30°C (winter): a) the entire generator; b) detail the permanent magnets - embedded transformer.



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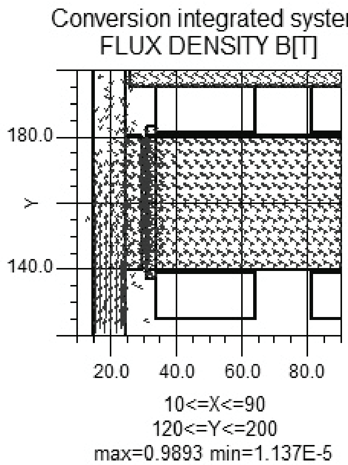
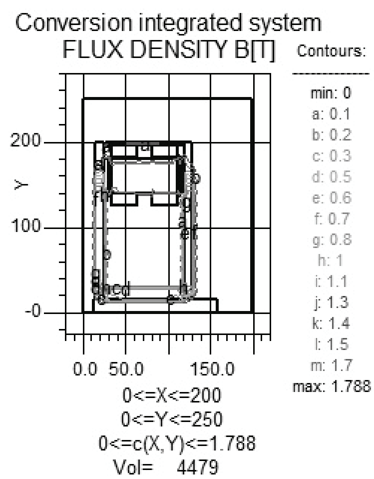


b)

Fig. 4 Distribution of the flux density vector of integrated system proposed for ambient temperature +40°C (summer): a) the entire generator; b) detail the permanent magnets - embedded transformer.

Figures 5 and 6 present the distributions of magnetic field lines in the structure, the magnetic flux density and magnetic field intensity for the two extremes of ambient temperature: -30^{0}C (winter) – fig. 5; +40^{0}C (summer) – fig. 6.



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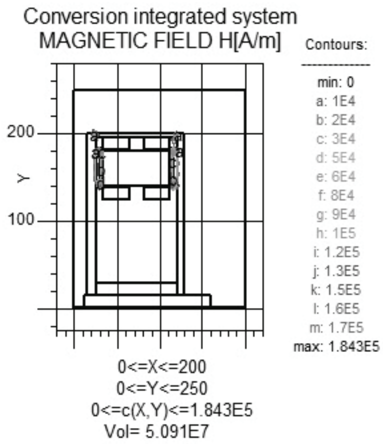

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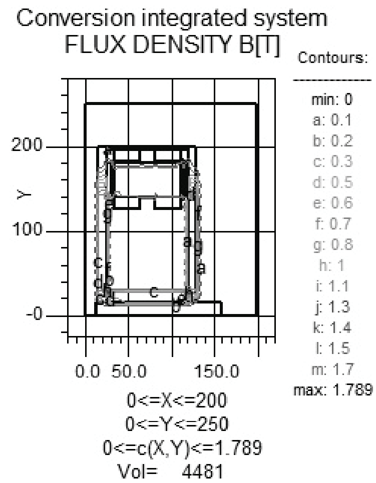
Fig. 5 Distribution of the flux density lines, respectively, magnetic field intensity of the integrated system proposed for ambient temperature -30°C (winter): a) magnetic flux density; b) magnetic field intensity.



a)

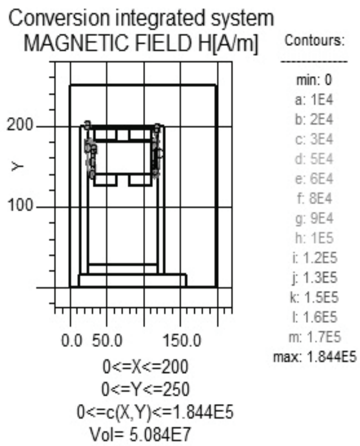


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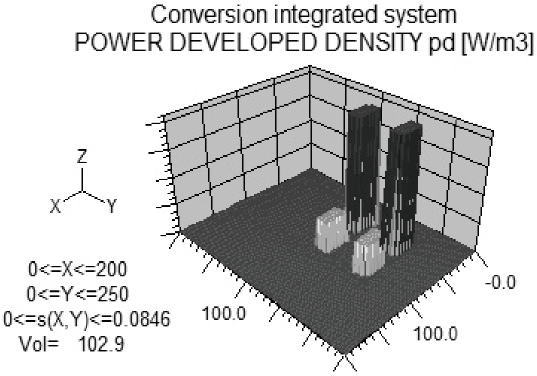
Fig. 6 Distribution of the flux density lines, respectively, magnetic field intensity of the integrated system proposed for ambient temperature +40°C (summer): a) magnetic flux density; b) magnetic field intensity.

Figures 7 and 8 show the spatial variation of power developed density and the distribution of temperature (in the analyzed structure), respectively - and especially the manner in which the internal heat balance between the heat source and external source (represented by environment) is created - in both emblematic cases studied: the ambient temperature of -30°C (winter) - Fig. 7, and the ambient temperature of +40°C (summer) - Fig. 8, respectively.



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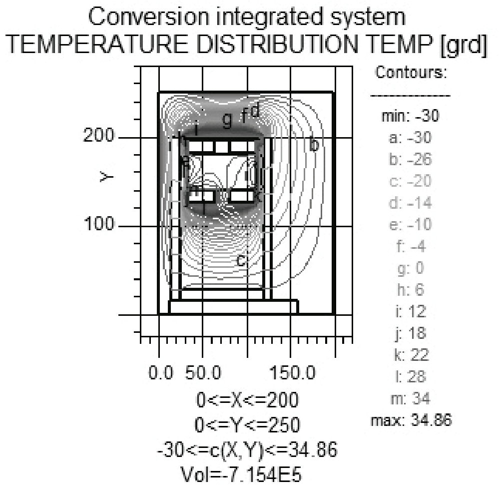

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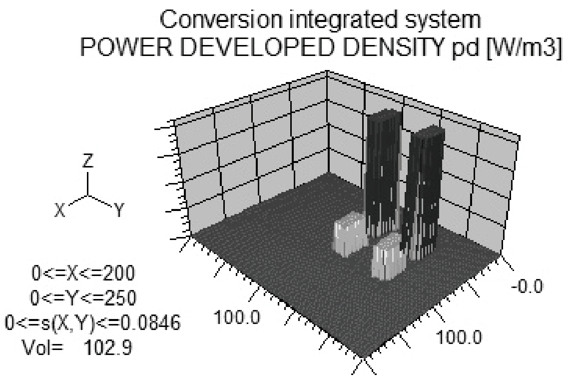
Fig. 7 Spatial variation of the power developed density, respectively, the temperature distribution of the integrated system proposed for an ambient temperature of -30°C (winter): a) spatial variation of the power developed density; b) temperature distribution.



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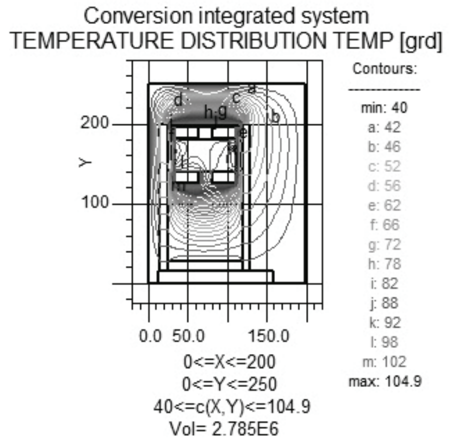

b)

Fig. 8 Spatial variation of the power developed density, respectively, the temperature distribution of the integrated system proposed for an ambient temperature of +40°C (summer): a) spatial variation of the power developed density; b) temperature distribution.

For usual current densities in existing windings (as in conventional electric machines), the power developed density is higher in the reaction winding synchronous generator area (which is also, the integrated electrical transformer primary winding), and lower in the transformer secondary area. This characteristic is not influenced by the variation in ambient temperature. However, if the source of the magnetic field remains the same, the structure's specific energy remains unchanged by the ambient temperature variation (in the simplified circumstances we utilized). Thus, the specific forces developed by the proposed integrated system remain mainly unchanged as well.

IV. CONCLUSIONS

The simplified analysis performed in this paper has highlighted the following aspects of the particular proposed structure:

- the structure has a great potential, potentiality that is less affected by temperature changes in the environment;

- due to structural features, seasonal changes in a wide range of ambient temperature the effects – for neglecting temperature variation parameters - of the magnetic flux density (and magnetic field), respectively, the specific energy (implicitly, specific forces developed) are very little;

- the temperature distribution in the structure (for both extremes of ambient temperature analysis) - and in the immediate proximity of electromagnetic conversion system - shows the occurrence of thermal peaks, which justifies as a first approximation, the aspects neglected in modeling. A maximum temperature (in a hot summer) of 105°C is acceptable for NdFeB magnets, which is lower than the class index of insulating materials used at present (F, H and C).

Nevertheless, for the practical implementation of the proposed generator an improvement on the geometry of the structure and a rigorous analysis that takes into account the variation with temperature, such as winding parameters, as reference sizes (magnetic characteristics) of permanent magnets and electrical resistivity of the insulation, respectively, is necessary. It is also mentioning that the analysis will have visualize the double interaction: electrical machine - environment (the source of disturbance being electrical machine) and environment - electrical machine (environment being the source of disturbance), respectively.

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