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TITLE OF THESIS

PhD Thesis - Abstract

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Introduction

In recent years, in step with engineering progress and in line with National and International Directives the production of energy from renewable sources, wind turbine technology has evolved rapidly, wind energy becoming one of the most competitive forms of energy among the resources of this type. In addition, variable speed wind energy conversion systems with active control of wind power and speed have been developed which offer a number of advantages and can reduce stresses in different parts of the turbine structure, including the blades and tower. This results in longer operating life, higher overall efficiency and improved power quality, which makes this type of wind turbine economically competitive despite higher initial costs [1].

On the other hand, with the increasing penetration of variable speed wind energy conversion systems in power systems around the world, permanent magnet synchronous generators are becoming more prevalent for use in variable speed applications. They offer several advantages such as the elimination of the excitation system, the possibility to operate without a gearbox, full system control and conversion of the maximum power obtained to wind variations by the maximum power point tracking method, high power density and high accuracy. In addition, the development of devices with power electronics has played an important role in perfecting their control and reliability [1].

Aim and objectives of the thesis

The constantly increasing energy needs have led to the development of numerous studies on both the optimal design of electric machines and the development of power electronics-assisted drives. This development trend includes synchronous machines, used for direct drive applications (as motors for ship propulsion, vehicle traction, elevators and as generators for wind turbines, micro-hydropower plants) which offer high torque and low speed, e.g. in wind turbine applications from which the speed multiplier has been removed. As a result of rapid technological development and performance, permanent magnets have come to be widely used from household to industrial equipment (e.g. automation systems, mechatronics), either as electric motors in traction (e.g. vehicles, lifts, pumps, compressors) and propulsion (e.g. ships) applications or as electric generators. They are particularly well suited to variable speed synchronous machines, including wind turbine generators with a kW-MW operating range, gas turbine generators and their use in the electric vehicle sector [2][3].

Electrical machines using permanent magnets as excitation sources are attracting increasing attention from both the research community and the energy industry, and developments in rare earth materials have made them more accessible. The advantages offered by permanent magnet synchronous generators have led to the consideration that they are among the most efficient electrical machines in use today. Thus they are a subject addressed in numerous research studies, with different structures and topologies being experimented for various applications. Their widespread use in low power wind applications has proven advantageous as they offer high efficiency, high power factor and increased power density [3][4][5].

There is currently a high level of interest in the use and development of wind energy conversion systems to generate electricity in urban and rural areas, especially where connection to the grid is not possible or economically reasonable. Thus these generators are well suited for use in applications such as street lighting, water pumping, residential housing. Advantages such as low wind speed at start-up and operation at moderate wind speeds facilitate the widespread installation of micro wind turbines in most areas around the world to fully exploit wind resources and significantly increase the availability of wind energy [4][6].

Considering the topicality of wind energy conversion and the advantages of permanent magnet generators, this paper presents and studies a prototype of a 5kVA direct coupled radial flux permanent magnet synchronous generator in two designs. The study is based on the idea that this prototype is intended for use in applications for wind turbines and micro-hydropower plants installed in urban or rural areas with the possibility of interconnection to the grid or in stand-alone mode, being efficient for energy conversion at low speeds. Direct coupling is an important advantage in terms of manufacturing and maintenance costs, as the absence of a gearbox simplifies the mechanical part, increases reliability and at the same time reduces noise, vibration, weight and size of the generator. The lack of a speed multiplier and operation at low speeds requires the use of a large number of poles necessary to achieve an operating frequency within the permitted range so that power quality is not affected. The performance evaluation and analysis process of aspects such as generator design, topology, structure and optimization are carried out using the OPERA 2D Vector Fields software package based on the finite element method. Subsequently the experimental results obtained from the simulations are compared with the results obtained from the measurements performed on the existing stand in the laboratory.

In view of the above, the following objectives have been set for this thesis:

- drawing the geometrical model of the prototype synchronous generator with permanent magnets mounted on the rotor surface and a very small number of notches per pole and phase in the stator (q=0.34) - Prototype 1, using the CAD interface in the OPERA software environment, 2D version;
- obtaining and interpreting the electromagnetic field spectrum calculated using the finite element method;
- presentation of induced electromotive voltage waveforms for different speeds;
- determining the parasitic torque of the prototype;
- obtaining the external characteristic and presenting methods to improve it;
- Performing measurements on the test stand and comparing them with the results obtained from simulations in the OPERA environment;
- Finite element analysis of a sonchron generator with permanent magnets inserted in the rotor to demonstrate the reverse saliency effect which will be found to be significant only for generators with a small number of poles;
- study of a prototype synchronous generator with permanent magnets mounted on the rotor surface and a small number of notches per pole and phase in the stator (q=0.65) - Prototype 2, and comparison with Prototype 1.

Two main physical resources available within UPT were used to achieve these objectives and implement the research programme, namely:

- the experimental stand which consists of a prototype of a permanent magnet synchronous generator of nominal power 5 kW and nominal speed 120 rpm which is set in motion by a variable speed drive machine;
- licensed OPERA Vector Fields software program and dongle with unlimited number of nodes for numerical computation.

Thesis structure

Structurally, the thesis presented is organised into eight chapters.

Chapter 1. Converting wind energy into electricity

This chapter presents the importance of wind energy to mankind from ancient times to the present day, and how people have known how to put it to good use. Nowadays, the main use of wind energy is in the energy sector and the electricity market. It was considered necessary to address this chapter in the thesis because the generator under analysis is mainly intended for wind to electricity applications.

Summarising the ideas in this chapter, it can be said that wind energy has always been of interest, especially in the sector of its conversion into electricity, with different wind turbine concepts being built and developed over time to maximise electricity production, minimise production and maintenance costs, increase efficiency and reliability. This has led to the design of wind turbines with a rated power of 9.5 MW.

Synchronous generators have played and continue to play an important role in this development process, and this trend has led to their very detailed study and analysis in order to improve their performance, offer the highest possible efficiency in the energy conversion process and provide electricity of the highest quality and standards.

It has been found that different types and concepts of wind turbines have been built and developed over time depending on the electrical generator used. For example, the first prototypes of grid-connected wind turbines operated at fixed speed and were equipped with synchronous generators, but soon the cage rotor induction generator was adopted as a cheaper and technologically simpler solution. Around the 1990s, the doubly-fed induction generator was introduced to wind power systems, allowing much better control of the transfer of electrical power to consumers. An important role in this process was and still is played by power electronics, which facilitates the control and optimisation of wind energy conversion.

It has been observed that nowadays many wind turbine manufacturers focus on variable speed wind turbines, although the electrical system for operation in this configuration is much more complicated compared to the fixed speed wind turbine system. One of the advantages of variable speed wind turbines is that they can be used for a wide range of wind speeds, so wind speed can be controlled and wind turbine efficiency maximised.

According to annual reports, electricity production shows that it is on an upward trend year on year. According to the BP Statistical Rewiew of World Energy June 2018, in 2017 the global electricity generation in the year 2017 stands at 25551.3 TWh, registering an annual growth rate of 2.8% calculated over the years 1985 - 2017.

In terms of wind energy to electricity conversion, the annual growth rate in this sector has been high, especially for the period 2006-2016, when it was 21.9%.

The cumulative installed capacity of wind power globally in 2017 is 514.7 GW, according to IRENA, Global Wind Energy Council and Navigant Consulting, with China leading the world with 164.1 GW of installed capacity.

According to BP Statistical Rewiew of World Energy June 2018 Romania ranked 12th in Europe at the end of 2017 in terms of cumulative installed capacity in wind turbines, with a value of 3038 MW.

The significant progress in increasing the share of wind energy in the global electricity sector brings another challenge, namely the integration of wind turbines into the power system and their impact on it.

Chapter 2. Low-speed permanent magnet synchronous generators

The second chapter of the thesis is devoted to a brief description of rotating electric machines from a constructive, functional and phenomenological point of view, in particular the synchronous machine. The characteristics of permanent magnet generators, their modes of use and the consequences on the constructive solutions are presented, as well as the advantages and disadvantages between different types of synchronous generators using permanent magnets, and their comparison with usual generators. A brief history of the evolution of permanent magnets, their types and their advantages for use in electrical machinery is presented.

As far as the use of small synchronous generators in wind systems is concerned, they are obviously less energy significant than large generators in wind systems, but the advantage of small generators is that as demand increases so will the interest in their research and development, which will lead to improved reliability while costs will fall. Another advantage of small wind power systems is their stand-alone use in remote areas where it is not possible or economically unreliable to connect the consumer to the grid.

It has been observed that from a technical point of view the presence of power electronics has produced a boost that has led to increased interest in concepts that operate at variable speed. These innovations have proved useful for wind turbines for a number of reasons including reduced mechanical stress, increased wind energy capture capacity, reduced noise and increased control.

Chapter 3. The finite element method used in the study of the electromagnetic field - "OPERA" environment

This chapter provides a general overview of the influence of engineering computation and numerical methods as essential components of the design process in the evolution of technology and human progress. An overview of the finite element method and OPERA software is also given.

With the rapid growth in demand for high performance electric machines, engineers are currently tasked with many competing requirements and specifications for designing or improving the performance of such a product. Whether it is motor applications for electric drives or industrial processes, or generator applications for renewable energy sources, engineers are faced with the challenge of designing them to represent in practice cost-effective solutions through increased efficiency, increased efficiency, reliability, reduced volume, lighter weight and reduced environmental impact. Many companies use simulation with dedicated software packages for this purpose, one of which is OPERA, a finite element method (FEM) based software environment, representing a routine part of the development process, recognising the benefits of using it to address engineering challenges [7].

It is noted that nowadays numerical computational methods implemented on computers whose computing power has been improved dramatically have led to the emergence of dedicated software packages, which are now powerful tools widely used in industrial and scientific applications because of the advantages they offer. Among the most important advantages they facilitate are reduced computation time, increased accuracy and significant diversification of the sizes and characteristics that can be determined.

Most of these software environments are based on the principle of the finite element method, which is an extremely useful and efficient method for solving problems from the simplest to the most complex, regardless of the type of construction of the structure under analysis, the material used, the type of analysis, etc. The computational philosophy addressed by this method, the main laws and theorems, the steps that are taken when building and solving a model, and the main areas of applicability of the method have been presented in this chapter. The most important theories of electromagnetism on the basis of which the solutions of the equations describing the electromagnetic field of electric machines can be determined have also been presented.

Chapter 4. Numerical analysis of a 5 kVA low speed permanent magnet synchronous generator - Prototype 1

This chapter is devoted to the presentation and analysis of the prototype permanent magnet synchronous generator studied. The constructive data of the generator are presented and the 2D geometry of the generator is drawn with the help of the CAD library provided by the OPERA environment, and then the numerical analysis is performed in this software program based on the finite element method to evaluate and improve the generator performance.

After building the model, both steady-state analysis of the generator and rotational motion analysis were performed. In the steady-state analysis, one of the main objectives proposed for the performance analysis of the studied permanent magnet synchronous generator was achieved, namely the obtaining of the magnetic field spectrum. Its determination is the starting point for the analysis of the generator performance, further resulting in different characteristics and parameters such as waveforms of induced electromotive voltages, external characteristic of the generator, currents, efficiency, parasitic torque, etc. Also, the magnetic field solution provided by the OPERA environment allows the analysis of some aspects related to the design process, i.e. the operation of the electrical machine, such as the identification of possible saturated ferromagnetic areas for which it is necessary to revisit the design process and the calculation of iron losses in the main magnetic circuit or in different adjacent regions. Also with regard to the magnetic field distribution, the variation of the useful magnetic flux and the stray flux as a function of the position of the magnet relative to the stator teeth and also the variation of the normal component of the inductance was revealed by means of simulations in OPERA. B_n in the intercooler over the whole machine for any given rotor position.

Another important aspect highlighted in this chapter was the influence of the number of nodes imposed by the user on the accuracy of the results obtained in OPERA, their impact being mirrored on the magnetic field lines. This was exemplified by displaying the magnetic field spectra calculated in OPERA based on three distinct discretisation grids in terms of the number of nodes. From this example it was found that the number of finite elements imposed by the user directly influences the calculations and automatically the results obtained, so the number of nodes should be chosen optimally so as to influence the calculation error as little as possible.

In the rotating motion analysis of the studied permanent magnet synchronous generator, waveforms of the induced electromotive voltage for idle operation at rated speed were obtained in the first phase. Also, one of the important design parameters in permanent magnet synchronous generators, namely the parasitic torque, was determined graphically. Since it does not contribute to the value of the useful torque and moreover can have negative effects on the operation of the machine, manifested by transient phenomena and vibration induction, it is important to know its value. Based on the finite element method calculations in OPERA it was found that for the studied synchronous generator the parasitic torque determined graphically represents relatively low values, falling somewhere around 0.17% of the nominal torque. It is known that for high values of the parasitic torque the normal operation and starting of the wind turbine assembly at low wind speeds may be affected, thus also the efficiency of the generator is affected. In this case, the knowledge of this parameter is particularly useful for the permanent magnet synchronous generator studied, as its low value primarily ensures that it can be efficient even in areas with lower wind potential.

The analysis of the permanent magnet synchronous generator based on the 2D magnetic field model represented by OPERA using finite element method calculation is particularly useful, especially in the design process, as it allows both the modelling of the no-load operation and the constructive-functional optimization of the generator.

Also in this chapter, the operating characteristics of synchronous generators have been briefly mentioned. Since the permanent magnet synchronous generator studied is mainly dedicated to wind applications and stand-alone operation, it is very important to know its external characteristics, as this is a parameter that provides information about the power quality. To this end, a series of simulations have been carried out in OPERA for different resistive loadings, and calculated results have been obtained based on the finite element method with which the external characteristic has been constructed.

Based on hypotheses discussed in literature articles, an experimental investigation of the influence of permanent magnet width on the external characteristic for the studied synchronous generator prototype was carried out. With the help of the OPERA environment the initial geometry of the permanent magnets was redefined and several simulations were performed for different permanent magnet widths. On the basis of the obtained results the external characteristics for each case were plotted and compared with each other, and it was concluded that the effective value of the induced voltage is directly proportional dependent on the value of their length.

A series of simulations were also carried out in OPERA to determine the influence of permanent magnet width on parasitic torque. It was found that the highest value of the parasitic torque corresponds to magnets with width $l_m = 32\ mm$. It was observed that with the reduction of the width of the permanent magnets to values between 28-32 mm the amplitude of the parasitic torque decreased significantly. Further decreasing the width of the magnets to $l_m = 24\ mm$ an increase of the torque value is observed.

Taking into account the results obtained from the simulations in OPERA, it was shown that in terms of external characteristic and parasitic torque the optimum width for permanent magnets is the one chosen in the design data, $l_m = 32\ mm$. Although in terms of parasitic torque it has the lowest value for $l_m = 28\ mm$, permanent magnets with width $l_m = 32\ mm$ are superior to those of $l_m = 28\ mm$ from the point of view of the comparison of the external characteristics obtained in the two cases at identical loadings. For example the value of the induced electromotive voltage for idling operation with $l_m = 28\ mm$ is $U_{l_m 28} = 159.38\ V$and for $l_m = 32\ mm$ the voltage value is $U_{l_m 32} = 170.12\ V$.

Another experimental study carried out in this chapter concerns the possibility of obtaining a reverse saliency effect by introducing ferromagnetic parts in the interpolar space in the rotor in order to improve the external characteristic and to achieve a voltage regulation overcoming the disadvantage of the absence of control over the magnetic field. Based on these considerations, the structure of the Prototype 1 rotor was modified in OPERA by introducing several layers of interpolating parts between radially arranged magnets on the rotor surface. The results of the modifications are compared with those obtained in the original prototype. From the point of view of the magnetic field spectrum, the magnetic flux density distribution in the interphase at the rest state of the rotor and the external characteristics obtained and compared for the two cases, it was concluded that the introduction of ferromagnetic pieces in the interpolar space does not have a significant effect in terms of improving the performance of the synchronous generator studied because the generator has a large number of poles and consequently a small polar pitch, this solution being advantageous only in the case of generators with a small number of poles [8][9].

The results of this study with the finite element method constitute a contribution of the thesis, namely that the improvement of the external characteristic of GSMP by introducing interpolating parts, which usually produce the "reverse saliency" effect, cannot be applied in the case under analysis and in general neither for GSMP with low speed and high number of poles.

Chapter 5. Experimental determinations and comparisons with calculated quantities

The prototype under study is intended for wind and water energy conversion applications. In terms of operating mode, it can operate either connected to the grid or in stand-alone mode. For generators intended for stand-alone operation, the interest of experimental tests is to determine the operating characteristics, which is also the main purpose for which the experimental stand in the D109 Electrical Machines Laboratory of the Faculty of Electrical Engineering and Electroenergetics of "Politehnica" University of Timisoara was designed.

In this chapter the experimental stand and the data acquisition and processing system were presented, with the help of which the proposed experimental determinations for the studied permanent magnet synchronous generator could be carried out. Thus the values of the parameters resulting from the experimental determinations on the test stand were presented. Comparative analysis of the experimentally obtained results with those obtained analytically from the calculation based on the finite element method in the OPERA environment was also carried out. The comparison showed that there is a good similarity between the parameter values obtained from the simulations and those obtained from the bench tests, as well as between the stress waveforms obtained from the numerical calculation and those obtained from direct measurements.

Chapter 6. Analysis of a 5kVA permanent magnet synchronous generator design - Prototype 2

In this chapter, the second prototype of a low-speed permanent magnet synchronous generator was presented, which is different from the first prototype studied in terms of construction by the number of stator notches. The model of Prototype 2 characterized by a number of 63 notches was built in OPERA and then the magnetic flux distribution, the amount of magnetic induction in the interphase, the waveforms for the electromotive voltage induced in the stator windings and the parasitic torque of the generator for rated speed were determined analytically. $n_N = 120\, rpm$.

A comparative analysis between two permanent magnet generators with low speed, of the same rated power, similar in construction, characterized by a simple structure, the main difference being the stator topology, was also presented.

In terms of functional performance both generators perform well. By comparing the induced electromotive voltages at idling and nominal rotor speed, it was shown that Prototype 2 outperforms Prototype 1. Regarding the stability of the two generators under load variations, the comparison of the external characteristics of the two prototypes showed that the voltage value at the terminals of Prototype 2 is higher than the voltage value at the terminals of Prototype 1 for the same value of load resistance. So also from this point of view Prototype 2 behaves better.

Regarding another important parameter of permanent magnet synchronous generators, namely parasitic torque, it was found that both prototypes are characterized by low values of it. Comparatively, based on the values obtained in OPERA, Prototype 2 offers an advantage over Prototype 1, presenting a much lower parasitic torque and automatically lower acoustic noise and vibration levels. As both prototypes are low power machines, parasitic effects such as unbalanced magnetic forces and acoustic noise caused by parasitic torque fall within acceptable levels. As a result, and from this point of view of parasitic torque value, Prototype 2 is better.

Another important conclusion from this analysis confirms that the c.m.m.m.c. values are a very good indication for the design phase of a permanent magnet synchronous generator in terms of parasitic torque control. In the present case it is considered that the c.m.m.m.c. values chosen for the two generators are too high, and even if they led to an almost complete decrease of the parasitic torque, unilateral magnetic forces appeared as a consequence. From this point of view it is considered that values between 500-800 c.m.m.m.c. are high enough to maintain a parasitic torque at an acceptable level. Thus, when choosing the number of notches, a balance must be maintained between achieving an acceptable level of parasitic torque and the appearance of other parasitic effects such as unilateral magnetic attraction forces.

Chapter 7. Performance analysis of a three-phase synchronous generator with permanent magnets and interpolated ferromagnetic parts

This chapter is devoted to the analysis of a three-phase synchronous generator with NdFeB permanent magnets inserted in the rotor with the aim of highlighting the reverse saliency effect of the rotor if it is built with a small number of poles.

Due to the small number of poles it is intended to demonstrate that in this type of rotor structure the reverse saliency effect occurs, in which case the reactance of the quadrature axis q is greater than the reactance of the direct axis d. As a result of this effect, the generator exhibits an inherent voltage compensation capability to maintain the terminal voltage almost constant at different loadings.

The characteristics and performance obtained with OPERA using the finite element method are presented and the benefits of this type of generator for applications where it is necessary to keep the output voltage almost constant regardless of the load, such as stand-alone generator operation, are highlighted.

Numerous simulations have shown that the introduction of ferromagnetic parts in the interpolar space has a positive effect only in the case of synchronous generators with a small number of poles, the case analysed in this chapter, as opposed to GS with a large number of poles as in the case of Prototype 1 studied, with 33 notches, where it was observed that this solution produces an insignificant effect in terms of the external characteristic of the generator.

The results presented demonstrate that this type of rotor-inserted permanent magnet synchronous generator has its own voltage compensation capability, and its performance is a significant advantage of the generator for use in stand-alone applications. In this case such a GS becomes a suitable and economical solution in a power system, especially in those with unity power factor, as it does not require an additional voltage regulation system.

The final practical conclusion resulting from this chapter is that in the case of the studied prototypes 1 and 2 an improvement of the external characteristic cannot be obtained by introducing ferromagnetic parts in the interpolar space, because these two prototypes have too large a number of poles. Therefore, in general, in the case of synchronous generators with permanent magnets with low speed, this constructive solution is not advisable.

Chapter 8. General conclusions, contributions and directions for further development

This chapter presents the findings from the studies conducted, personal contributions to this thesis and directions for further development of the research addressed in the thesis.

As a result of the activities and research carried out in the field, the following contributions are considered to have been made:

1. Theoretical analysis and experimental verification of a prototype synchronous generator with permanent magnets mounted on the rotor surface and a very small number of notches per pole and phase in the stator (q=0.34) - Prototype 1.
2. Theoretical analysis and experimental verification of a prototype synchronous generator with permanent magnets mounted on the rotor surface and a small number of notches per pole and phase in the stator (q=0.65) - Prototype 2.
3. Experimental verification of the influence of the number of notches on cogging parasitic torques in the permanent magnet synchronous generator mounted on the rotor surface.
4. Comparison between Prototype 1 and Prototype 2 and formulation of useful conclusions for series design of permanent magnet synchronous generators.

5. Study the possibilities of improving the external characteristics by construction methods, such as the introduction of ferromagnetic parts in the space between the magnets on the rotor.

   The research presented in the thesis can be further developed in the following directions:

- Study of unilateral forces by finite element method for GSMP with small number of notches per pole and phase;
- determination of a stator winding choice criterion (number of notches per pole and phase) that is a compomis for acceptable values of parasitic cogging torque and unilateral forces;
- study of GSMP operation under non-symmetrical load; operating characteristics;
- numerical simulation and experimental study of transient regimes [9][10][11][12][13].

Selected bibliographic references

[1] Youssef Errami, Mohammed Ouassaid, Mohamed Maaroufi, *Modelling and optimal power control for permanent magnet synchronous generator wind turbine system connected to utility grid with fault conditions*, World Journal of Modelling and Simulation, Vol. 11 (2015) No. 2, pp. 123-135, ISSN 1 746-7233, England, UK

[2] John Bird, *Electrical and Electronic Principles and Technology - Fifth edition*, Routledge, Taylor&Francis Group, London and New York, 2014.

[3] R. Saou, M. E. Zaim, K. Alitouche, *Modelling and Design of a Low Speed Flux Reversal Machine*, Journal of Electrical Systems, pp. 18-23, 2009

[4] Mihai Chirca, Claudiu Oprea, Petre-Dorel Teodosescu, Ștefan Breban, *Optimal Design of a Radial Flux Spoke-Type Interior Rotor Permanent Magnet Generator for Micro-Wind Turbine Applications*, Department of Electrical Machines and Drives Technical University of Cluj-Napoca, Romania, 2016

[5] Mohammadali Abbasian, Arash Hassanpour Isfahani, *Optimal Design of a Direct-Drive Permanent Magnet Synchronous Generator for Small-Scale Wind Energy Conversion Systems*, Journal of Magnetics 16(4), 379-385, 2011.

[6] Tong Wei, *Wind Power Generation and Wind Turbine Design*, WIT Press, Southampton, UK, 2010.

[7] Opera Simulation Software - Cobham Technical Services, *Electrical Machines Design*, Kidlington, Oxfordshire, UK, 2015

[8] Constantin Dobrean, Marian Greconici, Gheorghe Madescu, Marțian Moț, Marius Biriescu, *FEM Analysis of a Synchronous Generator with Inset Permanent Magnet Rotor*, International Conference on Optimization of Electrical and Electronic Equipment (OPTIM) & Intl Aegean Conference on Electrical Machines and Power Electronics (ACEMP), 978-1-5090-4488-7/17/$31.00 ©2017 IEEE, Brasov, 2017

[9] Marian Greconici, Gheorghe Madescu, Marțian Moț, Marius Biriescu, Danijela Milosevici, *Analisys of a PM Generator with Inset Magnets*, 2018 International Symposium on Electronics and Telecomunications (ISETC), Timisoara, Romania, DOI: 10.1109ISETC.2018.8583943

[10] D. Bang, H.Polinder, G. Shrestha, J.A. Ferreira, *Review of Generator Systems for Direct-Drive Wind Turbines*, Proceedings of the European Wind Energy Conference and Exhibition, Belgium, 2008

[11] Ion Boldea, *Synchronous Generators (Second Edition)*, CRC, Taylor&Francis Group, 2016.

[12] IEEE Std. 115-1995, IEEE, Part II, Sec. 12, *Standstill frequency - respons testing*

[13] BS 4999: Part 104: 1988, British Standard, *General Requirement for rotating electrical machines. Part 104. Methods of test for determining synchronousmachines quantities*