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A MULTIPOLAR INDUCTOR GENERATOROF ANNULAR DESIGN FOR WINDMILLS

DAUDZPOLU GREDZENVEIDA INDUKTORĢENERATORS VĒJA IEKĀRTĀM

V. Pugachov , N. Levin , L. Ribickis, M. Manonov

Keywords: inductor generator, wind plants, directly-driven, annular construction

Introduction

Improvement of a wind plant's efficiency depends in many aspects on the quality, reliability and ease of fabrication of its wind generator. As the simplest and the most reliable in operation there are considered wind plants (WPs) with brushless generators directly driven from the wind turbine, since such a design excludes the element, which is the most unreliable and complicated to operate - the step-up multiplier.

The wind turbines have a low rotational speed of hundreds to tens turns per minute, depending on the rated power. The generator mass considerably increases with decreasing the rotational speed, therefore on such generators particular requirements are imposed; first of all, the requirement that in the low-turn version their mass should be reduced as much as possible.

The present work considers a solution to this problem based on the application of a brushless two-core inductor machine as the low-turn generator of a directly driven wind plant. The power of the generator is 12 kW at the rotational speed of 100 min^{-1}. The rated phase voltage is 230 V.

Main features of the directly-driven WP generators

One of the most reliable WP designs which practically does not require technical sattendance is that of a direct-drive WP whose synchronous generator is directly driven from the wind turbine. Currently, these WPs are made by various leading companies, such as WORLD POWER (USA) producing WHISPER plants with a power ranged from 0.5 to 4.5 kW, PITCH – WIND (Sweden) producing WPs with a power from 20 to 30 kW, ENERCON (Germany) making WPs with a power from 200 kW to 1.5 mW and some others [1]. The first two companies mentioned employ synchronous generators with the excitation from permanent magnets, whereas in WPs made by ENERCON Co. there are installed generators with electromagnetic excitation.

The rotational speed of a wind turbine, determined by the power and design parameters of the WP, changes with increasing power from hundreds turns per minute for low-power plants to two tens turns for WPs with a power of 1.0 mW. Such a low rotational speed predetermines the search for optimal design solutions when working out synchronous generators.

It is known, that the sizes and mass of a synchronous machine, all other conditions being equal, are inversely proportional to the rotational speed n of the rotor and can be estimated by the expression

$$D^2 L = \frac{C_A S}{n} \qquad (1)$$

where S is the generator's power, D and L are the recess diameter and core length of the stator determining the mass and sizes of the electric machine, C_A is a constant coefficient determined by its design parameters and electromagnetic loads [2]. The mentioned above rotational speed range of wind turbines, with the current and voltage frequency f of the armature winding kept sufficiently close to 50 Hz, determines the necessity to use multipole version of synchronous generators. Thus a synchronous generator should possess 30 pole pairs at the rotational speed of 100 turns per minute and 150 pole pairs at the rotational speed of 20 turns per minute. The multipoleness of a generator predetermines its design with an increased diameter and, in compliance with (1), with a shortened core of the stator, i.e. with a raised D/L ratio. At D/L values being sufficiently large there is the so-called annular version of the generator, so that the majority of its active elements (electrical-sheet steel of the stator's and rotor's cores, armature and excitation windings and some other load-bearing members) are distanced from the rotation axis. In the inner space with a diameter up to 80% of the armature recess a lightened sleeve is placed, which links the rotor of such a generator to its shaft. Such a design allows for reducing the generator's mass 2-2.5 times as compared with the conventional version [3].

Apart from that, the multipole version opens wide possibilities for application of contactless synchronous inductor generators, which in this case possess a number of important advantages over classical synchronous generators with rotating excitation windings. One of the main advantages is that in inductor generators the multipoleness is reached without increasing the number of excitation winding's coils, which means that, independently of the pole number, the magnetic flow is created by one excitation coil whose *mmf* is only slightly larger than the *mmf* per one pole pair of a classical synchronous generator. In [4] it is shown that this important practical advantage manifests itself in the fact that with the number of pole pairs increasing the mass of one annular excitation winding is approximately p times less as compared with the excitation winding of an explicit pole synchronous machine. The same relationship holds also between the losses in the excitation windings under comparison. Another very important advantage of synchronous inductor generators is their being made in contactless version. The absence in such a generator of contact rings and brushes allows the generator's reliability to be considerably improved and the WP maintenance expenses to be cut.

Description of the contactless multipole inductor generator of ring design

As an example we will consider schematically the generator of a directly-driven WP with a power of 12 kW intended for supplying agricultural economies with electricity. The rotational speed of the wind turbine in a two-blade version is 100 turns per minute. The working condition of the WP for independent load and for electric network is established through an invertor with a DC element.

The longitudinal cross-section of the generator is shown in Fig.1. In casing 1 two cores of stator 2 are pressed, with three-phase windings 3 on each core. On the ferromagnetic sleeve of rotor 4 two windingless tooth-like cores, 5 and 6, are arranged. The number of teeth on each core determines the number of pole pairs of the generator and is equal to 60. The frequency at the rated rotational speed is f = 100 Hz. The increase in the number of pole pairs to 60 and in the frequency to 100 Hz allows for improvement of the generator's mass-size indices and achievement of appropriate working conditions of the WP.

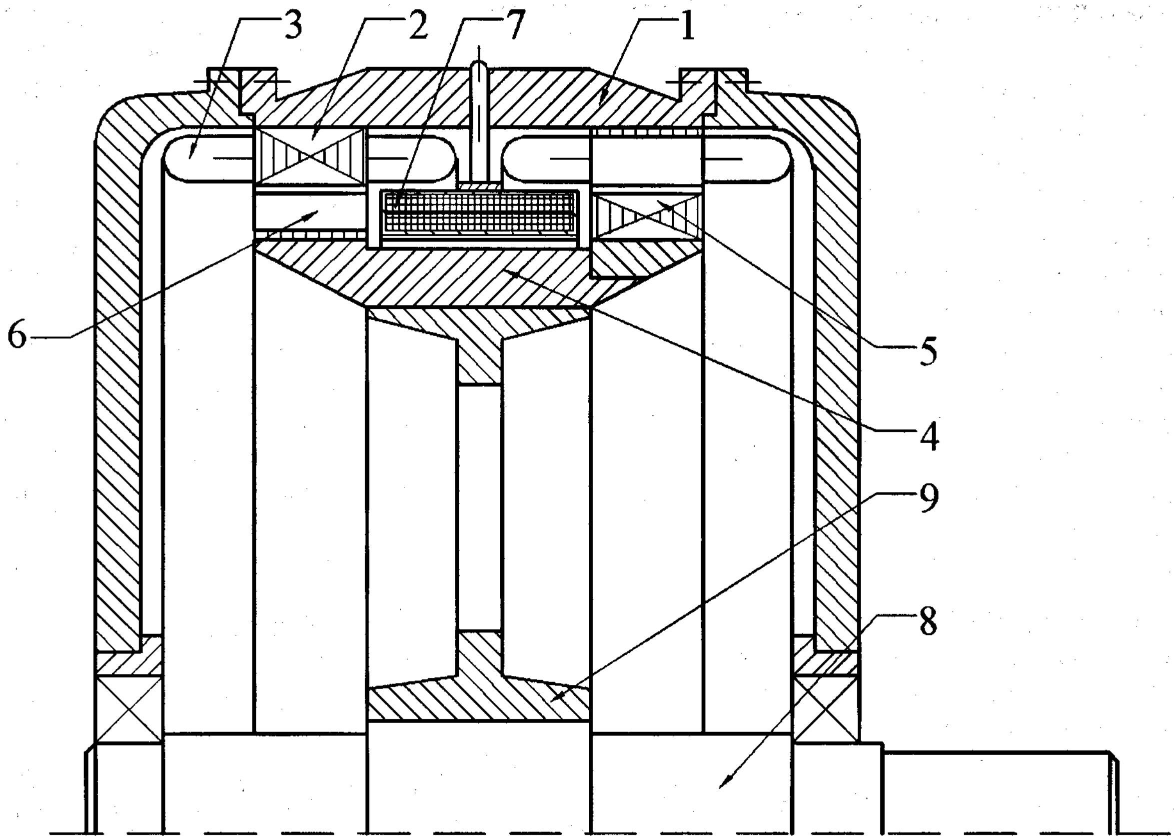

Fig.1. The structral scheme (longitudinal cross-section) of the generator

The stationary annular excitation winding 7 is fixed between the rotor's cores. The ferromagnetic rotor's sleeve 4 with the inside diameter D_0= 470 mm is connected with shaft 8 of the generator by means of a lightened non-magnetic sleeve 9. The diameter of the armature recess is D=580 mm, the outside diameter of the machine is D_1= 680 mm. Each core of the stator is 50 mm long.

The tooth zone and the armature winding

One of the most important tasks when designing multipole inductor generators is to substantiate and choose a rational geometry for the tooth zone, an optimum tooth number on the stator's cores where the three-phase armature winding is arranged, and the winding's circuit. For the generator under consideration the number Z_1 of stator teeth can be chosen based on the known relationship:

$$Z_1 = 2pmq \tag{2}$$

where p is the pole pair number equal to the number Z_2 of rotor teeth, m is the number of the armature winding's phases (in the project under consideration m=3),

q is the number of slots per pole and phase. Application of distributed armature windings at q≥1 is difficult technologically. Since in our case (Z_2=60) if q=1 a three-phase winding should be dropped on 360 teeth. Seeking to maximally reduce the tooth number Z_1 on the armature, we have chosen a teeth zone in which the numbers of stator and rotor teeth are mutually connected by the relationship

$$Z_1 = \frac{Z_2}{2m \pm 1} 2m \qquad (3)$$

In our example, at m=3 and Z_2=60 we obtain Z_1=72. Such being the relationship between the tooth numbers Z_1 and Z_2, the tooth zone can be considered as consisting of K=12 elementary modules arranged in the armature recess, each of the modules consisting, in turn, of six armature teeth and five rotor teeth. One of these modules is shown in Fig.2.

Since electric angle α between the magnetic flows of adjacent armature teeth is

$$\alpha = 2\pi \frac{Z_2}{Z_1} = 300 \text{ electrical degrees} \qquad (4)$$

On these teeth the three-phase two-layer distributed armature winding can be made with **a** first-to-fourth-slot pitch. In this case q = 0.2. The cutting coefficient for such a winding is sufficiently low (k_w = 2/3), however the efficiency improvement is reached here owing to the simultaneous use by each winding coil of magnetic fluxes of three teeth. Besides, the frequency increase up to 100 Hz also compensates the mentioned above shortage [5].

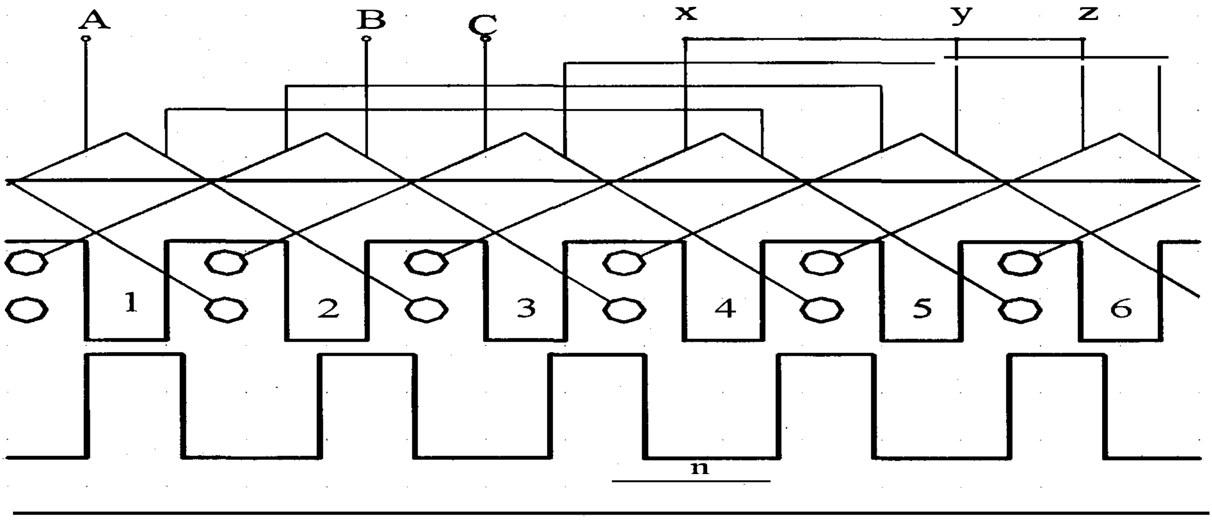

Fig.2. Elementary modul of the generator

The rated data and main design parameters of the generator

Taking into account the above-mentioned considerations the necessary electromagnetic calculations have been performed and a calculational model of the inductor generator has been worked out with the following rated data and main design parameters:

1.	Rated power P of the generator	12 kW
2.	Rated phase voltage U_f	230 V
3.	Rated rotational speed n	100 min^{-1}
4.	Frequency f	100 Hz
5.	Phase number m	3
6.	Diameter of the stator's recess D	580 mm
7.	Axial length of the stator's core L	50 mm
8.	Ratio D/L	11.6
9.	Relative outside diameter of the generator D_1/D	1.17
10.	Relative inside diameter of the core D_0/D	0.81

11.	Relative length Lg of the generator Lg/2L	3.4
12.	Number of teeth on the stator	72
13.	Number of the teeth on the rotor	60
14.	Mass of the generator G	280 kg
15.	Efficiency	0.86
16.	Specific power P/G	43 W/kg

The conventional inductor generator with the same data – sheet specificatiations has a mass of 550 kg.

Conclusion

Owing to the annular construction of the inductor generator, to the rational geometry chosen for the tooth zone and to the efficient circuit of the armature winding it was possible to work out a design for the generator of a directly-driven wind plant, which demonstrates a good performance. In the present work a theoretical substantiation of the design is given together with the results of calculation data for the modelled inductor generator. The calculation methods have been verified by experimental data for different inductor machines.

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Vladislav Pugachov, Head of Laboratory, Dr. Habil. Sc. Ing.
Latvian Academy of Sciences, Institute of Physical Energetics.
Adress: Aizkraukles str. 21, Riga, LV – 1006, Latvia.
Phone: +371 7558684. Fax: +371 7550839.e-mail: magneton@edi.lv

Nilolaj Levin, Professor, Dr. Habil. Sc. Ing.
Latvian Academy of Sciences, Institute of Physical Energetics.
Adress: Aizkraukles str. 21, Riga, LV – 1006, Latvia.
Phone: +371 7558610. Faks +371 7550839.e-mail:

Leonids Ribickis, Professor, Vice–Rector for Research, Dr. Habil. Sc. Ing.
Riga Technical University
Adress: Kalku str. 1, Riga, LV – 1658, Latvia.
Phone: +371 7089415. Fax: +371 7820094.e-mail: ribickis@adm.rtu.lv

Muhabat Manonov, Direktor.
Ventspils Fan Factory
Adress: Robezu str. 3/5, Ventspils LV – 3600, Latvia.
Phone: +371 3624764. Mob: +371 9216809.

Pugachov V., Levin N., Ribickis L., Manonov., A Multipolar Inductor Generator of Annular Design for Windmills.

A design of the inductor generator for 12-kW wind plants is considered, with the rotation speed of 100 min $^{-1}$, directly driven from a wind turbine without a step-up multiplier. The generator is ring – wise, with an increased ratio of recess diameter D to the cjre length L (D/L=11,6). The rotor of the generator is fastened on the shaft through a lightened non –magnetic sleeve. The mass of the generator is 280 kg, its efficiency – 86.

Pugačevs V., Levins N., Ribickis L., Manonovs M. Daudzpolu gredzenveida induktorģenerators vēja iekārtām.

Tiek piedāvāts induktorģenerators 12kW tiešās piedziņas vēja iekārtām **ar** *griešanās ātrumu 100 apgr/min. Gredzenveida ģeneratoram attiecība starp statora izvirpošanas diametru D un paketes garumu L ir palielināta (D/L = 11,6). Zobainais rotors savienots ar ģeneratora vārpstu caur vieglu nemagnētisku buksi.*
Ģeneratora masa 280 kg, lietderīgas koeficients – 86%.

Пугачев В., Левин Н., Рыбицкий Л., Манонов М. Многополюсный индукторный генератор кольцевого исполнения для ветроустановок.

Представлен проект индукторного генератора для прямоприводной 12 кВт ветроустановки при скорости вращения 100 мин $^{-1}$. Генератор кольцевого исполнения с повышенным отношением диаметра расточки якоря D к длине пакета L (D/L =11,6). Зубчатый ротор соединен с валом генератора через облегченную немагнитную втулку. Масса генератора 280 кг, коэффициент полезного действия – 86 %.