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The Comparative Analysis of Inductor and Reluctance Wind Generators

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Abstract - **In the presented work two designs of brushless generators are compared: inductor and reluctance. Both designs are multipolar and also can be applied as directly driven wind generators. Both one and the second designs are basically similar, but in the inductor generator are windings of excitation or permanent magnets which complicate a design, increase consumption of the copper and energy losses. In work shown that reluctance generator has no winding of excitation, it is simple and more reliable, it has less weight. It's more competitive for use in low power wind plants.**

I. INTRODUCTION

The wind power engineering makes rapid strides towards higher reliability and better economical efficiency of the developed wind power plants (WPPs). In this connection it is wind generators that are of primary importance for updating the WPP [1]. These electric machines, which are used for conversion of the wind turbine's mechanical energy into the electric one, should possess a number of important design peculiarities. First, such a machine should be without sliding contacts, which means absence of a collector, brushes, and contact rings. The presence of the latter makes a machine less reliable and more expensive under operation, especially when a WPP is used in winter. Apart from raising the mass and sizes of the generator, sliding contacts increase its mechanical and electric losses. Second, it is advisable to make the wind generator directly-driven, i.e. without using rather unreliable in operation mechanical multipliers. At the same time, the directly-driven design of a wind generator calls for its multipolarity, since only a multipolar generator in its low-turn version can have limited mass and sizes [2]. Third, to achieve the multipolarity, high reliability and low cost of production, it is important that the electric machine does not contain permanent magnets in the excitation system. Fourth, to improve the reliability it is necessary to minimize the number of windings, with the excitation winding also excluded.

In this context, an optimal electric machine meeting the above mentioned requirements are the inductor and reluctance [2-5]. Its design has no rotating windings, whereas the principle of its operation is based on a deep change in the inductance (reluctance) of the armature windings' phases at the rotation of a non-wound rotor. Depending on the specifics of the design arrangement of a inductor and reluctance generators, and its operating conditions a definite efficiency can be achieved, and, therefore, its possibilities of being used in the WPPs of different capacity.

II. FEATURES OF RELUCTANCE GENERATORS

Widely now in use inductor generators differs that, as the excitation winding and armature winding at them are located on stator. A tooth rotor without windings and each tooth determining a pair of poles. Teeth are more complex and also their design features are widely known [1, 2].

So, for example, inductor generators can be with axial excitation then the design essentially becomes complicated, because it is necessary to use two or more packages with annular coils between them. Advantage of such design is that with one coil possible to provide all necessary amount of excitation. In this design are reduced losses to a winding of excitation. However thus the massive enclosure and the insert is necessary that passed an axial magnetic flux, that essentially increases weight of the machine [1]. Are known also heteropolar inductor generators at which the massive enclosures and the inserts are not necessary, but it is necessary to increase number of windings of excitation that increases power losses and weight of copper.

The peculiarity of the proposed design in figure 1 is the identical arrangement of opposite pole horns with respect to the rotor's teeth. Here the neighboring pole horns are mutually shifted in phase by a half of the rotor's tooth division (180 electrical degrees). Coils 6 arranged on the pole horns are connected into a bridge, to one of the diagonals of which a d.c. biasing source is connected, while to the other – through capacitor 7 – the load resistance.

For development of a direct current biasing (excitation) in stator slot the additional low-power winding 8 is laid, which each coil consist of several turns. The voltage from this winding is set on the bridge-connected rectifier 9 and further in a contour of excitation of the generator, connected of turns of an armature winding.

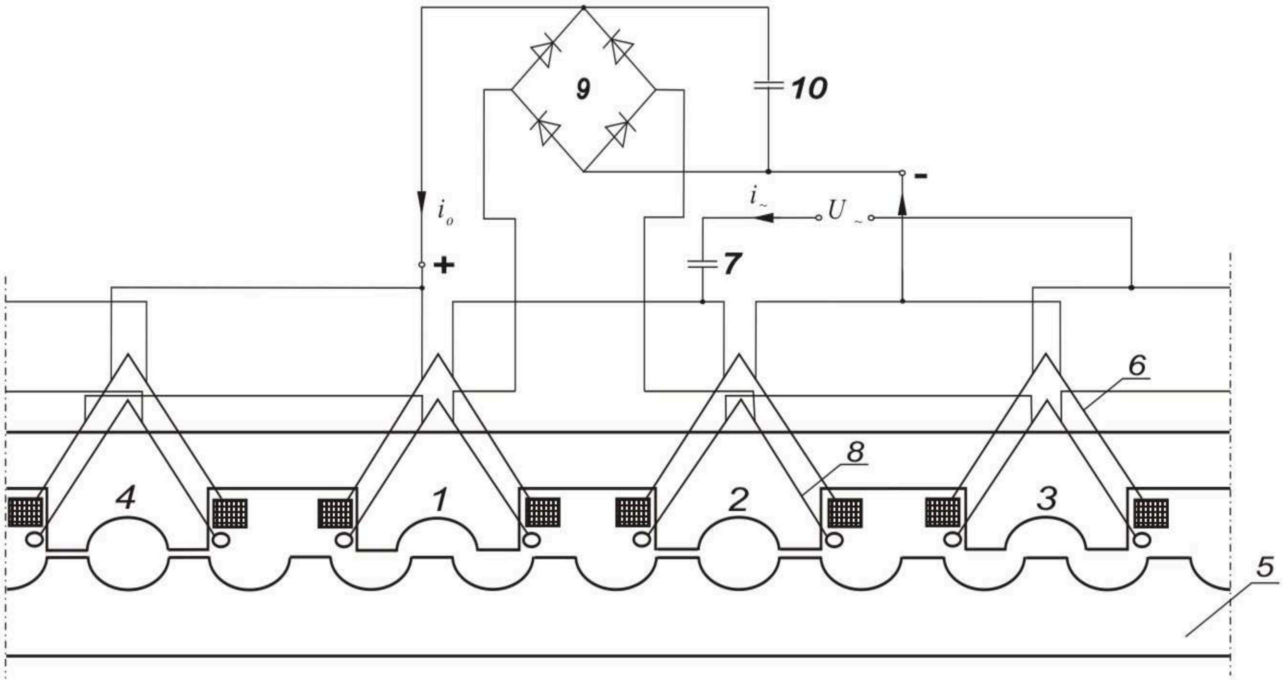

Fig. 1. Schematic design of a reluctance generator with biasing: 1-4 – pole horns; 5 – tooth rotor; 6 – armature coils; 7, 10 – capacitors; 8 – biasing coils; 9 - bridge-connected rectifier

The presented design is described by the equation

$$-u = i_\sim R_a + u_C + 2\frac{d\psi_k}{dt}, \qquad (1)$$

where u is the voltage across the load;
$i_\sim$ is the alternating current of the load;
u_C is the voltage across the compensating capacitor;
$2\psi_k$ is the magnetic-flux linkage of two series-connected coils.

The value of the magnetic-flux linkage of two series-connected coils in the a.c. branch is:

$$\begin{aligned} 2\psi_k &= W_k(\Phi_1 + \Phi_2) = W_k(F_1\lambda_1 + F_2\lambda_2) = \\ &= W_k^2[0,5(i_\sim - i_o)\lambda_1 + 0,5(i_\sim + i_o)\lambda_2] = \\ &= 0,5W_k^2(2a_o i_\sim + 2i_o a_1 \cos(Z_R\Omega)) = \\ &= W_k^2 a_o i_\sim + W_k^2 i_o a_1 \cos(Z_R\Omega). \end{aligned} \qquad (2)$$

The first term of expression (2) further determines the voltage fall across the inductive resistance of armature reaction due to the invariable component of the permeance of the stator's pole horn. The second term determines the EMF caused by the variable component of the permeance of the stator's pole horn.

In this case the capacitor capacity is chosen in a manner allowing the mentioned voltage fall across the armature reactance to be compensated. Then, in a complex form of notation, equation (1) is presented as

$$\dot{U} = 2\dot{E}_o - \dot{I}_\sim R_a, \qquad (3)$$

where $2E_o = W_k^2 a_1 I_o$ are the EMFs of two series-connected coils due to the variable permeance component (a_1) of the pole horn excited by direct current equal to $0.5I_o$.

Let's remind that the specific electromagnetic torque is very important parameter for low-speed generators, and it at reluctance machines has appeared essentially higher. Other important parameters are losses in copper (a winding of an armature and excitation) and efficiency.

Let's assume, that excitation windings of inductor generator are led to a winding of an armature, i.e. at $I_o^` = I_a$ takes place $R_o^` = R_a$. Then losses in copper of a winding of excitation and a phase of an armature will be

$$P_{CU} = I_o^{`2} R_o + I_a^2 R_a = 2R_a I_a^2. \qquad (4)$$

In reluctance generator the winding of excitation is combined with an armature winding, then

$$P_{CU} = R_a(\sqrt{I_o^2 + I_a^2})^2 = 2R_a I_a^2, \qquad (5)$$

If $I_o = I_a$, than

$$I_{ef} = \sqrt{I_o^2 + I_a^2} = \sqrt{2}I_a. \qquad (6)$$

Thereby, losses appear identical, but thus one winding (excitation) is excluded.

Reduction, practically twice, volume of spent copper takes place. And if to double, due to reduction of a winding of an armature losses in copper of reluctance generator will be reduced twice in comparison with inductor machine. And this leads to increase efficiency and reliability, not speaking about reduction in price of manufacture of such electric motors.

The aforesaid that reluctance generators are more simply, as they haven't a special winding of excitation, its role is carried out with an armature winding. Therefore we shall consider features of their design in more detail as these generators are poorly shined in the scientific and technical literature and are insufficiently deeply studied.

In figure 2 electric diagrams of the inductance and reluctance generators of single-phase and three-phase execution are presented.

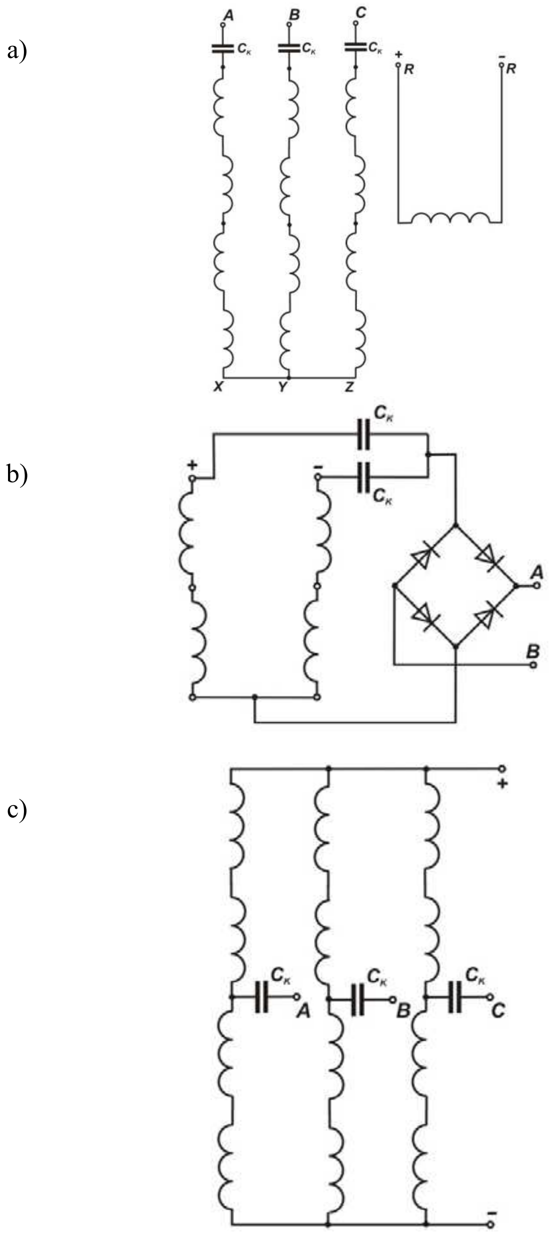

Fig. 2. Terminal connection schemas (1-12) for research of different type of generators: a) inductor; b) one-phase reluctance; 3) three-phase reluctance; "+", "–" – biasing DC terminals; A, B, *C* – output terminals; C_k – compensating capacitor

Below results of their experimental researches are presented.

III. RESULTS OF EXPERIMENTAL RESEARCHES

Figure 3 shows an experimental model of the axial inductor generator with two cores and annular excitation winding. Each core contained 12 pole horns, and on the rotor 46 teeth were arranged.

The tests were carried out at the rotational speed $n = 700$ min^{-1}.

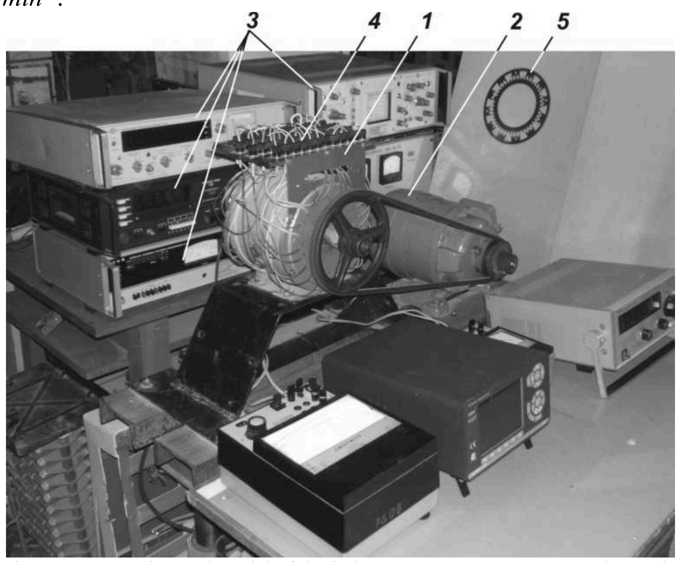

Fig. 3. An experimental model of the inductance generator. For experimental researches of reluctance machine only one core of inductance generator was used: 1 – generator; 2 – motor drive; 3 – measuring equipment; 4 – switching board; 5 – plates of stator and rotor

Table 1 shows the testing and calculated results for inductor and reluctance generators.

TABLE I

No	Parameter	Inductor		One-phase reluctance		Three-phase reluctance	
		Testing results	Calculate results	Testing results	Calculate results	Testing results	Calculate results
1	Number of turns in coil	160	160	160	160	160	160
2	Rotating speed, min^{-1}	700	700	700	700	700	700
3	Phase voltage, *V*	92	90	36	36	36	36
4	Phase current, *A*	1.3	1.35	3.7	3.8	3.7	3.8
5	Output power, *W*	330	333	103	102	309	310
6	Biasing power, *W*	30	32	30	33	90	100
7	Mass of the machine generating part, *kg*	11.5	10.5	2.8	2.7	8.5	8.0
8	Specific power, *W/kg*	28.7	31.7	36.8	37.8	36.4	38.8
9	Compensation capacity, μF	1.0	1.1	4.0	4.4	4.0	4.4

From table 1 follows, that reluctance generator has essential technical and economic advantages, smaller dimensions and weight, higher efficiency.

Fundamental parameters of comparative analysis for inductor and reluctance generators are a specific electromagnetic torque, losses of energy (efficiency), costs of manufacturing and reliability. At tests of the experimental model presented in figure 4 the specific electromagnetic torque for inductor and reluctance generators was fixed accordingly to adjusted rated currents. Acquired torque appeared the following: for inductor generator – 0.45 N·m/kg; for reluctance – 0.63 N·m/kg.

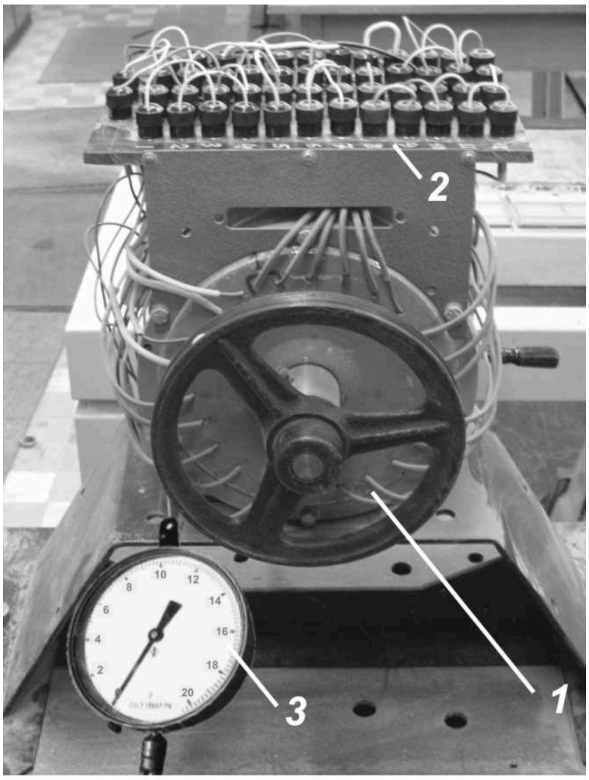

Fig. 4. An experimental model of the generator: 1 – generator; 2 - switching board; 3 – dynamometer

IV. CONCLUSION

The results of tests carried out in order to check the serviceability and performance of the wind generator for low-power WPPs based on the reluctance electric machine have shown that the proposed version possesses simpler design, higher reliability and lower cost of production; operational expenses are also reduced. This is achieved owing to the absence of windings and magnets on the running rotor, exclusion of a heavy ferromagnetic body and of a bush, a smaller number of windings and the possibility to make rotors with a large number of teeth, each tooth determining a pair of poles. All this has resulted in its multipolarity, low rotational speed, and, therefore, the possibility of its tie-in with the wind turbine without using a multiplier.

A reluctance generator, along with much simpler design, its higher reliability and being easier repairable at the same time, possesses mass-size indices that are by far better than those of the inductor machine.

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