ONE-PHASE REACTIVE GENERATOR WITH ANNULAR WINDINGS

VIENFĀZES REAKTĪVAIS ĢENERATORS AR GREDZENVEIDA TINUMIEM

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Introduction

Synchronous generators with permanent magnets are not always suitable for using in wind installations. The asynchronous machines possess a limited number of pole pairs, and, therefore, are not to be used in directly-driven wind plants [1-3]. As concerns inductor generators – they turn out to be heavy and not reliable enough.
However, if we remove the excitation winding in inductor generator we will obtain a reactive generator. In such a generator the armature winding is simultaneously an excitation winding. This version possesses the many advantages [4-7].

The design of reactive generator with annular armature winding

The reactive generator (Fig. 1) comprises a three-core stator, the outer cores of which 1, 2 are tooth-like, while the central one 3 with a smooth surface. The central core 4 of the rotor is also with smooth surface. The outer rotor cores 5, 6 are tooth-like, their teeth facing the tooth-like surfaces of the stator cores 1, 2.
The teeth on the stator and rotor cores are spaced evenly, with the tooth pitches being equal. Therewith, if the teeth of one of the stator cores are arranged opposite the teeth of the corresponding rotor core, then the teeth of the second stator core are facing the inter-tooth spaces of the other rotor core.
Between stator cores 1-3 four annular coils 7-10 of the armature winding are symmetrically arranged, which are connected into a bridge. The stator cores are pressed into an aluminium alloy body 11 having longitudinal laminated inserts 12 allowing the magnetic flow to pass from one core to another. Cylindrical body 13 for the rotor is also cast of aluminium alloy, with similar longitudinal laminated inserts 14 for the passage of magnetic flow. The rotor is pressed on shaft 15, while on its outer surface tooth-like 5, 6 and smooth cores 4 are arranged. The stator cores built-up of the electro-technical steel laminations are separated from the rotor cores by air gaps.
The bridge-connected annular coils 7-10 form two diagonals. One of them through compensating capacitors C_K is connected to the exit terminals of the generator, and the other - to a d.c. source («+», «-»). As the d.c. source there can be employed a low-voltage accumulator or a rectifying-transforming unit with its port coupled to the exit terminals of the generator.

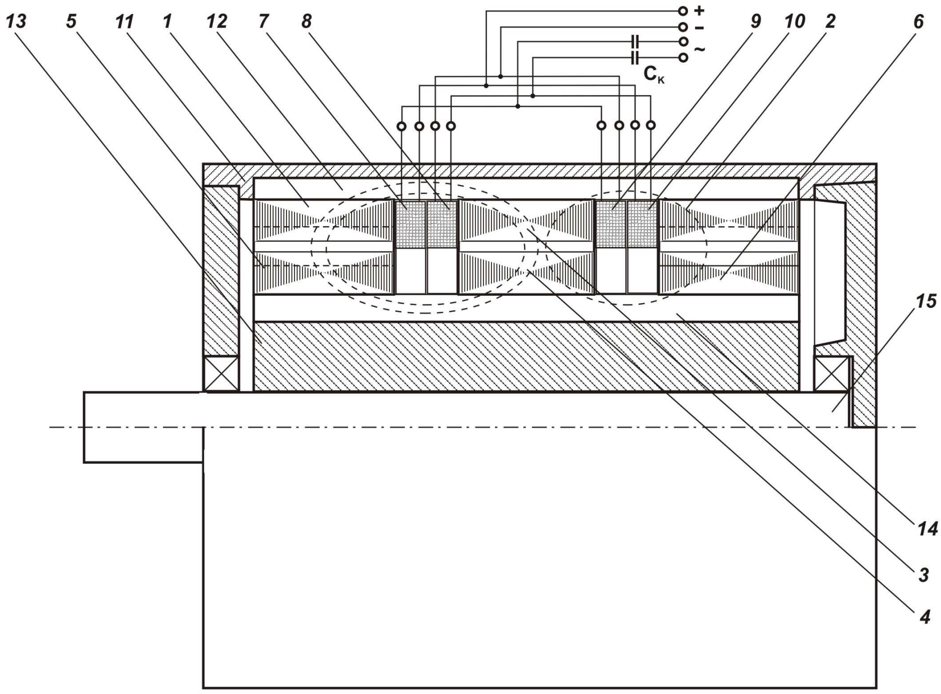

Fig. 1. The design of reactive generator: 1-6 – laminated stator and rotor packets; 7-10 – rotor coils; 11, 13 – aluminium alloy body of stator and rotor; 12, 14 – laminated inserts in enclosures of stator and rotor; 15 – shaft; C_K – compensating capacitors

The generator operates as follows. When the rotor is running, the flow of remanence magnetism of the stator tooth-like cores begins to change, with closing through the central core. The maximum flow arises in a core whose teeth coincide with the teeth of the rotor core, and vice versa (see dotted lines). In the annular coils of the armature winding an *emf* is induced. The voltage appearing on the exit terminals of the generator is fed, through the rectifying unit, to the second diagonal of the bridge. The magnetic flow in the stator and rotor cores grow, which is followed by self-excitation and the generator has reached the operating condition. The capacitors C_K owing to the resonance phenomena accelerate the self-excitation process and increase the output voltage. Under such conditions the C_K capacity is determined by the relationship

$$C_K = \frac{1}{2\pi^2 f^2 L_K},$$

where L_K is the inductance of the armature winding coil; $f = \frac{Z_R n}{60}$ is the frequency of the generator current, with Z_R being the tooth number of the stator core and n - the rotational speed of the rotor, $\min^{-1}$.

Optimal teeth zone of one-phase reactive generator

The presented design is described by the equation

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

where u is the voltage across the load; $i_{\sim}$ is the alternating current of the load; R_K is the active resistance of armature coils; $2\psi_K$ is the magnetic-flux linkage of two series-connected coils; u_C is the voltage across the compensating capacitor.

The value of magnetic-flux linkage of two series-connected coils 7, 10 in the a.c. branch (Fig. 1) is

$$2\psi_K = W_K(\Phi_7 + \Phi_{10}) = W_K^2 a_o i_{\sim} + W_K^2 i_o a_1 \cos(Z_R \Omega), \tag{2}$$

where a_o, a_1 are two first terms of Fourier's series representing a variable magnetic permeance of the air gaps between the stator's and the running rotor's teeth. The remaining terms of the series are small and can be neglected. i_o - magnetization current; Ω – angular velocity of the rotor.

The electro-magnetic power of the one-phase generator is determined by the expression:

$$P_E = EI = K_I E I_K, \tag{3}$$

where E is the electro-motive force; $I = K_I I_K$ is the load current expressed through the short-circuit current.

In turn, the *emf* of two series-connected coils is expressed as

$$E = 4{,}44 f W_K(\Phi_{\max} - \Phi_{\min}), \tag{4}$$

where $\Phi_{\max}, \Phi_{\min}$ are the maximum and minimum magnetic fluxes of the stator core at its teeth position being opposite to the rotor teeth or its inter-tooth spaces. The short-circuit current can be found from the relation:

$$I_K = \frac{E}{X_S}, \tag{5}$$

where $X_S = 2\pi f \dfrac{\Phi_{\max} + \Phi_{\min}}{F} W_K^2$ is the synchronous resistance determined taking into account the series-parallel connection of the coils and the magnetomotive force (*mmf*) *F*, acting in the magnetic flow circuit.

Equation (3), with account of (4, 5), is transformed to the following:

$$P_E = K_I \frac{E^2}{X_S} = K_I \pi F f \frac{(\Phi_{\max} - \Phi_{\min})^2}{\Phi_{\max} + \Phi_{\min}} \tag{6}$$

or, taking into consideration that $f = \dfrac{Z_R n}{60}$ and the rotational speed *n* is a parameter not influencing the optimal geometry of the tooth zone of an electric machine, the objective function *C* to the following

$$C = F Z_R \frac{(\Phi_{\max} - \Phi_{\min})^2}{\Phi_{\max} + \Phi_{\min}}. \tag{7}$$

The presented objective function was employed for determination of the optimal geometry of the generator's tooth zone. In so doing, the magnetic fluxes were computed using the final element method (FEM) [13]. Fig. 2 shows the results of such computations for a 5 kW generator with the rotational speed $n = 150\,\min^{-1}$, the stator bore diameter $D = 300\ mm$, the core length $l = 50\ mm$, the air gap $\delta = 0{,}8\ mm$, the slots being semi-circular, and with the optimal ratio of $\frac{b_z}{t_z} = \frac{1}{3}$ [8].

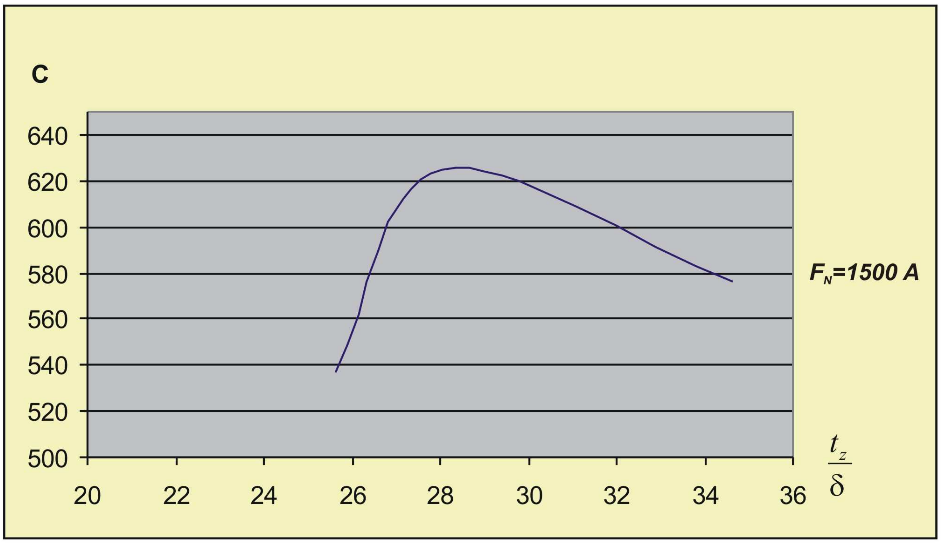

Fig. 2. Dependence of objective function from specific values of stator tooth pitch by *mmf* F=1500 A

As follows from Fig. 2, by the reasonable magnetization of stator core ($F = 1500\ A$) the optimal value of the relative magnitude of the tooth pitch is $t_z / \delta = 28.$.

Conclusions

The results of tests carried out in order to check the serviceability and performance of the wind generator for low-power wind plants based on the reactive 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. The optimal ratio of the $\frac{t_z}{\delta}$ for such generator is 28.

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Dirba J., Kamoliņš E., Levins N., Pugačevs V., Serebrjakovs A. Vienfāzes reaktīvais ģenerators ar gredzenveida tinumiem.
Tiek piedāvāts mazjaudas vējiekārtu vēja ģeneratorus izgatavot uz reaktīvo elektrisko mašīnu bāzes ar gredzenveida tinumiem. Turklāt būtiski tiek vienkāršota konstrukcija, paaugstināts tās drošums, samazinātas izgatavošanas un ekspluatācijas izmaksas. Tas iespējams tāpēc, ka uz rotējošā rotora nepastāv tinumi un magnēti, kā arī ir samazināts spoļu skaits un ir iespēja izgatavot rotoru ar lielu skaitu zobu, kur katrs zobs nosaka polu pāri. Tā rodas iespēja izgatavot daudzpolu elektrisko mašīnu un nodrošināt klusu darbību un arī iespēja sajūgt to ar vēja turbīnu, neizmantojot multiplikatorus.
Ģeneratora zobu zonas un polu pāru ģeometrijas optimālie pētniecības rezultāti tika iegūti, izmantojot ESM, balstoties uz aprēķinātajām magnētiskajām plūsmām, pielietojot galīgo elementu metodi. Reaktīvajam ģeneratoram, kura jauda tika izvēlēta 5 kW, griešanās ātrums n = 150 min^{-1}, statora paketes ārējais diametrs D = 300 mm, paketes garums l = 50 mm, gaisa sprauga δ = 0,8 mm, zoba platuma attiecība pret zoba soli $b_z / t_z = 1/3$ *un pie pusapaļas rievu formas, izrādījās, ka optimālā zoba soļa attiecība pret gaisa spraugu ir* $t_z / \delta = 28$. *Turklāt polu pāru skaits elektriskajai mašīnai ir* $p = Z_R = 42$.

Dirba J., Kamolins E., Levin N., Pugachev V., Serebryakov A., One-phase reactive generator with annular windings.
It is proposed to make wind generators for low-power wind plants based on the reactive electric machine with annular windings. In this case the design becomes essentially simpler, more reliable and cheap in making; the operational expenses are also less. All this is achieved owing to the absence of windings and magnets on the running rotor, a smaller number of windings and the possibility to make the rotor with a greater tooth number, with each tooth relating to one pole pair. This determines its multipolarity and possibility to be tied-in with the wind turbine without using a multiplier.
Determination of the optimal geometry of the generator's tooth zone and the number of pole pairs was made based on the computation of magnetic fluxes using the final element method (FEM). The computation for a 5 kW reactive generator with the rotation speed n = 150 min^{-1}, the stator bore diameter $D = 300\ mm$, *the core length* $l = 50\ mm$, *the air gap* $\delta = 0{,}8\ mm$, *and the semi-circular slots has given the optimal ratio of tooth*

width to tooth step $b_z / t_z = 1/3$. *The optimal* t_z / δ *ratio for such a generator was found to be 28, with the number of pole pairs* $p = Z_R = 42$.

Дирба Я., Камолиньш Э., Левин Н., Пугачев В., Серебряков А., Однофазный реактивный генератор с кольцевыми обмотками.

Предлагается ветрогенераторы малой мощности выполнять на базе реактивной электрической машины с кольцевыми обмотками. При этом существенно упрощается конструкция, повышается её надежность, удешевляется изготовление, снижаются эксплуатационные расходы. Обусловлено это отсутствием обмоток и магнитов на вращающемся роторе, сокращением общего числа обмоток и возможностью изготовления ротора с большим числом зубцов, где каждый зубец определяет пару полюсов. Отсюда многополюсность и возможность сопряжения с ветротурбиной без использования мультипликатора.

Опытное определение оптимальной геометрии зубцовой зоны генератора и числа пар полюсов было осуществлено на основе расчета магнитных потоков на ЭВМ с использованием метода конечных элементов (МКЭ). Для 5 kW генератора с частотой вращения $n = 150$ min^{-1}, *диаметром расточки статора* $D = 300$ *mm, длиной пакетов* $l = 50$ *mm, воздушным зазором* $\delta = 0{,}8$ *mm, отношением* $b_z / t_z = 1/3$ *и при полукруглой форме пазов оказалось, что оптимальное значение* $t_z / \delta = 28$. *При этом число пар полюсов электрической машины* $p = Z_R = 42$.