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V. V. CHUMACK, M. A. KOVALENKO, I. V. TKACHUK, I. Y. KOVALENKO

COMPARISON OF SYNCHRONOUS GENERATORS FOR AUTONOMOUS GASOLINE INSTALLATION SYSTEM

There are many power plants like thermal, solar, hydro, nuclear etc. but there are some disadvantage of it like CO2 emission pollution, problem of global warming requirement of fuels cost etc. To avoid such factors we developed system is biomass power plant to meet the demands of electricity and environment concern day by day price of fuels that fact to which motivate to use renewable energy. Biomass is renewable in nature, carbon neutral and has the potential to provide large productive employment in rural areas. It is considered as one of the promising sources for generation of power / energy using commercially available thermal and biological conversion technologies. The fossil fuels are depleting very fast, it is very important to replace fossil fuels with best alternative fuel modes which will be available for requirement in abundance at the same time if it is ready at one's disposal is a eminent balance to the environment. The sanctification for this need is the bio mass power plant; on finding the major advantage of bio mass power plant is the fuel which is agricultural waste (rice husk, wood, etc.) segregation available in unnumbered tons around the world. It is very important to utilize this in the context of energy. It is also found that the sulphur content in the biomass is very less when compared with coal. The wood fuels contains very little ash (-1% or less), so increasing the ratio of wood in biomass coal blends can reduce the amount of ash that must be disposed. In biomass power plants, wood waste or other waste is burned to produce steam that runs a turbine to make electricity, or that provides heat to industries and homes. Fortunately, new technologies including pollution controls and combustion engineering have advanced to the point that any emissions from burning biomass in industrial facilities are generally less than emissions produced when using fossil fuels (coal, natural gas, oil), biomass is burned in a combustor or furnace to generate hot gas, which is fed into a boiler to generate steam, which is expanded through a steam turbine or steam engine to produce mechanical or electrical energy. In this paper were performed comparison of traditional synchronous generator with electromagnetic excitation and permanent magnet generator for autonomous gasoline installation system.

Keywords: synchronous generator, electromagnetic excitation, permanent magnet generator, gasoline installation.

В. В. ЧУМАК, М. А. КОВАЛЕНКО, І. В. ТКАЧУК, І. Я. КОВАЛЕНКО

ПОРІВНЯННЯ СИНХРОННИХ ГЕНЕРАТОРІВ ДЛЯ АВТОНОМНОЇ БЕНЗИНОВОЇ УСТАНОВКИ

Існує багато електростанцій, таких як теплові, сонячні, гідро-, атомні тощо, але вони мають певні недоліки, такі як забруднення викидами CO2, проблема глобального потепління, вартість палива тощо. Щоб уникнути таких факторів, розроблено систему, яка відповідає експлуатації автономних електростанцій на біомасі. Потреби в електроенергії та навколишньому середовищі стосуються щоденного зростання цін на паливо, що спонукає до використання відновлюваної енергії. Біомаса є відновлюваною за своєю природою, вуглецево-нейтральною та має потенціал для забезпечення великої продуктивної особливо в сільській місцевості. Вона розглядається як одне з перспективних джерел генерації електроенергії/енергії з використанням комерційно доступних технологій термічного та біологічного перетворення. Викопне паливо виснажується дуже швидко, тому дуже важливо замінити викопне паливо найкращими альтернативними видами палива, які будуть доступні для потреб у великій кількості одночасно, якщо вони будуть наявні у розпорядженні – це сприяє позитивному балансу для навколишнього середовища. Основна перевага електростанції на біомасі є паливо, яке утворюється в результаті сільськогосподарської діяльності – відходи (рисове лушпиння, деревина тощо), яке доступне незліченними кількостями по всьому світу. Дуже важливо використовувати це для перетворення такої енергії в електричну, враховуючи контекст ситуації в країні. Також виявлено, що вміст сірки в біомасі набагато менший порівняно з вугіллям. Деревне паливо містить дуже мало золи (-1% або менше), тому збільшення частки деревини в сумішах вугілля з біомаси може зменшити кількість золи, яку потрібно утилізувати. На електростанціях, що працюють на біомасі, відходи деревини або інші відходи спалюються для виробництва пари, яка запускає турбіни для виробництва електроенергії, або забезпечує тепло для промисловості та будинків. Нові технології, включаючи контроль забруднення та інженерію спалювання, просунулися настільки, що будь-які викиди від спалювання біомаси на промислових підприємствах, як правило, менші, ніж викиди, створені при використанні викопного палива (вугілля, природного газу, нафти), біомаса спалюється в камері згоряння або печі для отримання гарячого газу, який подається в котел для отримання пари, яка розширюється через парову турбіну або паровий двигун для виробництва механічної або електричної енергії. У цій роботі проведено порівняння традиційного синхронного генератора з електромагнітним збудженням і генератора з постійними магнітами для автономної бензинової установки.

Ключові слова: синхронний генератор, електромагнітне збудження, генератор з постійними магнітами, бензинова установка.

Introduction. Generating power through the use of biomass represents the cost-effective and cleanest way to provide renewable electricity in biomass potential regions with high levels of biomass resources and its processing activity. Furthermore, use of this resource helps become more energy independent and use of a locally derived fuel provides employment and direct economic benefit to local communities.

Biomass is used for facility heating, electric power generation, and combined heat and power. The term biomass encompasses a large variety of materials, including wood from various sources, agricultural residues, and animal and human waste.

Biomass can be converted into electric power through several methods. The most common is direct combustion of biomass material, such as agricultural waste or woody materials. Other options include gasification, pyrolysis, and anaerobic digestion. Gasification produces a synthesis gas with usable energy content by heating the biomass with less oxygen than needed for complete combustion. Pyrolysis yields bio-oil by rapidly heating the biomass in the absence of oxygen. Anaerobic digestion produces a renewable natural gas when organic matter is decomposed by bacteria in the absence of oxygen.

Direct combustion systems feed a biomass feedstock into a combustor or furnace, where the biomass is burned with excess air to heat water in a boiler to create steam. Instead of direct combustion, some developing technologies gasify the biomass to produce a combustible gas, and others produce pyrolysis oils that can be used to replace liquid fuels. Boiler fuel can include wood chips, pellets, sawdust, or bio-oil. Steam from the boiler is then expanded through a steam turbine, which spins to run a generator and produce electricity.

The biggest problems with biomass-fired plants are in handling and pre-processing the fuel. This is the case with both small grate-fired plants and large suspension-fired plants. Drying the biomass before combusting or gasifying it improves the overall process efficiency, but may not be economically viable in many cases.

The relevance of the work lies in the evaluation of the effectiveness of replacing a traditional synchronous generator with electromagnetic excitation by a generator with permanent magnets, which is used in an autonomous gasoline installation.

The peculiarity of the comparison is that the geometric dimensions of the studied generator remain unchanged.

Replacements concern only the rotor of the generator under study - instead of the excitation winding, a rotor with permanent magnets is mounted.

Such a technical solution will improve the reliability of the autonomous installation, reduce losses and increase efficiency.

The purpose of the work is the development of two-dimensional field mathematical models of a synchronous generator with electromagnetic excitation and a generator with permanent magnets. This will make it possible to evaluate the use of a synchronous generator with permanent magnets as part of an autonomous gasoline installation powered by biofuel.

To estimate the increase in the output parameters of synchronous generators when the load changes, it is necessary to develop a numerical simulation mathematical model that takes into account the change in the output parameters of the generator when the load changes and vice versa, a system in which a change in the output state of the generator leads to a change in the parameters of the drive motor.

Mathematical model. In this work a two-dimensional and graphic models was developed of the designed generator in two-dimensional system automated design and drawing of AutoCAD. Three-dimensional graphic the model is a three-dimensional digital image of the required object, non-negative part of the technical documentation, as well as the basis for creating a prototype object.

A two-dimensional mathematical field model of the generator was also developed. Creating a two-dimensional graphical model is necessary for the future mathematical modeling of the designed generator in COMSOL Multiphysics software package.

On the fig. 1 shown traditional synchronous generator construction with electromagnetic excitation, which is basic for permanent magnet generator construction.

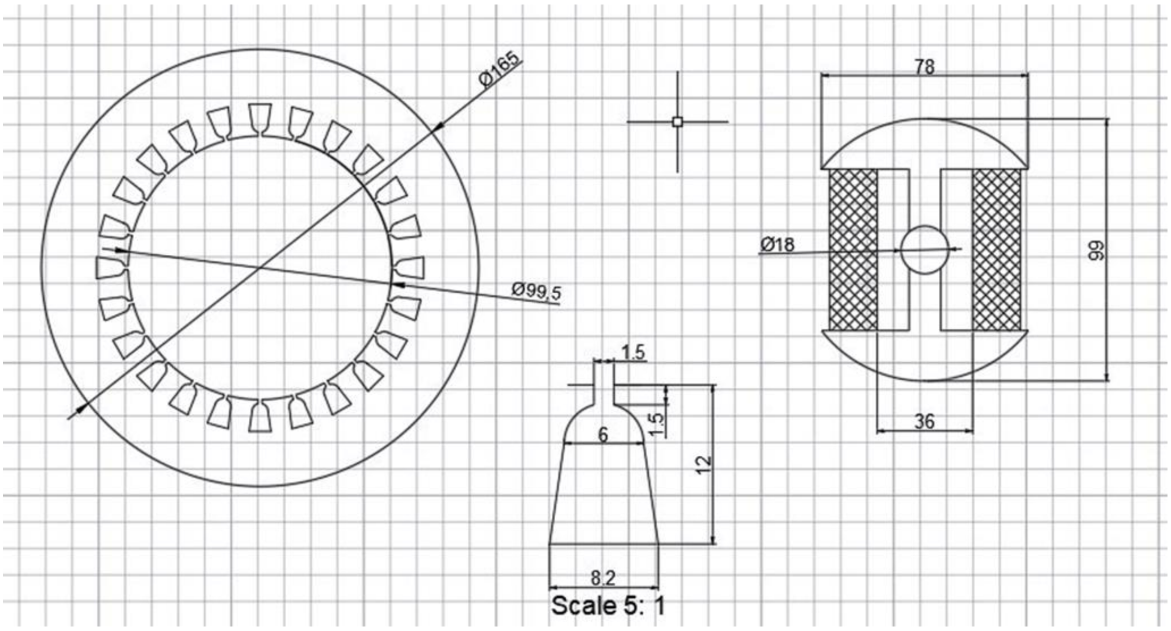


Fig. 1. Traditional generator construction 2-dimensional model prototype

In the drawing, the middle line of the air gap was additionally constructed for further calculation of the moment and the grooves of the stator were made closed to make a limited area for marking the phase of the motor in it. The dimensions for the construction of the engine drawing.

It is important when building a model is the coincidence of different types of lines. This should be achieved by using bindings to characteristic points of lines, such as endpoint, middle, quadrant, tangent, and the use of parameterization – parallelism, perpendicularity, coincidence, and so on. When creating an array of elements, it is necessary to avoid approximate size values, instead use integrated computational tools or other construction methods.

The construction of geometry is carried out in stages according to the obtained geometric dimensions shown in Table 1.

Table 1 – The main parameters and initial data used for modeling the generator are given in table

Number of slots	24
Axial generator length	102 mm
Number of poles	2
Number of turns	141
Inner rotor diameter	99 mm
Number of magnets	2
Generator type:	Synchronous with PM;
Number of phases:	3
Supply voltage:	220 V
Winding resistance:	1,34 Om
Current consumed:	3,86 A
Type of magnets	N50 NdFeBr

The two-dimensional circle-field mathematical model of aA permanent magnet synchronous generator (PMSG) is considered in the work. The expediency of developing a circuit-field model is that the electrical and electromagnetic phenomena in this type of motor are interconnected, and the motor power supply is pulsed. The voltages of the motor windings are a function of time and change periodically according to a certain law. It is impossible to realize the relationship between electrical and magnetic phenomena using classical field calculation. This can only be implemented using a circle-field model.

This model is multiphysical, it takes into account the mutual influence of electrical parameters on the magnetic and vice versa. It is possible to implement such a model using the program for multiphysical calculations COMSOLMultiphysics.

The paper uses a built-in interface for modeling electric machines that support rotor rotation with a given frequency.

Equation of three-dimensional electromagnetic field, relative to the vector magnetic potential A [xx]:

$$\nabla x\left(\frac{\nabla xA-B_r}{\mu}\right)=J_e \tag{1}$$

where B_r is the final induction of the permanent magnet; J_e – current densities in the rotor winding; μ – magnetic permeability.

The differential equation in partial derivatives is formulated within the calculation area, which reflects the design of the generator. This area includes the structural elements of the generator.

The calculation area is limited by the outer boundaries of the creation model.

To obtain an unambiguous solution at the boundaries of the calculation area, the boundary conditions of the first kind are set:

$$A\ (x,y,t)|G1=0,\ \{x,y\}\ \epsilon G1, \tag{2}$$

this means accepting the assumption of the absence of magnetic fluxes passing through the selected boundary of the calculation area.

Periodicity conditions, which are set in cases when it is known in advance that the field distribution is periodically repeated along the selected direction in the calculation area.

The theoretical basis for mathematical modeling of electromagnetic fields is the field equations formed by Maxwell. Maxwell's equations establish the relationship between vector field functions, characteristics of field sources and physical parameters of material environments. In the modern form of writing, these equations are as follows:

$$\begin{aligned}
&rotH=J\\
&rotE=-\partial B/\partial t\\
&divB=0\\
&divD=\rho\\
&B=\mu H,D=\varepsilon E\\
&J=\gamma E+\partial D/\partial t+\gamma\left(v\times B\right)+\gamma E_e+\rho v_r+rot\left(D\times v\right)
\end{aligned} \tag{2}$$

In the given system the following are marked: field functions – vectors of intensity of magnetic H and electric E of fields, vector of magnetic induction B and vector of electric displacement D; coefficients that characterize the physical properties of material media – magnetic permeability μ, electrical conductivity γ, dielectric conductivity ε; density of electric charges ρ. Expression (2) allows to find the current density J, due to the sum of terms of different physical nature. The term γ·E causes the induced current density in the conductive medium; term (∂D)⁄∂t – dielectric displacement current density; the term γ(v×B) determines the "convective component" of the current density, which is due to the motion of the conductive medium with velocity v relative to the magnetic field with induction B. Appendix J_e=γ·E determines the current density, which is caused by third-party EMF; the term $\rho\cdot v_r$ characterizes the density of currents moving free charges, and the term rot(D×v) is the "convective component" of the current density, which is due to the motion of the polarized dielectric.

In the general case, any field function is a vector function, and each of its components depends on four independent variables – three spatial coordinates of a point and time.

When calculating the magnetic field used a nonstationary nonlinear differential equation for the vector magnetic potential (A) in a moving electrically conductive medium:

$$\vec{\nabla}\times\frac{1}{\mu}\left(\vec{\nabla}\times\vec{A}\right)-\gamma\frac{\partial A}{\partial t}+\gamma\vec{V}\times\left(\vec{\nabla}\times\vec{A}\right)=J_e \tag{3}$$

where: μ, σ –magnetic permeability and electrical conductivity; V ,J_e –vectors of medium velocity and external current density; ∇ is a differential Nabla operator.

To calculate the electromagnetic field in the quasi-static mode, equation (3) takes the following form:

$$\vec{\nabla}\times\frac{1}{\mu}\left(\vec{\nabla}\times\vec{A}\right)-\gamma j\omega+\gamma\vec{v}\times\left(\vec{\nabla}\times\vec{A}\right)=J_e \tag{4}$$

Equations that describe the materials used in the simulation:

For steel:

$$H=f\left(|B|\right)\frac{B}{\left(|B|\right)} \tag{5}$$

For permanent magnets:

$$B=\mu\cdot\mu_0\cdot H+B_r \tag{6}$$

For windings:

$$B=\mu_r\cdot\mu_0\cdot H \tag{7}$$

The magnetization curve was used to describe the dependence B=f(H) for steel. A typical steel from the internal COMSOL Multiphysics library for this type of generator is used.

The expansion of the scope of CAD/CAM/CAE systems has prompted the creation of software available to a qualified engineer on a personal computer. The rapid development of computer technology has led to the fact that now an engineer and a student are able to form for themselves a fairly powerful automated workplace designer.

This approach allows you to increase the productivity of the designer in comparison with the traditional design technology - drawing technology.

This is ensured by:

- reducing the number of design errors;
- reduction of design time;
- obtaining automated drawings on tested models of parts, assemblies, devices (verification is carried out in the mode of assembly of the assembly, device);
- rapid engineering analysis of the created structure.

Determination of the value of the induced EMF in the windings of the collectorless motor is as follows:

$$E_f = \frac{2 \cdot N_p \cdot L_1}{S_p \cdot a_1} \int_{S_i} E_z \cdot ds \tag{8}$$

Where S_i is the area of integration, N_p is the number of effective conductors in the slot, S_p is the area of the slot, a_1 is the number of parallel branches of the stator winding, L_1 is the axial length of the stator core.

In the most common areas of research, the above formulas can be used to calculate instantaneous values of force and torque. But it is often necessary to calculate the average value of these values during the cycle, or for example a pair of electromagnetic forces in another branch of physics. The average value of the cycle in the Maxwell stress tensor is calculated as:

$$M_{em} = \frac{2 \cdot p \cdot R_2 \cdot L_2}{\mu_0} \int_0^{\tau} B_n B_\tau dl \tag{9}$$

where B_n, B_τ – normal and tangential to the rotor surface components of magnetic induction; R_2, L_2 – radius and length of the rotor, p – the number of pole pairs; τ is the pole division of the rotor. The calculation of the field, EMF and electromagnetic moment is performed at each time step Δt. Combining the obtained solutions on the interval [0…T] gives the required time dependences E_f (t) and M_{em} (t).

The peculiarity of the integration of field and electric circuit models for calculating the magnetic field is that in contrast to the field model, where the current densities in the conductors are set, in the field-field model, the currents are determined on the basis of specified voltages and conductivities.

Mechanical dynamic equations of each generators describes by the following:

$$\begin{gathered} \frac{d}{dt}\omega_r = \frac{1}{J}\left(T_e - F\omega_r - T_m\right) \\ \frac{d\theta}{dt} = \omega_r \end{gathered} \tag{10}$$

Simulation results. In general, you need to check the model to make sure everything has a physical meaning. The model, which does not match most often, is simply installed in some non-physical versions. Finite elements mesh of studying permanent magnet synchronous generator shown on the fig. 2.

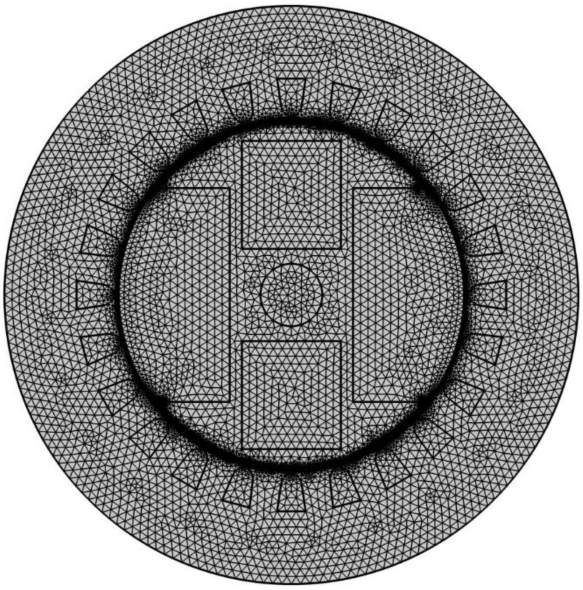


Fig. 2 Finite element mesh of simulation permanent magnet synchronous generator

Mesh of finite elements on the surface distribution of the electromagnetic field in the calculated volume of the permanent magnets.

Electromagnetic field and magnetic vector potential distribution of basic synchronous generator with electromagnetic excitation shown on fig. 3.

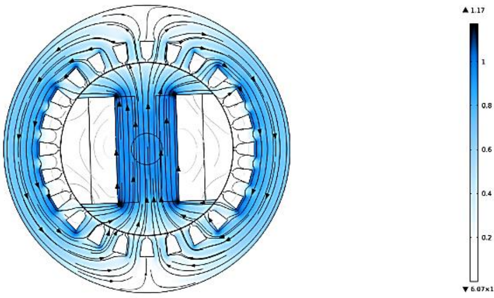
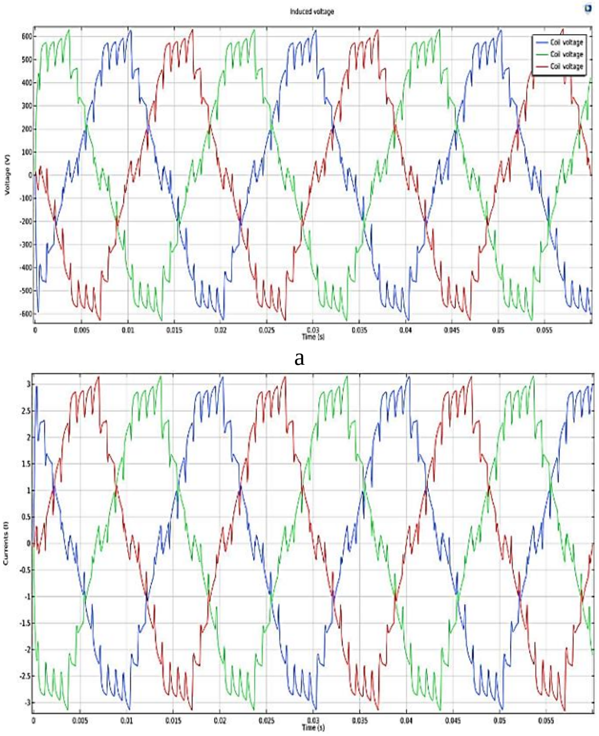


Fig. 3. The of the average value of magnetic induction and vector potential distribution

Distribution of magnetic flux in the calculation area with ferrite barium magnets. The maximum value of induction in acute zones reaches 1,17 T; in the teeth; in the air range from 0,4 to 0,7 T. The highest magnetic flux density is observed in the corners of the teeth and magnets - this is due to the influence of edge effects. According to the color, the residual induction in permanent magnets is 0,5 T and 0,7 T for the south and north poles, respectively.

Instantaneous value of induced voltage and current in stator winding of synchronous generator with electromagnetic excitation shown on fig. 4.



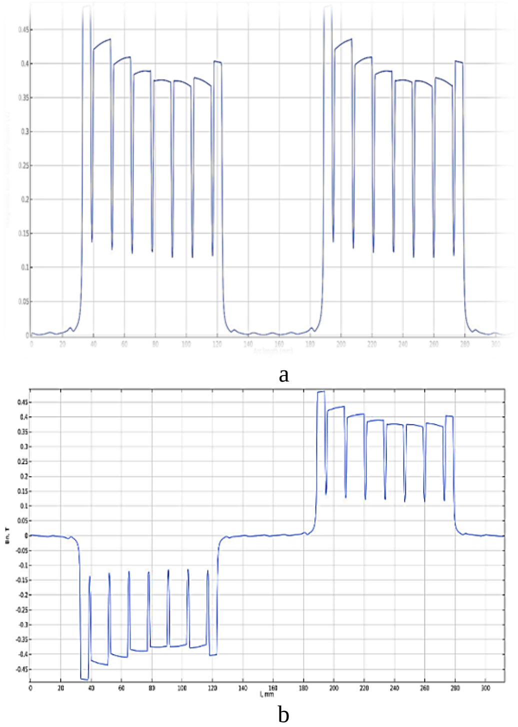
a

b

Fig. 4. Induced parameters in stator winding of synchronous generator with electromagnetic excitation:
a – induced voltage: b – induced current

Voltages and currents in the stator winding according to the fig.4, the phase amplitude voltage is 700 V; and the current is 3.5 A. Fluctuations in the current amplitude within ± 0.2 A due to the uneven air gap and the error of the solver.

The magnetic flux density in air gap, obtained in the process of mathematical simulation of the generator with electromagnetic excitation is shown on Fig. 5.



a

b

Fig. 5. Magnetic flux density in the air gap:
a – average value; b – normal part

Normal part of magnetic flux density responds for the induced electromotion force level.

Electromagnetic field and magnetic vector potential distribution of permanent magnet synchronous generator shown on fig. 6.

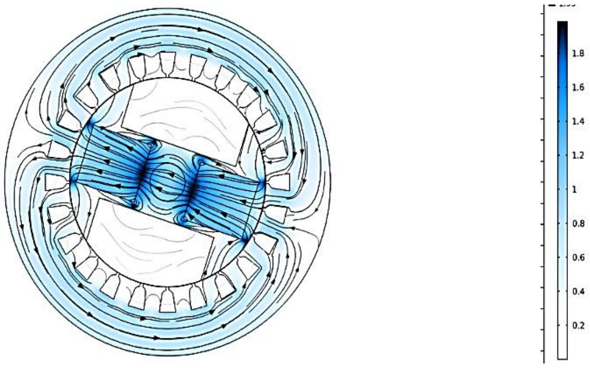
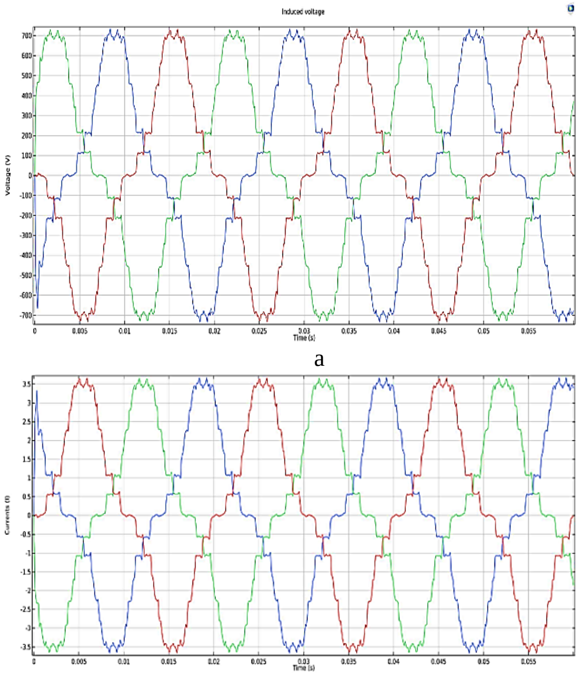


Fig. 6. Distribution of electromagnetic field and vector magnetic potential of permanent magnet synchronous generator

The maximum value of induction in acute areas reaches 1,99 T in the teeth; in the air gap from 0,4 to 1 T. The highest magnetic flux density is observed in the corners of the teeth and magnets – this is due to the influence of edge effects. It is also clear that at the moment two of the three phases of the motor are active, which confirms the theoretical calculations regarding the nature of the voltage coming from the semiconductor converter.

Instantaneous value of induced voltage and current in stator winding of permanent magnet synchronous generator shown on fig. 7.



a

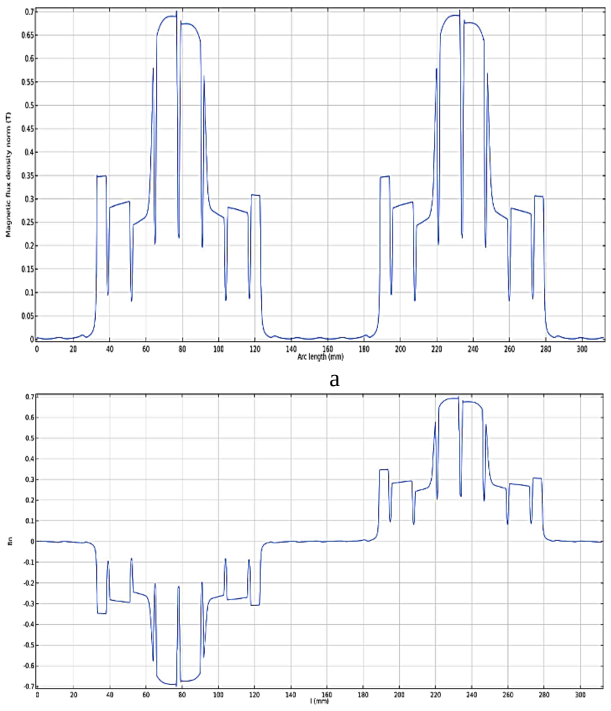
b

Fig. 7. Induced parameters in stator winding of permanent magnet synchronous generator:
a – induced voltage: b – induced current

Voltages and currents in the armature winding according to the fig.7: the phase voltage is 700 V; and the current is 3,5 A. Fluctuations in the current amplitude within

± 0,2 A due to the uneven air gap and the error of the solver.

The magnetic flux density in air gap, obtained in the process of mathematical simulation of the permanent magnet synchronous generator is shown on Fig. 8.



a

b

Fig. 8. Magnetic flux density in the air gap:
a – average value; b – normal part

The average value of magnetic induction in air gap is 0,1 T; minimum 0,35 T; maximum 0,68 T. According to the normal value of induction is 0,5 T; minimum 0,6 T; maximum 0,7 T; pulsations ± 0,1 T due to the uneven size of the air gap due to the use of flat magnets.

Comparison of obtained results of the traditional and permanent magnet synchronous generators are shown in Table 2.

Type of generator	PMSG	SG
Size	small	PMW converter big
Mode	High torque at low speed	Low torque
Current	3,5 A	3,2 A
Cost	less maintenance	High maintenance
Average magnetic flux density in air gap	0,223 T	0,218 T
Average magnetic flux density inthe teeth	1,44 T	1,37 T
Average magnetic flux density in yoke	0,78 T	0,71 T
Peck phase voltage value	≈600 V	≈700 V

Permanent magnet synchronous generators have some advantages comparison to the traditional synchronous generator construction.

Conclusions. The main advantages, as the obtain results show, of using permanent magnet synchronous generators are:

1. Absence of sliding contact (loss on contact, limited resource, can work in an aggressive environment (no oxidation)), increased reliability in humid tropics.

2. There is no traditional excitation system. The main field of excitation is created by permanent magnets. Stabilization of the mode can be provided by control capacitor systems, the specific cost of which is currently several times less than the specific cost of the machine.

3. Due to the absence of the need for the initial excitation current (no-load EMF is provided by the action of permanent magnets), the efficiency of the generator can be increased by 5-3%, depending on the power of the machine. The greatest gain is achieved in generators for individual or small group use with a capacity of up to 100 kW.

4. Material consumption and dimensions of the proposed machine can be significantly reduced in comparison with machines of traditional design. The specific consumption of materials, primarily electrical and structural steel and, to a lesser extent, winding copper can be reduced by 40-30%, depending on the generator power.

5. Reducing the volume of magnetic materials (electrical steel, winding copper) while maintaining electromagnetic loads, we reduce the amount of losses by 3-5%, depending on the generator power.

Disadvantages of using permanent magnet synchronous generators are:

1. Certain difficulties of the proposed design arise in organizing the cooling of the core, since the main solution for providing ventilation and cooling (in machines of limited power) is a longitudinal injection ventilation system, due to which ventilation losses can return up to 0.5% of the rated power of the machine.

2. The voltage stabilization system during autonomous operation or ensuring the specified voltage during parallel operation with the network requires the use of step capacitor compensation systems similar to those that are now widely used to ensure the constancy of the power factor of power consumers connected to power supply networks.

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Відомості про авторів / About the Authors

Чумак Вадим Володимирович (***Chumak Vadim Vladimirovich***) – кандидат технічних наук, доцент, Національний технічний університет України "Київський політехнічний інститут імені Ігоря Сікорського", доцент кафедри електромеханіки, тел.: (050) 208-38-43; ORCID: https://orcid.org/0000-0001-8401-7931; e-mail: chumack_kpi@ukr.net.

Коваленко Михайло Анатолійович (Kovalenko Mykhaylo) – кандидат технічних наук, доцент, Національний технічний університет України "Київський політехнічний інститут імені Ігоря Сікорського", доцент кафедри електромеханіки, тел.: (067) 656-36-51; ORCID: https://orcid.org/0000-0002-5602-2001; e-mail: kovalenko_ma@i.ua.

Ткачук Ігор Валерійович (Tkachuk Ihor) – аспірант кафедри електромеханіки, Національний технічний університет України "Київський політехнічний інститут імені Ігоря Сікорського", тел.: (097) 988-51-24; ORCID: https://orcid.org/0000-0002-5717-2458; e-mail: baja0073@gmail.com.

Коваленко Ірина Яківна (Kovalenko Iryna Yakivna) – асистент, Національний технічний університет України "Київський політехнічний інститут імені Ігоря Сікорського", аспірант кафедри нетрадиційних та відновлювальних джерел енергії, тел.: (097) 939-96-73; ORCID: https://orcid.org/0000-0003-1097-2041; e-mail: 2048141@ukr.net.