Low-speed generator with permanent magnets and additional windings in the rotor for small power wind plants and micro hydro power plants

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Abstract. Recently due to the worldwide population grows much attention has been paid to increasing total electricity generation. However, traditional power plants, which are used hydrocarbon fuels, cause one of the challenging problems like environmental contamination and global warming in the world. In this case, renewable or alternative energy sources can be a promising replacement for traditional hydrocarbon fuels. Uzbekistan has lots of small rivers and water reservoirs and the use of these potentials in the perspective to generate power it is a unique decision of the problem. Usually in small power plants use low-speed generators and efficiency of these type generators are very low. Hence, the main objective of this study is to increase the efficiency of the low power generator by improving and optimizing the specifications and parameters of the low power generators. The use of low-speed generators with permanent magnet excitation for micro-hydroelectric power plants and wind turbines is relevant in terms of providing good weight and size indicators, simplicity of construction, lack of sliding contacts, with the ability to perform a generator of low rotation speeds, which causes low cost and high reliability. In this study, the natures of the influence of the main geometric dimensions of the mass-dimensional parameters and the air gap on the energy indicators of the generator are estimated. Theoretical and experimental research results are submitted.

1. Introduction
Nowadays power resources are becoming scarcer as people exploit these vital resources aggressively. Global power demand grows by 62% between now and 2050, or by 1.5% per year. Renewable and alternative energy sources can be a promising replacement for traditional hydrocarbon fuels. More than two-thirds of the global population today live in countries where solar or wind, if not both, are the cheapest source of new electricity generation. Just five years ago, coal and gas dominated that picture. By 2030, new wind and solar ultimately get cheaper than running existing coal or gas plants almost everywhere. In China, this second “tipping point” occurs for coal in around 2027. The energy obtained from alternative energy sources can be used for both permanent power supply and backup power supply [1].

Renewable energy is the energy received as a result of natural processes, which are replenished faster than they are consumed. Common sources of renewable energy include solar, wind, geothermal, and some types of biomass.
More than 80% of global energy consumption is fossil resources, which are depleted faster than they can be recovered. Due to growing concerns about carbon emissions and uncertainty in fossil fuel supplies, interest in clean and renewable energy is constantly growing [2].

The research object in this study is the use of low-speed generators with permanent magnet excitation for micro-hydroelectric power plants and wind turbines.

The objective of the research is the development of low-speed generator with permanent magnet excitation for micro-hydroelectric power plants and wind turbines with improved specifications as providing good weight and size indicators, design simplicity, lack of sliding contacts, with the ability to perform a generator of low rotation speed, which causes low cost and high reliability.

2. Materials and methods

In recently in the power engineering sector of the industry in Uzbekistan has growing interest in developing synchronous generators with permanent magnets. Some parameters of the synchronous generators such as mass and size of the generator with permanent magnets are determined by its main dimensions. In this study, the nature of the influence of the main geometric dimensions of the mass-dimensional parameters and the air gap on the energy indicators of the generator is estimated. The installation of additional cross windings ensures the efficiency of the proposed low-speed electric generator with permanent magnets.

Because in the research the magnetic field of a low-speed generator with permanent magnets and additional windings in the rotor for low-power wind turbines and micro hydroelectric power plants using the method of finite element analysis are studied.

3. Results

It should be noted that each machine topology has its strengths and weaknesses. Topologies without stator cores are used for small and medium power generators and they have advantages such as no gear torque, linear torque characteristics, high power density and compact design [3, 4, 5, 6].

Due to the lack of losses in the stator core, generators of this type can operate with higher efficiency than conventional generators.

A low-speed electric generator with a permanent magnet requires an axial magnetic flux. If the thickness of the dummy air gap is too large (this usually means a large stator thickness), the path of the magnetic flux will pass through the neighboring magnet, rather than the opposite one [7, 8, 9, 10, 11]. Consequently, a very small portion of the magnetic flux will pass in the axial direction (a large leakage flow), and the machine will generate less torque and electromotive force (EMF) [12].

![Figure 1. Rotor: 1 is rotor disk, 2 is permanent magnet, 3 is additional transverse windings, 4 is battery](image-url)
A low-speed permanent magnet electric generator contains a rotor (Figure 1.) in the form of two flat disks, a stator (Figure 2.) is placed between the rotor disks and is made in the form of a disk connected to a fixed case, the anchor winding is located on the disk along the radii - reel magnets with alternating poles and additional transverse windings mounted on the side parts of the rotor in an amount of 36 to 360 on each disk [13].

The goal is to improve the efficiency of the generator. The technical result is an increase in power, an increase in EMF, a decrease in rpm and rated speed, and a decrease in electromagnetic torque [14].

The graphs in figures 4-7 represent the calculated characteristics of the output parameters.
Figure 4. Graphs of the load current change from the rotation speed of the generator armature, where 1 is the load current generated by the generator with permanent magnets and additional transverse windings in the rotor, 2 is the load current generated by the generator without structure.

Figure 5. Graphs of changes in the EMF of idling and voltage at the generator output depending on the armature rotation speed: 1,2-EMF of idling and voltage at the output of a synchronous generator with permanent magnets and additional transverse windings in the rotor; 3,4-EMF of idling and voltage of the synchronous generator without structural changes.
4. Discussion

The generator is the most important element of the wind turbine and micro-hydroelectric power plant. The advantages of generators with permanent magnets include high reliability, design simplicity, and maintenance associated with the absence of sliding contacts and rotating winding, autonomy since no constant current is required for excitation, less heating due to the absence of excitation losses [15].

In a low-speed synchronous generator, electromagnetic processes occur that affect the performance of the structure.

The setting parameter of the electromagnetic processes of the generator is magnetic induction, knowing which, you can find the force with which the rotor is attracted to the stator, and an important argument will be the size of the working air gap. The larger the air gap, the smaller the magnetic induction in it and vice-versa. The force of gravity, in turn, will also depend on the air gap. Structurally, the unevenness of the air gap leads to an increase in the attractive force at the place of the
smallest value of the gap, which leads to the appearance of a bending moment. As a result, there is a skew of disks, and the load on bearings increases [16, 17, 18, 19].

A generator with a permanent magnet rotor can be built according to various schemes, differing from each other by the joint arrangement of windings and magnets. Alternating polarity magnets are located on the rotor of the generator. Windings with alternating winding direction are located on the stator. If the rotor and stator are coaxial disks, then this type of generator is called axial or disk [20].

The overall dimensions of the SGPM are determined by its main dimensions - the length $l_r$ [mm] and the active part of the rotor with a diameter $D_r$ [mm] [21, 22]:

$$D_r^2 \cdot l_r = \frac{C_A \cdot P_{est}}{n} \quad (1)$$

$$C_A = \frac{6.1 \times 10^7}{\alpha_i \cdot k_f \cdot k_0 \cdot A \cdot B_\delta} \quad (2)$$

where $P_{est}$ is the estimated power of SGPM, [W]; $C_A$ is the Arnold’s machine constant; $\alpha_i$ is the estimated coefficient of pole overlap; $k_f$ is the coefficient of the shape of the curve of the field; $k_0$ is the winding coefficient; $A$ is the linear load, [A / cm]; $B_\delta$ is the maximum value of induction in the air gap at rated load [T]; $n$ is the rotor speed [r / min].

The most important geometric parameter of the generator is also the width of the air gap $\delta$ (Figure 8). For the generator, the value of $\delta$ is determined approximately from the ratio [23]:

$$\delta = (5 - 8) \times 10^{-3} \cdot D \quad (3)$$

Path 1 represents the mean magnetic flux. The magnetic flux that does not follow the mean flux path (path 1) is considered to be leakage flux and represented by path 2 (magnet to air) and path 3 (magnet to magnet).

![Figure 8. Sectional view of the generator. $d$ is the fictitious air gap, $d_s$ is the stator thickness, $t$ is the rotor thickness $d_d$ is the air gap thickness and $l_{AM}$ is the distance between adjacent magnets.](image)

In an ideal situation, the magnetic flux would follow the mean flux path, but in reality, there is also the leakage flux, which can be reduced by using measures listed in [24, 25]:
- the axial length of the air gap has to be smaller than double thicknesses of the PMs in the
magnetization direction (d < 2hpm),
- the distance between neighboring PMs on the same disk has to be larger than the fictitious air gap ($l_{AM} > d$).

5. Conclusion

- The proposals presented here open in further research on the extremely important problem of estimating the power of low-speed generators with permanent magnets and additional cross windings.
- The installation of additional cross windings ensures the efficiency of the proposed low-speed electric generator with permanent magnets.
- An assessment of the nature of the influence of the main geometric dimensions of the mass and size parameters and the air gap on the energy indicators of the generator is given.
- A comparison of the characteristics in the design and experimental studies of a generator with permanent magnets showed that the use of additional cross windings in the rotor allowed significantly improve the basic specifications of the low-speed generators.

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