MODELING AND ANALYSIS OF OPERATING MODES OF A LOW-SPEED ELECTRIC GENERATOR IN THE MATLAB/SIMULINK SYSTEM

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Abstract: *This article describes the theoretical foundations and mathematical model of a low-speed permanent magnet electric generator designed for low-head and low-water micro hydroelectric power plants. The equations for determining the balance of magnetic forces in the generator's magnetic system, the saturation coefficient of the magnetic circuit, and the magnetic induction in the air gap are presented. Expressions for voltage, current, electromagnetic power, and torque are generated using a dynamic model based on the d–q axis method. The electrical and energy performance of the generator is evaluated using a simulation model developed in the MATLAB/Simulink environment, and the effect of changes in water consumption on the output parameters is analyzed. The results of the study show that the use of low-speed generators increases the efficiency and reliability of micro hydroelectric power plants.*

Keywords: *Micro hydroelectric power plant, low head, permanent magnet generator, d–q model, magnetic induction, electromagnetic torque, mathematical modeling, MATLAB/Simulink, energy efficiency.*

Introduction. In recent years, interest in micro hydroelectric power plants aimed at generating electricity from low-pressure and low-water sources has been growing. In such conditions, the overall efficiency of the device largely depends on the technical parameters of the electric generator used. Therefore, choosing the optimal generator type for micro hydroelectric power plants is one of the urgent issues.

Traditional in systems rotation speed increase for with reducer transfers is used, but this mechanic losses, noise and reliability to decrease take comes. These shortcomings eliminate to grow low rotation for the purpose at speed directly worker from generators use to the goal Such generators are suitable water napery small and variable was Stable even in conditions to work provides and of the device energetic efficiency increases.

The low- speed generator being designed is as follows: main to the requirements answer to give necessary: battery even at low frequencies batteries charging for enough EUC harvest to make; noise and vibration level minimize; construction simplicity and technological in terms of working release comfort; energy their losses reduce; small rotation at speed high useful work to the coefficient achievement; economic efficiency and operational comfort to provide.

Generator design in the process magnet material, its geometric dimensions and number, as well as magnet field induction and strength main parameters as is considered. Because by the generator harvest to be done voltage and power indicators directly this to factors is related.

Conductor located of the environment relative magnet absorbency following connection through is defined [1; pp. 228–334]:

$$\mu_{rrec} = \frac{1}{\mu_0} \cdot \frac{\Delta B}{\Delta H} \qquad (1)$$

this on the ground: μ_0— magnetic constant ($\mu_0 = 4\pi \cdot 10^{-7}$N/m); ΔB— magnet induction change, T; — ΔHchange in magnetic field strength, A/m.

Electricity generator magnet in the system magnet forces balance following equations through expressed [2; pp. 411–442]:

$$\begin{cases} \frac{B_r}{\mu_0 \mu_{rrec}} \cdot 2h_M = \frac{B_g}{\mu_0 \mu_{rrec}} \cdot 2h_M + \frac{B_r}{\mu_0} \cdot 2g + H_{Fe} \cdot l_{Fe} \\ \frac{B_r}{\mu_0 \mu_{rrec}} \cdot 2h_M = \frac{B_g}{\mu_0 \mu_{rrec}} \cdot 2h_M + \frac{B_r}{\mu_0} \cdot 2g \cdot k_{sat} \end{cases} \qquad (2)$$

this on the ground : B_r— residual magnetic induction of the permanent magnet, T; h_M— half-thickness of the magnet; B_g— air between magnet induction ; g— air gap length ; H_{Fe}— magnetic field strength in the iron part; l_{Fe}— magnet stream railway line passing by length ; k_{sat}— iron saturation coefficient.

Magnet of the chain saturation level following expression through is defined as:

$$k_{sat} = 1 + \frac{l_{Fe}}{2\mu_r(g + 0{,}5t_w)} \qquad (3)$$

this on the ground: t_w— chulgam thickness; μ_r— relative magnetic absorption of the iron material.

Horizontal arrow along placed and opposite in the direction magnetized two permanent magnets between magnet induction value magnet field power, induction and magnets between to the distance related is the following expression with is defined [3; pp. 3066–3071]:

$$B_g = \frac{2B_r h_M}{2h_M + (2g + t_w)k_{sat}\mu_{rrec}} \qquad (4)$$

Magnets between distance when reduced magnet induction increases, but this condition of stator windings length and number to shrink take comes. That's why the generator design in the process all geometric and electromagnetic optimal values of parameters determination necessary.

Mathematician modeling energy in the field devices in design expenses reduce and technician indicators improve opportunity The device complexity of modeling as it increases importance further increases. Electricity their cars software in the environment modeling, usually mathematical equations formation and to calculate simplification for certain assumptions from entering as a result, currents, magnetic flow and voltages representative main variables is determined and synchronous cars in the equations periodic coefficients eliminate is being done.

Permanent magnetic horizontal arrow generator dynamic processes analysis to the d–q arrows in making based equivalent replacement scheme is used. Anchor in the mud inducible voltages following equations through is defined [4; pp. 56–58]:

$$\begin{cases} U_d = R_s i_d + L_d \frac{di_d}{dt} - \omega L_q i_q \\ U_q = R_s i_q + L_q \frac{di_q}{dt} + \omega L_d i_d + \omega \psi_{PM} \end{cases} \quad (5)$$

Three- phase permanent magnetic generator manufacturer releasing electromagnetic power [5]:

$$P_e = \frac{3}{2}\omega[\psi_{PM} + (L_d - L_q)i_d]i_q \quad (6)$$

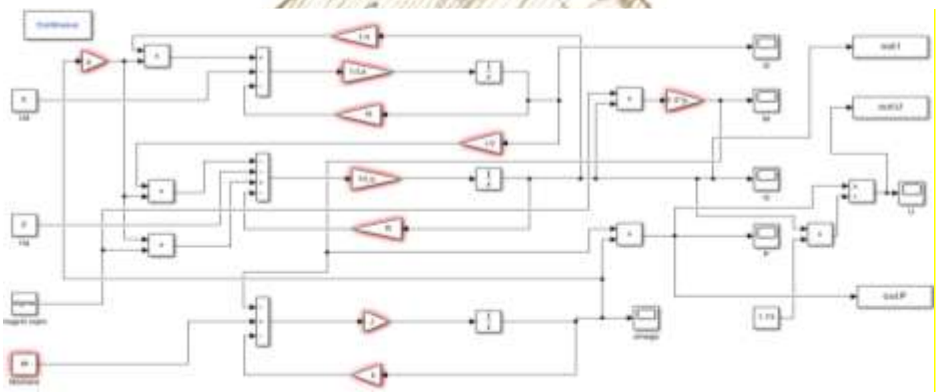
Electromechanical torque:

$$M_e = \frac{3}{2}p[\psi_{PM} + (L_d - L_q)i_d]i_q \quad (7)$$

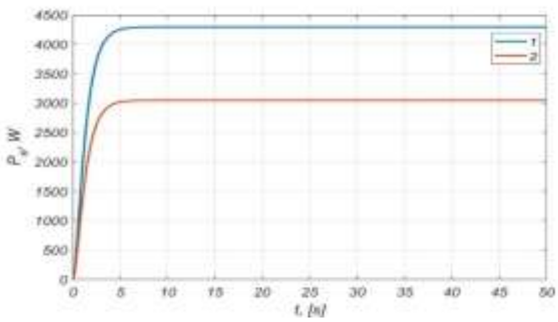
this on the ground: ψ_{PM}— magnetic flux; p— number of pole pairs.

Next equations through phase currents on the d–q axes equivalents, voltages coupling, inductances, EFC, power losses and general efficiency is determined.

In Figure 1, in the MATLAB/Simulink environment electricity generator electricity and energetic parameters determination for working issued. An imitation model is presented. Using this model, anchor in the bushes currents, voltages and electromagnetic power values Water spend change generator output as a result of parameters dynamic change is modeled and axial generator work modes is evaluated.



1. Matlab/Simulink program with the help of working issued electricity generator simulation model.



2. Matlab/Simulink program using working issued electromagnetic power of the generator in dynamic mode value graph cited.

Above graphic from the analysis, it seems that the inductor immovable and anchor excitable was electricity to the generator relative, inductor and anchor mutual reverse in the direction from a movable generator structure when used electromagnetic power working release indicator about 30% higher will be. Conducted research works to the results based on, spoon-shaped feathered micro hydroelectric stations for energy efficiency increased, low rotation at speed worker axial typical generator constructive and energetic optimal values of parameters is determined and they based on experiment sample designed working is released.

Conclusion. According to the results of the study, the use of a permanent magnet generator operating at low rotational speed for low-pressure micro hydropower plants is technically and energetically feasible. The developed mathematical model and a simulation model based on MATLAB/Simulink made it possible to determine the electrical and electromechanical characteristics of the generator. The results obtained confirm the stable operation of the device and the possibility of achieving high efficiency even under conditions of variable water consumption.

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