Printed as manuscript

Dennis Morosoff

DESIGN OF LOW-SPEED AXIAL-FLUX SYNCHRONOUS GENERATOR

Master's thesis for competition
Master's degrees in the direction of Design and technological support of engineering industries (15.04.05)
Master's program - Automation of design and technological design (15.04.05.01)

Krasnoyarsk 2017

The work was carried out at the department "Design and technological support of machine-building productions" of the Polytechnic Institute of the Federal State Autonomous Educational Institution of Higher Education "Siberian Federal University"

Scientific adviser:
PhD, Associate Professor Natalia Kolbasina

Reviewer:
PhD, Professor Alexey Vstovsky

Defense of the thesis will be held on June 28, 2017 at 9 am in the Federal State Institution of Higher Education "Siberian Federal University" at the address:
660074, Krasnoyarsk, ul. Ak. Kirenskogo 26, aud. D530

Abstract of the master's thesis can be found on the SFU website http://edu.sfu-kras.ru/engineering and in the open access archive: http://elib.sfu-kras.ru

The head of the master's program:
PhD, Professor Michael Golovin

Relevance

In connection with the intensive development of natural resources, the removal of settlements from centralized sources of electricity in the Siberian Federal District, there was a large deficit of energy capacity, which in some cases is economically and technically impractical to satisfy by means of large energy. This problem can be solved by developing a small alternative energy using wind resources.

Wind-wheel in direct-drive wind turbines, depending on the type of terrain and the power of the unit, rotates at a speed of 80-200 rpm. For such rotation speeds, small-sized high-efficiency axial-flux synchronous generators (with power range from watt to several kilowatts) are increasingly used as an energy installation for such turbines. It is made possible by the development of high-tech electronics and the recent sharp drop in prices for rare earth materials used to make permanent magnets.

In connection with the lack of developments in the field of modeling and construction of end-point electric machines, there are no methods and criteria for choosing the optimum generator design for specific operating conditions, especially in the choice of layout schemes for the core of the machine.

The task of synthesizing the parameters of an axial-flux electrical machine is, in its essence, multi-physical; The processes occurring in the electric machine are connected with a complex of influences (fields) having different physical nature (magnetic, electric, thermal and mechanical). An adequate model that ensures the machine's working capacity can be realized only as a complex model that takes into account the entire set of impacts on the technical and operational characteristics of the machine. Such a model, realized as a stage of design procedures, makes it possible to increase the reliability of estimates, to ensure the optimization of the machine parameters while substantially reducing the time spent at the design stage.

In connection with the orientation of the production of wind turbines on a private customer, an individual approach to the design of the machine for specific wind and electrical parameters, needs and requirements of the customer is needed. This problem can be solved by combining the stages of numerical simulation of physical fields and the automated synthesis of electrical machine designs with their design under a multilevel structure for modeling the electromagnetic and stress-strain state.

Goal

The purpose of the thesis is to develop a system for the design of axial-flux generators for specified quality indicators, which allows to implement optimization at each design stage.

Tasks

To achieve the goal, it is necessary to solve the following tasks:

1. Develop a component CAD scheme that will allow to implement the design cycle of the axila-flux generator from an arbitrary stage at the user's choice
2. Development of a data model including a system of parameters describing the working functions of the generator
3. Development of an information model that allows dynamic management of a system of parameters at various stages of design
4. Implementation of the developed information model in the form of a software product
5. Solution of the variational optimization problem in the design of both the initial stage and any intermediate

Methods

The finite element analysis of the stress-strain state of the generator is used in the work. In this work, methods of multicriteria optimization are also applied. The software is developed using object-oriented programming methods. The standard for the development of cyber-physical systems NIST CPS Framework v1.0.

Novelty

A data schema that allows you to implement the design process as a multi-stage, as well as dynamically change data flows and optimize the solution at each stage.

Practical value of the work

Development of a software product that implements the full cycle of designing an axial-flux generator for specific operating conditions.

Place of the thesis and passing of international internships

The place of fulfilment of the thesis – Work was completed at the Department "Design and technological ensuring of engineering industries" Polytechnic Institute of Federal State Autonomous educational institution of higher education "Siberian Federal University"

The course of international internships – the Company "CADFEM" inc, Germany: Munich (Grafing), Stuttgart, Hannover.

Summary of the work

The introduction describes the development trends of alternative energy in the world. The main reasons for the use of small-sized axial-flux electric machines as a power plant for wind turbines are given. The urgency of the topic is substantiated, the solved scientific and technical problem is determined, the purpose and main tasks of the dissertation are formulated.

In the first chapter, an analysis is made of existing methods for designing axial-flux machines. The shortcomings of traditional automated methods are noted and a conclusion is drawn on the effectiveness of creating and using an integrated environment built on the principles of supporting the product life cycle, which includes a number of subsystems: synthesis and optimization of generator parameters, automated parametric three-dimensional modeling, and analysis of the operability of the active part of an electrical machine.

The design features of the low-speed axial-flux generators, existing now in the world, are considered.

The second chapter is devoted to the development of CAD architecture of the axial-flux electric machine. The possibilities and available resources are considered. Intellectual property: 9 patents for the construction of generators; Methods for synthesizing the parameters of the generator core; Finite-element model of the generator core, performed in Ansys Workbench; A mathematical model for estimating the capacity of wind resources based on measurements on the ground; 3D parametric model of the active zone of the generator, made in Solidworks.

Stakeholders were identified, their interests, points of view and descriptions of the system for them. Of special interest are the needs of the designer of the generator, which include: automation of as many calculations as possible; Control over the maximum number of parameters; Changing and expanding the list of parameters used; Building up functionality by connecting new extensions. Based on the identified needs, a list of requirements for the system was formed.

In order for the system to meet all the formulated requirements, it was divided into the following components (see Figure 1):

– Library of electromagnetic generator calculation
– Package for finite element analysis of the stress-strain state
– Magnet selection library and winding wire section
– User interface subsystem
– A personal computer running Windows
– Database of standard products and GOST tables

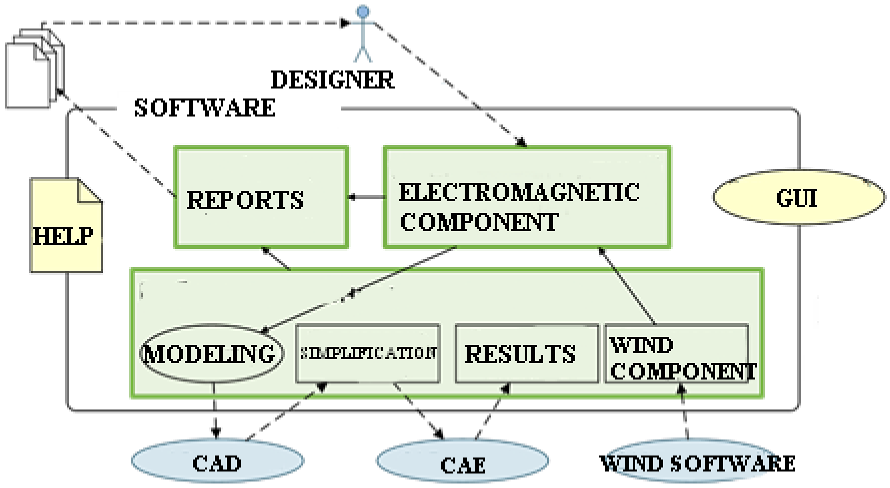

Figure 1 - Component diagram of the system

The technologies used to design the system are described: the version control system, the Component Object Model, the abstract data storage format for objects JavaScript Object Notation, the compiled help file (Microsoft Compiled HTML Help), the global unique identifier (Globally Unique Identifier) , A format for the 3D representation of PARASOLID objects.

The third chapter describes the implementation of the modules of the system, as well as the features of their integration through a common pool of parameters that make it possible to realize multivariate optimization by the method of searching by parameter space.

The module for calculating wind resources is based on the works of Alexey Kalmykov and Catherine Dyuks from the Massachusetts Institute of Technology. In this module, from the measured wind parameters, it is possible to determine the theoretical maximum power for a wind turbine with a given length of blades from the dependence:

$$P_T = \frac{1}{2}\rho A v^3 C_P,$$

Where ρ - density of air, kg / m^3;
A - rotor area, m^2;
V - wind speed, m / s;
C_P is the power factor assumed to be 16/27.

The speed of the wind depends on the terrain and is measured by an anemometer at different altitudes and at different times of the day.

Electromagnetic design model allows to form a data stream, including:

– energy characteristics (power, efficiency, voltage, stator winding current);
– weight and size parameters required for the machine manufacturer (weight of electrical steel, copper winding, magnets)
– weight and size indicators necessary for the consumer (total mass of the machine, its overall dimensions);

- geometric parameters of the machine (internal active diameter, active length of the stator and rotor, diameter of the winding wire, number of turns of the stator winding, dimensions of the magnet, height of the stator and rotor yoke, air gap);
- Machine design parameters (number of slots, number of poles, sizes of poles and magnets of the rotor, number of teeth in the winding module).

The calculated energy and design parameters as an input stream are transferred to the automated parametric 3D solid modeling module in the CAD environment of SOLIDWORKS.

At the next stage, the resulting model for assembling the active part of the generator via the neutral PARASOLID format is transferred to the ANSYS CAE environment. One of the criteria for the efficiency of the axial-flux generator is the condition for the existence of an air gap between the rotor magnets and the stator slots. The axial displacements can be estimated by solving the structural static problem by the finite element method.

The statement of the multidimensional optimization problem, which can be started at each stage of the generator design, looks as follows (for example, the optimization of electromagnetic characteristics):

$P_{max} = f_1(D_i, l_\delta, \delta, B_0, j) \to max;$ где
$\sum C_{gen} = f_2(D_i, l_\delta, \delta, B_0, j) \to min;$
$F_{attr} = f_3(\delta, B_0) \to min;$
$D_e = f_4(D_i, l_\delta) \to min;$

D_i – internal diameter, m
l_δ – active length, m
δ – air gap, m
B_0 – induction in the yoke of the stator, T
j – is the current density, A / mm^2

Here on the left is a list of quality criteria selected by the user, and to the right are varying parameters corresponding to this list.

The optimization algorithm is reduced to the following set of required steps:

1. n-dimensional parameter space that consists of points A with coordinates $(\alpha_1, \dots, \alpha_n)$, where $\alpha_i^* \leq \alpha_i \leq \alpha_i^{**}$, $(i = 1,2, \dots, n)$
2. Quality criteria $\Phi_v(A) \to \min$
3. The Pareto optimal set of criteria $\Phi_v(A^*)$
4. The truncated set $\Phi_v(A^*) \leq \Phi_v^{**}$
5. Ranking of the set according to the set priorities

Conclusions

The developed integrated system for the automated design of the axial-flux generator for the wind turbine (see Figure 2) allows you to automate the most time-consuming part of the work.

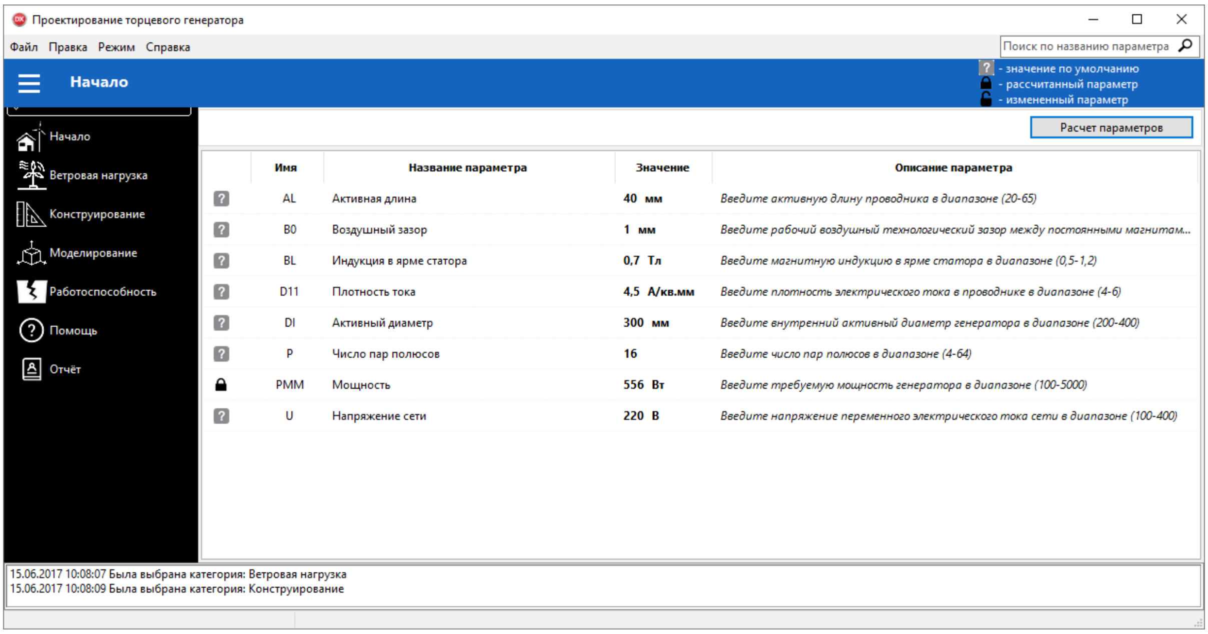

Figure 2 - CAD interface of the axial-flux generator

The system allows you to find the response of any parameter from an arbitrary set of user-selected parameters when there is a functional link between them.

The system in the future can be adapted for the development of any product that involves the automation of several design stages linked by common parameters.

The main results of the thesis are presented in the following publications:

1. Morozov DI, Gosteva TA, Kuksov E.E. Automated construction of solid parts of complex geometry // Technical sciences - from theory to practice: coll. Art. Intern. Scientific-practical. Conf. - 2016

2. Morozov DI, Pyanzin AA, Zakharin AS Using the API package Solidworks Simulation / / Integration of science, society, production and industry: Sat. Art. Intern. Scientific-practical. Conf. - 2016. - P. 90-94.

3. Morozov DI, Kouksov EE, Gosteva TA Analytical calculation of the stator mass of the axial-flux generator with the help of the theory of circular plates / / Scientific community of students of the XXI century. TECHNICAL SCIENCES: Sat. Art. By mat. XLII Intern. Stud. Scientific-practical. Conf. No. 5 (41). URL: http://sibac.info/archive/technic/5(41).pdf (date of circulation: 08/06/2016)

4. Grishechkina, M.G. Problems of preparation of the Solidworks environment for automated modeling / M.G. Grishechkina, D.I. Morozov // Science yesterday, today, tomorrow. - 2016. - No. 1 (23). - P. 11-14. - ISSN 2310-0257

5. Morozov, D.I. Methods of automation of calculations in CAE-package ANSYS with the help of technology ACT / Д.И. Morozov, A.P. Smirnov // International Scientific and Research Journal. - 2017. - No. 1 (4). - P.100-103.- ISSN 2303-9868

6. Karpenko EV, The problem of ensuring the constancy of the air gap in the face synchronous generators / EV Karpenko, DI Morozov, NA Kolbasina // Reshetnev's readings. - 2013. - T.1. No. 17. - P. 285-286

7. Karpenko EV, Carrying out the structural analysis of the active part of the axial-flux generator in the ANSYS environment / EV Karpenko, NA Kolbasina, DI Morozov. // Vestnik of the Siberian State Aerospace University. Academician M.F. Reshetnev. - 2014. - No. 3 (55). - P. 63-67

8. Morozov DI, The scaling model of the wind turbine design cost / Morozov DI, Grishechkina MG. // Youth and Science: Prospekt Svobodny - 2016