Multi-criteria optimization of wind power plant parameters

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Abstract. The use of renewable energy sources to generate electricity is a hot topic. The author has developed a mathematical model of the aerodynamic process of a wind power plant with the solution of a multi-criteria optimization problem. The optimal range of controlled parameters affecting the aerodynamic process with a minimum amount of blown surface and maximum electrical energy production is determined. Regularities of aerodynamic process are established. The convergence of the results of the study in the calculation on the basis of theoretical dependencies and the solution of the mathematical model is determined. To find the optimal controlled parameters of the aerodynamic installation, a complex research method developed by the author is applied, based on multi-criteria optimization of parameters with the introduction of empirically obtained data. The preliminary procedure of IOSO NM 3.8 consists in the formation of an initial plan of the experiment, which can be implemented both in a passive way (using information about various parameters, optimization criteria and constraints obtained earlier) and in an active way, when too much is generated in the initial search area in accordance with a given distribution law. For each vector of variable parameters, the values of optimization criteria and constraints are determined by direct reference to the mathematical model of the object under study. The number of points that make up the initial plan of the experiment depends on the dimension of the problem and the chosen approximation functions. The solution results in a Pareto (optimal) set of solutions.

Introduction
The use of renewable energy sources, namely wind power plants to generate electricity is a topical topic. The generation of electric energy depends on the dimensions of the wind wheels of the wind power plant. To optimize the parameters of the wind power plant and improve its design, a complex method can be applied [1]. This method is based on the optimization of the parameters of the wind power plant on the basis of solving a multi-criteria multi-parameter mathematical model [4] and checking the results on an experimental stand. To find the optimal parameters of the wind power plant with its maximum generation of electric energy, a mathematical model of the multi-criteria problem of parameter optimization in Microsoft Excel is developed, which is solved using the IOSO NM 3.8 calculation and software complex.

Statement of the research problem
The wind speed on the surface of the ribs determines the rotational speed of the gearbox of the wind power installation and generation of electric energy, and the radius of the wind wheel – dimensions of the wind power plant and the capital cost of a wind power installation, therefore, as the optimization criteria for the production of a mathematical model selected: 1) wind power capacity installed, \( J_1 \); 2)
the mass of the wind power plant, \( J_2 \). As controlled parameters: 1) the radius of the wind wheel, \( U_1 \); 2) the width of the wind wheel, \( U_2 \); 3) the thickness of the wind wheel, \( U_3 \); 4) the number of wind wheels, \( U_4 \); 5) the material density of the wind wheel, \( U_5 \). As unmanaged parameters: 1) air density, \( x_1 \); 2) wind utilization factor, \( x_2 \); 3) wind speed, \( x_3 \).

The parameters characterizing these changes are within the allowable limits set for this process.

Dependence of criteria for optimization of wind turbine parameters:

\[
J_1 = J_1(x_1,...,x_5;U_1,...,U_5) \rightarrow \max,
\]

\[
J_2 = J_2(x_1,...,x_5;U_1,...,U_5) \rightarrow \min.
\]  
(1)

The parameter limits are within the following range:

\[
J_{i}^{\text{min}} \leq J_i(x_i) \leq J_{i}^{\text{max}}
\]

\[
x_i^{\text{min}} \leq x_i \leq x_i^{\text{max}},
\]

\[
U_i^{\text{min}} \leq U_i \leq U_i^{\text{max}}.
\]  
(2)-(4)

The problem of finding the optimal solution is reduced to finding the optimal set of values: find \( x \in D \) in cases where

\[
J_1 = J_1(x_1,...,x_5;U_1,...,U_5) \rightarrow \max,
\]

\[
J_2 = J_2(x_1,...,x_5;U_1,...,U_5) \rightarrow \min.
\]  
(5)

Thus, the problem can be formulated as follows: it is required to find such controlled parameters of the wind power plant design that are optimal from the point of view of the selected criteria under given constraints.

The mathematical model is based on the basic equations of physics for the wind power plant [3] and economic theory.

The mathematical model is based on the basic equations of physics for a wind power plant.

\[
P_a = \frac{3.14 \cdot R^2 \cdot \rho \cdot \nu^3 \cdot \xi}{2}
\]

(6)

where \( P_a \) - generated power of wind turbine, watt; \( R \) - radius of the wind wheel, square meter; \( \rho \) - the air density, kg/m\(^3\); \( \nu \) - the wind speed, m/s; \( \xi \) - coefficient of use of wind energy.

\[
m = R \cdot b \cdot h \cdot n \cdot \rho_m
\]

(7)

\( m \) - the mass of the material for the manufacture of wind wheels, kg; \( R \) - radius of the wind wheel, m; \( b \) - width of the wind wheel, m; \( h \) - thickness of the wind wheel, m; \( n \) - the number of wind wheels, m; \( \rho \) - is the density of the material of the wind wheel, kg/m\(^3\).

As a software package for solving the multi-parameter nonlinear multi-criteria problem of multi-criteria optimization of a wind power plant, the calculation and software complex IOSO NM 3.8 is used [2].

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direct reference to the mathematical model of the object under study. The number of points that make up the initial plan of the experiment depends on the dimension of the problem and the chosen approximation functions. The solution results in a Pareto (optimal) set of solutions.

**Description of the experimental stand**

To test the solution of the mathematical model of optimization of the parameters of the wind power plant in IOSO NM 3.8, an experimental stand installed in National Research Moscow State University of Civil Engineering (Moscow) is used. The General view and scheme of the experimental stand are shown in figures 1,2 respectively.

![Diagram and photo of the experimental stand of the wind power plant](image)

**Figure 1.2.** Diagram and photo of the experimental stand of the wind power plant (wattmeter 1; voltmeter 2; ammeter 3; anemometer 4; tachometer 5; wind wheel 6; wind generator 7; mast 8; to change the resistivity of the active load, the main load resistance regulator 9 (R = 0..100 kOm) and accurate regulator 10 (R = 0..100 kOm), fan 11).

| Table 1. The parameters of the controlled process of the wind power plant |
|------------------|----------|----------|
| **Title** | **Parameter** | **Unit** |
| Gear speed | 800 < rotation/| min |
| Wind speed | 10 < m/s |
| Power | 200 < mV |
| Amperage | 100 < mA |
| Voltage | 10 < V |
| Resistance | 1100 < Oм |

**Results**

For figure 3 the restrictions on the controlled parameters of the wind wheels, at which the model of the wind power plant is calculated, are given. The width of the wind wheels is adopted from 25 to 50 mm, radius of wind wheels from 160 to 250 mm, the number of wind wheels 3 to 6, the density of the material of wind wheels from 1500 to 1600 kg/m³, the thickness of the wind wheel 2 to 5 mm, the density of air is assumed constant at 1.2 kg/m³, the wind speed is assumed constant 5 m/s, the utilization factor of wind wind power installation 0.593.
Figure 3. Criteria of wind wheels of wind power plant at which the model is calculated

In figure 4 shows the dependence of the mass on the power of the wind power plant for all solutions. The number of calculated iterations is 15000. The weight of the wind wheels ranges from 0.035 to 0.36 kg, power of the wind power plant from 3.5 to 8.8 watts.

![Figure 4. The mass dependence on the power of the wind wheel with all the options](image)

Table № 1. Twenty Pareto set of solutions for 15,000 iterations.

| The radius of the wind wheel, meter | The weight of wind wheel, kg | The power of the wind power plant, watt |
|-------------------------------------|----------------------------|-----------------------------------------|
| 0.16                                | 0.036                      | 3.6                                     |
| 0.164                               | 0.037                      | 3.8                                     |
| 0.168                               | 0.038                      | 3.9                                     |
| 0.173                               | 0.039                      | 4.2                                     |
| 0.178                               | 0.040                      | 4.4                                     |
| 0.183                               | 0.041                      | 4.7                                     |
| 0.19                                | 0.043                      | 5.0                                     |
| 0.196                               | 0.044                      | 5.4                                     |
| 0.23                                | 0.045                      | 5.6                                     |
| 0.206                               | 0.046                      | 5.9                                     |
| 0.213                               | 0.048                      | 6.3                                     |
| 0.218                               | 0.049                      | 6.6                                     |
| 0.221                               | 0.050                      | 6.8                                     |
| 0.227                               | 0.051                      | 7.2                                     |
| 0.231                               | 0.052                      | 7.4                                     |
| 0.237                               | 0.053                      | 7.8                                     |
| 0.24                                | 0.054                      | 8.0                                     |
| 0.244                               | 0.055                      | 8.3                                     |
| 0.248                               | 0.056                      | 8.6                                     |
| 0.25                                | 0.056                      | 8.7                                     |

In figure 5 shows the dependence of the mass on the power of the wind power plant at Pareto in a set of solutions. The number of optimal values obtained is 20. The weight of the wind wheels ranges from 0.036 to 0.056 kg, the power of the wind power plant from 3.6 to 8.7 watts. The optimum width of the wind wheels is 25 mm, the number of wind wheels is 3, the material density of the wind wheels is 1500 kg/m³, the thickness of the wind wheels is 2 mm.
In figure 6 shows the dependence of the mass on the radius of the wind wheels at Pareto in a set of solutions. The weight of the wind wheels ranges from 0.036 to 0.056 kg, the radius of the wind wheels from 160 to 250 mm.

In figure 7 shows the dependence of the power of the wind power plant on the radius of the wind wheels at Pareto in a set of solutions. The power of the wind power plant ranges from 3.6 to 8.7 watts, the radius of the wind wheels from 160 to 250 mm.
CONCLUSION

1. The author solved the problem of optimization of wind power plant parameters using a complex research method based on the formulation of a mathematical model of a wind power plant based on Microsoft Excel, solving a multi-criteria problem of optimization of a mathematical model in the software package IOSO NM 3.8 and testing the mathematical solution on an experimental stand.

2. To develop a mathematical model, optimization criteria, controlled and unmanaged parameters, restrictions on the parameters of the wind power plant with the formulation of a mathematical model in Microsoft Excel are defined.

3. To find the optimal controlled parameters of the wind power plant, a complex research method developed by the author, based on multi-criteria optimization of parameters with verification on an experimental stand, is applied.

4. As an example, the optimization of the wind power plant obtained the following optimal control parameters: width of wind wheels 25 mm, the number of wind wheels 3, the density of the material of wind wheels 1500 kg/m$^3$, the thickness of the wind wheel 2 mm, radius of the wind wheel from 160 to 250 mm; optimization criteria: the weight of the wind wheels to 0.036 0.056 kg, the power of the wind power plant from 3.6 to 8.7 watts.

5. The results obtained by solving the mathematical model are compared with the data obtained on the experimental stand. The convergence of the results is 5%.

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