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Experimental and Theoretical Studies of the Efficiency of Autonomous Multistory Wind Power Plants

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Abstract—The compact multistory wind power plants developed by authors for the first time in the world have been studied. Their efficiency due to the autonomy, compactness, and use of draft effect, which occurs between stories, has been shown. Thanks to this, compact multistory wind power plants will have some advantages in comparison with conventional wind power plants and separated wind-driven generators with the same power.

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INTRODUCTION

The urgency of alternative renewable and pollution-free sources of energy is evident all over the world.

Presently, native wind engines have not been produced in Kazakhstan. The development of wind engines with high power (MW) needs high technologies, which can hardly be developed in Kazakhstan in the near future. Therefore, the production of small competitive wind engines, which are developed by many groups of scientists, is urgent for Kazakhstan.

The power of the wind power plant suggested by the authors can be increased up to any desired level thanks to the installation of a necessary number of small wind-driven generators on the stories of the station [1].

The design of a novel autonomous compact multistory wind power plant (CMWPP), which is unrivaled throughout the world, was suggested in 2011 by the group headed by Dr. T. Kunakbaev, associate professor of the Department of Mechanics at the Al-Farabi Kazakh National University.

The use of autonomous CMWPPs is especially oriented on the electric power supply of regions isolated from the central power network; the difficulties in electric power supplying these regions is the necessity to provide them by various kinds of fuel, which substantially harm the ecology, and power transmission along electric power lines, where considerable electric power losses occur especially in winter (the icing effect). Different small and medium enterprises, farms, railways control offices, ecological and meteorological stations, frontier and army posts, small business entities such as mills and churns, single-family houses, etc., need CMWPPs [1].

The aim of this study is experimental and theoretical analysis of the efficiency of autonomous compact multistory wind power plants and demonstration of their advantages in comparison with conventional wind power plants and separate wind-driven generators with the same power.

STUDY TECHNIQUE

Experimental and theoretical methods were used in this study. The experimental studies were carried out by means of the field tests of a prototype of a compact three-storied wind power plant (CTWPP) with a power up to 3 kW (Fig. 1) in Baitugan of the Nurinskii region of the Karaganda oblast, Kazakhstan [1].

The CTWPP is a three-storied building and composed with a frame, on the stories and roof of which wind-driven generators of different types and with different power, are situated (Fig. 2).

Wind power plants usually occupy large areas. Underpopulated and unutilized lands are used to construct them. CMWPPs show the following advantages in comparison with conventional wind power plants

Fig. 1. Prototype of a CTWPP with a power of 3 kW.

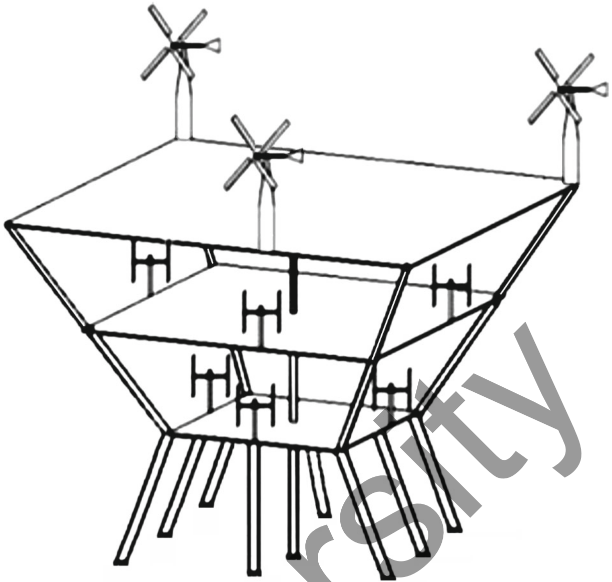

Fig. 2. Schematic of a CTWPP.

and separate wind-driven generators with the same power [1].

1. Economy of land areas: A CMWPP occupies severalfold less area than a conventional power plant with the same power and wind-driven turbines placed on one ground floor.

2. The space between inter-floor coverings forms an air passage that assists the efficient passing of wind flow like the one that develops in an aerodynamic tube (draft effect). Thus, the efficiency of using wind energy increases.

3. The simplicity of the design of a CMWPP and its assembly and disassembly (like a Kazakh yurt) in comparison with individual wind generators of greater height of the same power.

4. The support structure of a separate wind-driven generator with high power is less stable than the multistory support structure of a CMWPP with the same power.

5. More stable use of wind power due to the installation of wind-driven generators at different heights since the velocity of a wind flow changes depending on the height.

6. The possibility to combine different kinds of wind-driven turbines with different rotational speeds.

7. An increase in the efficiency of using the wind energy due to the installation of wind-driven turbines on upper stories, where the wind velocity is usually higher.

The main element of a CMWPP is the wind-driven turbine that transforms the energy of a wind's spontaneous flow into mechanical energy of shaft rotation, which in its turn can be converted into electric and thermal energy. It is a good idea to install rotor-type wind turbines of the Darrieus design with a vertical rotation axis on upper stories. The installation on floors of multi-story wind farms of Darrieus type rotary wind turbines is necessary to fulfill the compactness of the CMWPP, since the wind flow swirls only around each wind turbine, and when the propeller type wind turbines are installed on the floors with horizontal rotation, a turbulent trail is formed behind each such wind turbine, which negatively affects to other wind turbines and thereby decreases the value of the energy utilization of the wind flow.

We have shown earlier that to satisfy the condition of compactness of multistory wind power plants, the number of wind turbines should not be higher than three; otherwise, the negative effect of their mutual shading from wind flow occurs [1].

The theoretical studies were carried out by the methods of aerodynamic simulations using conventional software.

EXPERIMENTAL AND THEORETICAL RESULTS

The field tests of a CTWPP were carried out in different seasons at different wind velocities. The curves of averaged experimental results of power of three identical Troposkino wind turbine systems with blades of NASA shape on the second floor and roof (photo in Fig. 1) are shown in Fig. 3.

The comparison shows that the power generated by wind generators installed on the second floor between the inter-floor coverings, where there is a more

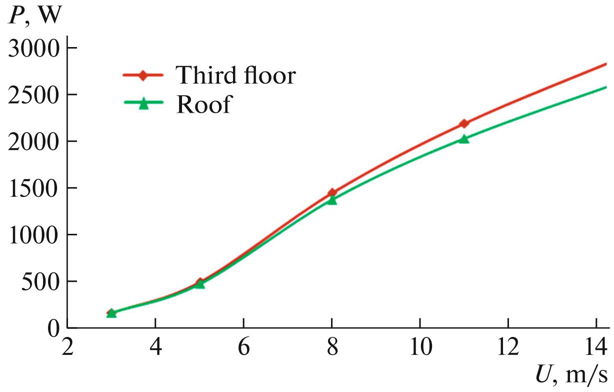

Fig. 3. Dependences of total powers of three wind generators Troposkino with the blades of NASA shape on the velocity of an air flow on the third floor and roof of the CTWPP.

directed wind flow (draft effect), is by 5–10% higher on average than that generated by the wind generators on the roof of a CTWPP, where there is no directed wind flow.

This experimental fact proves the main advantage of CMWPPs over conventional ground wind power plants concerning the efficiency of using wind energy. It means that the processes of interaction between a wind flow and wind-driven turbines on the roof of a CMWPP and on the ground are the same. It is seen that at higher wind velocities this advantage enhances.

Naturally, there appears a question about the cost per kilowatt of generated power. This comparison can be carried out in the future when developing production samples of CMWPPs. However, it can be assumed that the cost of production samples of CMWPPs will be less than that of conventional ground wind power plants since the high masts of wind turbines are complicated in fabrication, more expensive, and less stable than the structures of multistoried wind power plants. Moreover, the structures of multistoried wind power plants are easier to maintain and can be prefabricated, like Kazakh yurts, which makes their relocation possible (if necessary).

The efficiency of the CMWPPs primarily depends on the optimal minimum relative position of the wind turbines to fulfill the compactness condition. Its criterion is the beginning of the appearance of the laminar flow of air flow between wind turbines.

The aerodynamic simulations of a turbulent flow, which were carried out based on Reynold's averaged 3D Navier–Stokes equations (RANS), were considered. Currently, this approach to simulation of turbulence is most widely used when solving practical problems.

In the calculations of similar problems, an SST "$k\omega$" turbulence model (Menter's model) is usually used; however, the Autodesk Simulation CFD solver has a wider range of turbulence models to solve other problems. The Accelerant calculation technique in Autodesk Simulation CFD consists of several advanced intelligent components, each of which is optimized for rapidly and efficiently obtaining extremely accurate and reliable results.

- The Accelerant solving unit is the system to solve the dispersed Krylov matrices, which uses two preconditioning levels. Each level is controlled by the cutoff tolerance and constructed during factorization. When factorization is complete, it used in the loop of iteration convergence.
- Autodesk Simulation CFD is the intelligent controller over solving the problems.
- Automatic selection of convergence parameters and time step.
- Automatic assignment of convergence: due to the tracing of a process and automatic stopping of simulations when the needed value is obtained, the customer knows exactly when the selection of a desired solution will be completed.

After aerodynamic simulations, we can obtain a picture of one of the cases of the flow between wind turbines (Fig. 4).

To measure the aerodynamic characteristics, in particular, velocity, it is necessary to use the XY Plot instrument, inset the points, between which a line will be drawn (Fig. 5), along which a change in the velocity

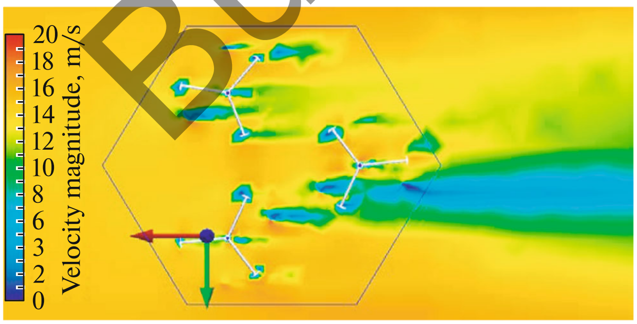

Fig. 4. Picture of the flow between wind turbines at a velocity of the incoming air flow of 15 m/s.

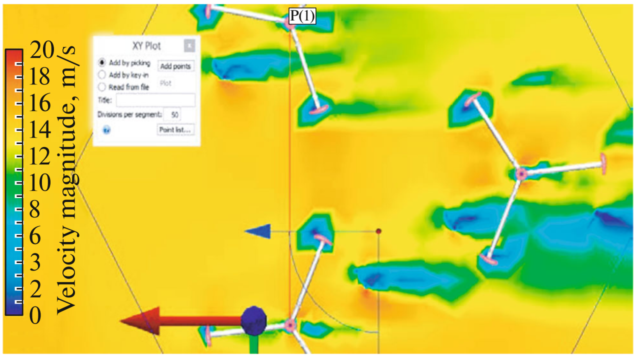
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Fig. 5. Selection of points to measure the aerodynamic characteristics.

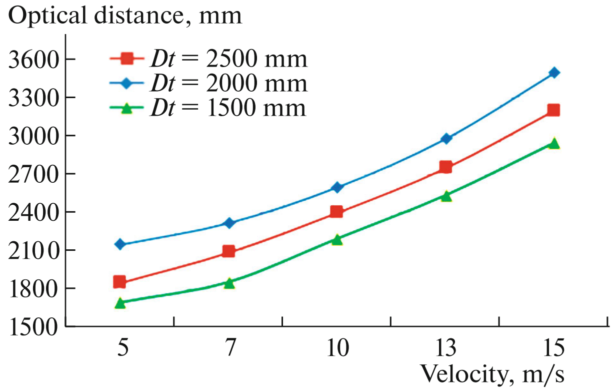

Fig. 6. Dependences of optimal minimum distance between the wind turbines on the velocity of an air flow at different diameters (*Dt*) of wind turbines.

is measured; in our case, between the blades of wind turbines. In this case, the criterium of the occurrence of the necessary laminar flow is the equality of velocities of air flows between the wind turbines and the velocity of the incoming flow. At this moment, the optimal minimum distance between the axes of wind turbines is fixed.

As an example, the results are shown in Fig. 6.

The considered method of aerodynamic simulations allows one to determine optimal minimum distances between the wind turbines with different diameters and to pass to the direct development of CMWPPs with any power. In this case, there is no necessity in expensive prototypes and innovative products can faster get to the market.

CONCLUSIONS

Based on the obtained experimental and theoretical results, the following conclusions can be made.

The experimental results have confirmed the advantage of the "draft effect" used in the design of a CMWPP.

The optimal minimum distances between the wind turbines at different velocities of air flows and wind turbine diameters have been determined using aerodynamic simulations.

Thus, the experimental and theoretical studies of the efficiency of autonomous CMWPPs, which allow one to develop competitive autonomous pollution-free renewable sources of energy, have been carried out.

CONFLICT OF INTEREST

We declare we do not have any conflicts of interest.

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