Economic Cluster Analysis and Fuzzy Modelling of Operation
of Wind Power Plants in the Arctic

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Abstract. Renewable resources are of particular importance in decentralized power systems typical of the Arctic and remote areas of a number of countries. One of the fastest growing renewable energy sources is kinetic wind energy used for power generation. Over the past two decades alone, the installed capacity of wind turbines in the European Union has increased hundreds of times, with a significant reduction in the cost of generation. The article discusses some aspects and features of wind power development in Northern and remote areas. In some areas of the Arctic coastal and remote areas, the wind speed has a fairly large value; on the one hand, it is considered highly favourable conditions for the economically efficient use of wind energy. On the other hand, wind speed exceeding certain limits can cause significant loads to be placed on wind turbines components and parts, resulting in the destruction of the device as a whole. The article discusses the possibilities of improving the reliability and durability of wind turbines operating under extreme loads. In addition, as a rule, wind farms are used where the wind speed is characterized by appropriate values, in places with low terrain and a shortage of natural resources. On the basis of methods of multidimensional scaling, cluster analysis, fuzzy modelling, the article investigates the possibilities for determining the most suitable, from the point of view of economic efficiency, places for installation of wind farms with optimization of schemes of their joint application. The technique of determining the wind characteristics and taking into account these characteristics to identify regions with the most favourable conditions for the use of wind turbines and the development of wind power in general are shown.

1. Introduction

One of the main objectives of the economic growth of many countries, including Russia and China, is to ensure the sustainable economic development of the Arctic and remote regions [1, 2, 3]. The solution of this problem is impossible without the provision of such regions with energy resources.

The development of wind power in China began in the 1980s and its development has lagged behind, but the starting point is relatively high. The Chinese government supports and encourages the development of wind power, so that wind power enters a stage of rapid development [4, 5, 6]. At present, China has the world's largest installed capacity for wind power and cumulative installed capacity, and it has become the world's largest and fastest growing market for wind power generation. The wind energy reserves that China can develop and use are about 1 billion KW. Among them, about
253 million KW of wind energy is stored on land, and 750 million KW of wind energy is available for exploitation and utilization at sea, totalling 1 billion, and wind energy resources are abundant. China is recovering to a vast extent and has complex terrain conditions. The state and distribution of wind energy resources vary with the terrain and geographical position. The relatively abundant areas are mainly located on the southeast coast and nearby islands as well as in the north (Northeast, North China and Northwest China). There are also individual wind energy rich spots inland. In addition, offshore wind energy resources are also very abundant [7]. With the rapid growth of economy development in China, the demand for power resources is increasing. According to the statistic from China Electricity Council, electricity consumption increased from 2500 TW·h in 2005 to 6307.7 TW·h in 2017, with an average annual growth of 7.9%. Due to the gradual depletion of fossil fuels and environmental issues, the proportion of traditional coal-fired power generation methods in the power production industry has gradually decreased, while renewable energies such as wind, solar and biomass energy are favored for their clean, pollution-free, and renewable characteristics, and they have occupied more and more positions in today’s power production. In 2016, coal fired power generation in China was 870 TW·h, while wind power contributed 130 TW·h, with an annual growth rate of 12%. The installed capacity for wind power reached over 160GW, accounting for about 34% of global capacity worldwide, which, according to Chinese government, is expected to reach to 200GW by 2020 and to increase further to contribute to the 13th five-year-plan on renewable energy [8, 9, 10].

2. Theoretical part

 Depending on the wind characteristics, we have developed a technique to identify the most favourable places for wind power plants. We show the methodology of such analysis on the example of information on wind characteristics in the vicinity of settlements of the Republic of Sakha (Yakutia, Russia). Fig. 1 shows the Box-plot diagram for the source variables. As you can see from the chart, the widest range of values change is variable “Repeatability of different gradations of wind speed for a year,% , <= 1”. Emissions are such settlements as Tiksi bay, Kyusyur, Sangar.

![Figure 1. Chart "Box-plot" for the original variables.](image)
With help of methods of multidimensional scaling by using the procedure "Alscal" we will construct the diagram (Fig.2), allowing to present initial information in a visual form.

As you can see, in the diagram, the "Box-plot", there are the settlements Tiksi bay, Kyusyur, Sangar. But, unlike the chart "Box-plot", group charts (Fig.2) in a visual form to monitor settlements with respect to existing wind conditions. However, according to the received group schedules it is difficult to cluster settlements with identification of the most favorable places for placement with the greatest efficiency of wind turbines. Therefore, to solve this problem, we will conduct a cluster analysis [11]. The first cluster consists of 20 settlements: Aldan, Vilyuy, Vitim, Jalinda, Druzhina, Zyryanka, Seek, Lensk, Upland, Nyurba, Nyuya, Olekminsk, Olenek, Srednekolymsk, Suntar, Suresnes-Kuelle, Tompo, Tuy-Haya, Eyyk, Yakutsk. The second cluster consists of 14 settlements: Allah-yun, Anga, Verkhoyansk, Iema, Cross Khalday, Nera, Oymyakon, Okhotsk, Sukhana, Tommot, Ust-May, Ust-Mom, Chulman, Shelagontsi. The third cluster includes 7 settlements: Jarjan, Zhigansky, Possack, Kyusyur, Sangar, Saskylah, Tiksi bay. In Fig. 3 the dendrogram is presented, which clearly shows that the most optimal way to divide the initial settlements but three clusters.

3. Scientific novelty. Methods of applying fuzzy modelling methods

Due to the variability of wind characteristics, it is advisable to install several wind turbines for the stability of the required output characteristics. On the basis of fuzzy modeling we have developed a technique that allows us to determine the required number of wind turbines, the degree of need to turn on the electromechanical braking device. On the basis of the developed technique, we have compiled an algorithm for controlling the complex of wind turbines as a single wind power station. The following variables were used as input variables: wind speed on the weather vane (Speed) in the range 0...30 m/s with five grades, and the installation height of the blade unit (Height) in the range of 0...100 m with three gradations. The height of the installation interested us because, as noted in the section "analysis of wind characteristics", the wind speed increases with the increase in height and is determined by the formula above. Fig. 4 shows the adopted membership functions for the input parameters.

The output variables were: the number of wind turbines included in the network (Number) in the range 0...4 with three gradations followed by rounding of the output value to the nearest integer of 1,2,3 and the probability that the braking device must be switched on (Probability) in the range 0...1 with three gradations. Fig. 5 shows the adopted membership functions for the input parameters. The
established algorithm allows to find the recommended values of output variables by the input variables. For example, as noted in Fig. 6 (a), when the values Speed=5.387 m/s and Hight=50 m should be included in a joint of the robot three wind turbines, with the probability of necessity of the braking device only 0.2994. Therefore, the braking device may not be used. At values of Speed=17.113 m/s and Hight=61.62 m, Fig.6 (b) one wind turbine is enough. The likelihood of the need to incorporate a braking device at this relatively high (0.7412), therefore, the braking device should be used.

![Figure 4. The membership functions of fuzzy sets: (a) Speed, (b) Height.](image)

![Figure 5. The membership functions of fuzzy sets: (a) Number, (b) Probability.](image)

![Figure 6. The quantitative results of fuzzy analysis: a) Speed=5.387 m/s, Hight=50 m, b) Speed=17.113 m/s, Hight=61.62 m](image)
4. Application
As it can be seen from this table, the most favorable places for installation of wind power plants are
towns in the third cluster. In these points, the values of the wind characteristics are optimal for placing
wind turbines with the described protection system in the case of non-standard values of wind loads.
Settlements of the first cluster are less favorable for the solution of the task. Note that the first cluster is
the largest. Here it is rational to install two units in conjunction with the control system for us
developed algorithm. This algorithm is based on fuzzy modeling methods. An explanation of this
algorithm is given below. The settlements of the second cluster with the minimum values of wind
characteristics are the least favorable for the installation of wind generators. In these points it is
advisable to install three wind turbines with a similar automatic control system in a complex, as in the
case of settlements of the first cluster.

5. Conclusion
The presented technique of optimal choice of wind power plant installation sites depending on the
statistical values of wind characteristics has shown its effectiveness and can be widely used in the future
in terms of energy development in the Arctic and remote areas. The article describes the necessary for
the analysis of wind characteristics, presents the dependence for calculating the values of these
characteristics. The technique is based on cluster analysis and multidimensional scaling using such
tools as: dendrogram, box-plot diagrams, group graphs and others.

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