Overview of solutions in the field of generation and transport of wind power production

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Abstract. The use of wind power is one of the most promising ways to obtain renewable energy. In this article, based on a literature review, an analysis of the development of alternative solutions in the field of wind energy is carried out. The classification of wind turbines (WT) according to the orientation of the wind-sensing rotor is given. A comparison is made of the operation of horizontal-axis and vertical-axis wind turbines in different operating conditions. Alternative and unconventional technical solutions in the WT designs and elimination of shortcomings using modern knowledge in the field of application of composite materials and methods of mathematical modeling are presented. It is shown that increasing energy efficiency and release of energy is a key factor in ensuring the profitability of the WT using in various climatic and geographical conditions. The main trends in the WT development, both high-power wind farms and small local WT are determined, including directions for the development of integrated transport networks and energy storage. The tool for the successful introduction of new "green technologies" to the market in modern conditions is marketing-oriented management, which can be implemented through cooperation in the activities of technology start-ups and the state on the principles of mutually beneficial partnerships.

1 Introduction

Wind power is one of the most promising renewable energy resources. The most acceptable classification of wind turbines (WT) is based on the orientation of the wind-receiving rotor relative to the wind: horizontal-axis WT (HAWT) and vertical-axis WT (VAWT). HAWT are widely used in many countries on a large scale. But HAWT can effectively use the wind energy can wind power in areas where wind is weak and has a large variability in speed. VAWT advantages: a good work in weak and variable wind, low noise, high safety. This review is an attempt to consider the solutions achieved over the past ten years in the field of promoting the VAWT into the real power.

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2 Literature review and methods

This section reviews the most relevant publications in the field of alternative solutions to the use of wind power.

In [1] after the series of experimental studies indicated the need for increasing the number of blades for VAWT. The results of the study also showed the effectiveness of application a variable profile of the cover blade for WT. The analysis of release energy and efficient energy use was considered in [2]. Proceeding from the level of technical solutions, it is argued that the efficiency for HAWT can be 44-55%, while for vertical-axis (VAWT) 50-53%. However, it has been found that the achievement of this level is difficult, since the densely filled structures towns and urban centers have a low wind flow quality, including high turbulence, considerable fluctuations of the wind speed and higher frequency change its direction. The study [3] when considering the quality requirements of the wind flow is determined that VAWT have special advantages for use in marginal-marine and open ocean areas, which especially include the versatility of VAWT in the perception of the wind flow and low overturning moment the entire installation with better accessibility to service the transmission and generator. It is emphasized that the technical solutions of VAWT designed for active control of the blade pitch, are mechanically simpler for VAWT than for traditional HAWT. The use of VAWT in offshore deployment provides a real opportunity to reduce the cost for deepwater areas, due to lower requirements for supports and foundations.

On the other hand, the key advantage of VAWT - invariance direction of wind flow – allows simple accommodation of low-power WT in settlements on the roofs of buildings of any purpose [4]. It is emphasized that low-power VAWT are capable of wide application, even when enough successful conditions of its location, and will be very useful when supplying power for lighting of buildings, streets bridges in communities, especially in developing countries. It is essential that even small-sized VAWT are able to perceive the vertical wind component, which at low speeds carries up to 30% of all wind energy [5] in turbulent zones, and the Darrieus rotor is the most effective in this case.

Decisions in the field of design and installation of VAWT were discussed in [6], where the need to abandon ensuring the stability of WT through the use of wire guys and application of tubular towers-supports for rotating rotors was emphasized. It has been established that VAWT of a tubular-tower structure will be significantly effective for use in rural areas, wind farms, and especially for “green houses”. Expansion of the possibilities of VAWT using n these areas is associated with technical solutions in the field of materials used and methods of their installation at the site of use. The advantages of VAWT are shown in [7], where it is demonstrated that the working blade of a wind turbine with a length of 60 m has a weight of about 9000 kg, while for HAWT the weight of a blade of the same length is approximately 15500 kg when they are made of the same materials, reinforced fiberglass. It is especially emphasized that the blades of VAWT have lower production costs in their manufacture, since they can have a uniform profile along the length, be transported, therefore, in parts and assembled at a lower height during the installation of WT excluding the use of specialized transportation and assembly mechanisms. It is indicated that VAWT in general have fewer moving parts and do not need a multiplier gearbox, which guarantees their reliability in operation. The same advantages are shown in [8], which indicates the need for the development of methods for VAWT modeling and calculating, since these methods for them significantly lag behind in their development from modeling methods for HAWT. At the same time, experimental methods are still the most accurate.

The placement of VAWT in marginal and open sea areas allows the creation of large wind farms. The study of these was carried out in [9], and the scalability of the simulation results for increasing the number of WT is shown. It has been established that the placement of individual VAWT by clusters (the cluster has a triangular shape) has a high efficiency, and even when using rotors of a wind turbine of the Savonius type, the efficiency of a cluster of nine VAWT will be 26%, which is higher than that of nine separately standing VAWT. Scaling the model showed that the efficiency of a cluster wind farm of twenty seven VAWT will already be 37%, which is also significantly higher than that of twenty seven isolated WT. The developed cluster wind farm of twenty seven VAWT with the Savonius rotor provides a specific power from the territory of 4.5 W/m2, which is three times higher than that of twenty seven separate VAWT.

The need for the use of aerodynamically highly efficient wind flow energy converters requires the use of appropriate solutions, in particular, the use of VAWT Darrieus system, the disadvantage of which is the low torque at low wind speeds, which makes it impossible to start them independently. In [10], an optimized Darrieus rotor is demonstrated, capable of self-starting at low wind speeds due to the use of blades with a variable angle of attack. A different solution for the use of low-intensity wind was proposed by combining the vertical-axial and horizontal-axial systems in one WT with using one support [11]. This solution will reduce the area occupied by one WT with the same power.

Another solution to the use of low-intensity winds is based on the use of the Gorlov rotor, which has blades covering the rotor axis along a screw generatrix. In [12], it is noted that the Gorlov rotor can be upright while maintaining its advantages and therefore is the main candidate for use in portable VAWT. The experiments have shown that the design of VAWT with the Gorlov rotor, developed by the authors [12], works stably at low wind speeds, which makes this WT promising for use in cities and towns.

The simplest solution for starting of VAWT rotors from low-intensity winds was proposed and considered in [13], where it was proposed to combine Darrieus and Savonius solutions in a hybrid rotor. Such hybrid rotors have demonstrated significant efficiency and the ability to sustainably self-start from low winds. Another version of the hybrid solution was discussed in [14], where a combination of HAWT and VAWT on a single tower-support was proposed, and the support itself served as the axis of VAWT rotor. Research has shown that such a system can develop power significantly higher than the individual power of each component under the same conditions. It was found that the combination in one similar system of HAWT for 12 kW and VAWT for 10 kW allows to develop along the entire power system to 33.5 kW.

Tests of VAWT in urban conditions were carried out [15] in order to ensure the design and modeling of a small-scale VAWT, which can be used in urban environments. It is noted that WT development for urban areas is critically necessary to ensure the use of the penetration of technology for generating electricity from wind in cities and suburban areas. The experiments and tests carried out have shown that the designs proposed by the authors, when applied in WT or the described conditions, will provide consumers with a payback in 3.5 years the opportunity to receive a net income from electricity generation within 20 years of VAWT using.

The advantages of VAWT technologies achieved over the past period of development are considered in [16], where the authors point to the most important achievement of such systems – a lower specific noise level per rotor circumferential speed. It is emphasized that VAWT are most suitable for use in a populated - rural and urban – environment. The experiments showed that when using the Gorlov wind turbine with a high blade chord, an efficiency of 0.479 is achieved at a peripheral relative speed of 3.5, which makes VAWT with such a rotor very quiet.

The efficiency of VAWT using at low speed winds is so great that such VAWT was even developed for use on Mars. This decision is based on the use of current knowledge in the field of composite materials and the best methods for modeling fatigue loads. Recent advantages provide the creation of solutions in the field of marine use of VAWT and it is shown that the specific power of marine WT has the potential to increase by an order of magnitude compared to that of HAWT in the same areas of use [17].

The solution to the problem of transport produced by renewable energy sources is associated with the development of distribution systems. The inclusion of energy storage components in distribution power systems creates a new type of facilities for distributing and using electrical energy – integrated energy distribution systems (IEDS). They differ in a fundamentally different level of difficulty. Such systems can be considered as a key prospect for the development of electrical energy distribution systems due to the possibility of using renewable energy sources. It is noted that they combine the dual characteristics of engineering and social systems. The variety of scenarios for the energy relation of such systems and the complex interaction within them create the problem of effectively resolving the conflict between the balance of energy supply and demand and the requirements of a low-carbon economy [40]. The researchers note that most of the studies performed on the accumulation of energy within the framework of its generation or transport are focused on estimating the costs of technology and do not take into account the potential benefits from combining the means of energy generation and transport into a unified network [43].

Studies show that it is advisable to organize the management of combined networks of energy production and distribution on a two-level principle: at the level of source control, the optimal location and production volumes from various distributed energy sources are determined, and then these parameters are transferred to the control scheme of energy distribution and auxiliary services of the network [41].

Recently, it has become possible to connect local microgrids to large distribution networks by forming intelligent networks that include energy sources and storage facilities [42], while there has been an increase in various methods for optimizing energy storage systems. However, it has been established that by now the practical application of energy storage is more common for the facilities of its consumption and local distribution than for the facilities of its transport from sources to the consumer [42].

Strictly in terms of technology costs, hydraulic storage has the lowest cost with short battery life. As the requirement for longer battery discharge duration increases, hydrogen eventually becomes the cheapest technology due to the much lower capital cost of energy storage. It has been established that the most economical storage systems have an unloading time of no more than 1 day; if it is necessary to discharge the accumulator for more than 2 days, the only cost-effective technology is hydrogen due to the higher energy intensity/cost ratio [43].

To evaluate the synergy between energy storage and transport, solutions were sought by comparing the performance and cost-benefit ratios of three storage technologies (hydraulic storage, compressed air storage, and hydrogen storage).

When combining energy transport and storage facilities, the economic efficiency of energy storage processes depends on many aspects, such as the dynamics of the share of renewable energy sources in the system, the amount of capital costs for creating an integrated network (Table 1), the ability of management tools to provide additional services of the interconnected network to its consumers, including support new parameters of network competitiveness, reliability and fault tolerance [43].

Table 1. Partial cost structure of 1 MW-h in the system of transport and storage of wind energy with a period of storage-return of 1 day (calculated according to [43] and [44])

Storage methods in the system	Capital costs	Fixed costs for exploitation and maintenance of the system	Costs for storage
hydrogen storage	0,05%	13,59%	2,80%
hydraulic storage	0,10%	28,71%	54,01%
storage by compressed air	0,11%	30,01%	56,02%

It is emphasized that the benefits of deploying storage facilities in local networks of transport and energy distribution cannot be adequately modeled. The optimal project in terms of power system or national importance will not necessarily be the same as that of a region or municipality, as the expectations of local users, investors and network management may differ significantly. In general, large-scale deployment of storage facilities is relevant only with a high penetration of renewable sources into the overall system of energy generation and transport; at the same time, the increased costs of deploying energy storage facilities are more than offset by reduced costs for renewable energy power plants and the transport energy network [44].

3 Results and Discussion

Let's review alternative solutions in the field of wind power using in the Russian Federation. Domestic researchers generally recognize similar areas of application for VAWT [18, 19]. Special attention is paid to the using of VAWT in the conditions of territories with a low wind energy potential [20] and emphasizes the need for an all-round increase in release energy from VAWT. Increasing of release energy is a key factor in ensuring the profitability of VAWT using, especially in areas with low wind load [21].

The main area of VAWT application is proposed to use them in power supply systems for remote agricultural consumers. The use of diffuser and wind-guiding devices in VAWT structures is considered by the method of increasing release energy [22]. Another direction for increasing the release energy is the introduction of intelligent control systems for VAWT complexes [23], considerable attention is paid to the use of Smart Grid technologies, optimization of consumption energy efficiency and dispatching of local power systems with using the renewable energy sources.

A very important area of domestic research takes the search for alternative and innovative technical solutions in the construction of VAWT. Based on the design features of VAWT rotor, it’s proposed to use the electromagnetic bearings for support of VAWT rotor [24], that provide the absence of friction and mechanical wear in the rotor supports, eliminate the need for lubrication and give VAWT, in the whole a greater degree of independence from the environment conditions and service. It was revealed that the application of an electromagnetic suspension in Savonius wind turbine is practically unacceptable due to the large relative own energy consumption of VAWT (own energy consumption on the suspension will be at least 20% of the generated electrical energy). The energy consumption of an electromagnetic suspension in the Darrieus wind turbine can be comparable with the losses of rotor kinetic energy for friction in mechanical bearings, which opens up the full possibility of using EMF in WT of this type. An important achievement is the use of the modular approach methodology in the design and manufacture of VAWT with the preceding mathematical modeling of VAWT components that are independent clusters or modules, which was proposed in [25]. Studies conducted in South Ural State University have demonstrated high rates of power generation by experimental vertical-axis constructions of a number of capacities of 0.1-30 kW, performed according to this methodology. In addition, within the framework of a modular approach, it is proposed to use aerodynamic control of the blades; creation of a supporting structure as a ring or a hexagon, with the exception of all possible extensions to reduce the resistance and replacement the horizontal traverse with aerodynamic regulators and fairings with traverses of an oval (aerodynamic) shape in section. Another set of proposed solutions in the field of increasing release energy includes the power control by blade turning, aerodynamic control of the rotor speed, drag on the rotor by the ballast resistance and combined intelligent control of the control system complex [26].

The problem of producing an aerodynamically improved products for VAWT forces us to look for ways to use the technologically simple solutions of the rotor designs for VAWT with an increase in their release energy through the use of additional components in the WT structure. This component is most often considered as an aerodynamic diffuser. In [27], to increase the release energy in WT with Savonius wind turbine, the most effective direction is the addition of a wind tunnel-diffuser to the structure. An omnidirectional diffuser is considered in [28], where a tower-tube is proposed, installed above an axial wind wheel in a ring. The vortex system ensures the creation of a vacuum over the wind wheel and an increase of the flow speed passing through it. Vortex flow gain can be created in various constructive devices with the flow direction and swirl, similar to the round tower mounted above the wind wheel in the ring. For typical systems, the tower diameter can be 3 times the diameter of WT rotor, and the tower height – 3 times its diameter, or 9 times the diameter of WT rotor. The use of an output device (bell) in WT leads to a significant decrease in the minimum wind speed for starting the rotor - up to 45% of the wind speed when WT starting without an output device. By using the optimized geometry at a nominal speed of 12 m/s wind power useful for WT rotor is increased more than 2-fold, compared with the WT original design. Other solutions [29] provide for the use of the principle of differential drag in the Savonius rotor, since these rotors are able to operate at very low wind speeds and better suited for further improvement. The blade design with variable dimensions has been created depending on the effect of the air flow on it, which contributes to an increase in the aerodynamic characteristics of the blade. Using the wind guide screens allows to start the Savonius rotor at a wind speed of 0.5 m/s, which contributes to efficient operation in the range of wind speeds from 0.5 m/s to 4.5 m/s, and at speeds from 4.5 m/s from up to 15.0 m/s, the air flow speed in the volume of the WT rotor is regulated by wind guiding screens. When hurricane winds appear, wind guiding screens are able to cover the WT rotor, preventing its damage.

The search for optimal conditions and areas of VAWT application is relevant for modern Russian researchers. In [30], the high energy efficiency of their application in various regions of Russia is shown. The use of mobile VAWT was proposed [31] and their applicability was shown under conditions of low wind loads.

In [32] it is shown that the power supply for communication of Far North autonomous objects in in conditions of constant winds, it is advisable to use the vertical-axis wind power plants. For this, VAWT with increased resistance to storm winds, increased reliability and simplified operation technology has been proposed. On the basis of experimental studies, it has been demonstrated that the use of VAWT based on the Darrieus – Savonius combined wind turbines [33] will ensure the achievement of the maximum power factor value for VAWT 0.60, which exceeds the theoretically possible values of this coefficient for HAWT 0.59. Similar VAWT with power 1 – 10 kW are useful for the generation of electric and thermal energy in national parks and reserves. The search for solutions to increase the release energy of VAWT leads to the idea of eliminating an intermediate converter of wind power into electricity by VAWT creating with direct drive. A design of screw sucker-rod and pump unit (SRPU) for lifting oil from a well using a combined VAWT (CVAWT) based on a combination of the Darrieus and Savonius wind turbines has been proposed [34]. It has been shown that with an increase in the wind speed from 2 to 10 m/s and the swept area from 5 to 20 m^2 the power of CVAWT increases from 8 W to 4.5 kW. According to calculations, with a typical feed for SRPU from 3 to 50 m^3/days, pressure 10-15 MPa and energy conversion efficiency 0.50, SRPU power with drive from CVAWT will be 0.78-8.68 kW and WT cross-sectional area will be 4.7-52.5 m^2, i. e. it has quite acceptable values, and CVAWT must be directly combined with a polished rod for rotary motion transmission to SRPU screw pump in an oil well. Savonius wind turbine efficiency will be 0.36, which is only slightly lower than the efficiency value for VT with the Darrieus rotor. Annual energy savings will reach 1370-15200 kWh per year, the payback period, according to preliminary estimates, will not exceed 3-5 years. Another example of WT application with direct drive is the experimental use of combined VAWT (CVAWT) based on the Darrieus and Savonius wind turbines on wind-driven ships [35]. The options for the location of the Darrieus and Savonius rotors on the ship CVAWT are proposed: single-stage three-bladed Darrieus rotor with the double-stage Savonius rotor located on top and single-stage three-bladed Darrieus rotor with located above and below single-stage Savonius rotors.

Comparison of research results for VAWT carried out over the past 10 years in the world and in Russian Federation show the revealed prospects of VAWT application. To increase the efficiency of the latter, it is first of all proposed to use active control of the geometry of the rotor blades to ensure the use of weak winds for energy generation and the possibility of self-starting. The main trend in the improvement of VAWT should be considered the development of their designs for use primarily in large installations and wind farms of marginal-marine and ocean location for large-scale production of electrical energy which is due to low relative loads on the base, possible ease of maintenance and the possibility of placement in deepwater areas, and also ensuring the applicability of small VAWT for generating the electrical energy in places of its direct consumption, primarily in settlements due to the simplicity of their control, manufacture and low noise. The main object of research is the Darrieus rotor, as it has the highest aerodynamic efficiency. VAWT studies carried out in the Russian Federation are more multifaceted and ocused primarily on the search for designs that provide VAWT application in the widest possible area. VAWT advantages: simplicity, low noise, the ability to achieve a high aerodynamic efficiency are the main arguments in favor of this approach. It should be noted that the research of VAWT in Russian Federation is focused both on the use of Darrieus and Savonius rotors, which is associated with the technological and production simplicity of the latter.

It must be assumed that the current trend to place the energy storage facilities as close as possible to consumers limits the ability of transport energy networks to provide a highly competitive product and additional services to the market. The authors believe that the deployment of energy storage facilities in the future is primarily associated with its large-scale transport systems, including hydrogen.

In most cases, research tool is the computer modeling of aerodynamic flows. Research in the field of high-power VAWT in Russian Federation is not carried out, which creates well-known fears of a lag in the development of advanced technological solutions in the energy industry. The energy strategy of Russia for the period up to 2030 provides for the active use of renewable energy technologies, in particular, onshore wind energy industry. But Russia does not have the technologies for the production and operation of WT with a capacity of more than 500 kW. Wind energy industry is a high-tech branch of the global economy. Unfortunately, Russia is poorly represented there. Attention should be paid to the fact that there are significant obstacles to both the successful implementation and replication of innovative developments, and the actual research and design and experimental activity itself. Ten years ago, researchers have noted that innovation in the field of "green technologies" innovation began to focus on climate protection outcomes by government institutions, policies and resources, which in turn shaped market behavior. Initially it was thought that the efficient technologies of final use contribute to a significant potential reduction of emissions and provide higher social returns on investment than power engineering technology [36], yet state institutions and financial structures are increasingly favored is power engineering technologies.

Subsequently, the course of development showed that this course remained prevailing, which led to positive consequences: state support for R&D (research and development) and restricted fares had a positive effect on the number of patent applications in the wind power sector, while the impact of state support for R&D on wind power is more significant if it is accompanied by the use of restricted fares. In the study [37], on the basis of these facts, it was concluded that technological innovations in the field of "green technologies" require both R&D and practical application, and for this reason, state R&D programs in the field of "green energy industry" should not be developed in isolation from their practical application.

The study [38] showed that local authorities and municipal governments are increasingly involved in planning the energy transition to "green technologies". The partnership between government and business in professional startup organizations usually improves the situation during the transition period, especially at the municipal level. This partnership, realizing through the creation of regional clusters, causes the positive effects of networking cooperation and synergistic control type.

Obviously, that approaches to the conditions for organizing the energy transition does not affect such an important element as the marketing feasibility of the production and sale of solutions and ideas in the field of energy transition technologies, focused on the demand and consumption analysis in the areas of application of these technologies. The authors of this publication see the highly efficient means reducing the length of energy transition duration in the marketing-oriented management of innovative energy projects. Such control can be achieved through cooperation in the activities of technology startups and the state on the principles of mutually beneficial partnerships, which will provide a synergistic effect from the implementation of the results, as already shown. Researching and positioning relationships in the management of "green" technology projects should be seen as an important condition for their successful market launch. Thus, the development of effective mechanisms of state support for the wind power development is an important scientific and practical problem to the solution of which scientific teams from both the technical and economic environment can be involved. Researchers notes that the macroeconomic development on an interdisciplinary basis can lead to a truly green marketing based on the concept of sustainable development and holistic thinking [39]. Green marketing has a particularly important role to play in the management of integrated energy transport and storage networks, integrated with IoT and Smart Grid networks, ensuring true competition in energy supply and maintaining a balance of supply and demand.

4 Conclusions

This publication defines the main trends of VAWT development: high power VAWT for offshore application, attack angle regulation of their blades to ensure self-starting, the creation of small cheap VAWT for local self-supply, "green houses" and Smart Grid.

VAWT research in Russia have quite a variety of topics, but initially focused on the search for solutions in small VAWT field of mass production and application. Consequently, the risk of technological priority loss in the high power VAWT field the application of which can be widely and effectively than HAWT due to the significant advantages of VAWT. Marketing-oriented management acts as a tool of successfully launching new “green technologies” on the market in modern conditions.

References

1. M. El-Samanoudy, A.A.E. Ghorab, Sh.Z. Youssef, *Effect of some design parameters on the performance of a Giromill vertical axis wind turbine.* Ain Shams Engineering Journal, 1, **85-95** (2010)
2. K. Pope, I. Dincer, G.F. Naterer, *Energy and exergy efficiency comparison of horizontal and vertical axis wind turbines.* Renewable Energy, 35(9), **2102-2113** (2010)
3. A. Shires, *Design optimisation of an offshore vertical axis wind turbine.* Energy, 166(EN1), **7-18** (2013)
4. P. Gulve, Sh. Bh. Barve*, Design and construction of vertical axis wind turbine.* International Journal of Mechanical Engineering and Technology (IJMET), 5(10), **148-155** (2014)
5. Kung-Yen Lee, Shao-Hua Tsao, Chieh-Wen Tzeng, Huei-Jeng Lin, *Influence of the vertical wind and wind direction on the power output of a small vertical-axis wind turbine installed on the rooftop of a building.* Applied Energy, 209(C), **383-391** (2018)
6. W. Tjiu, T. Marnoto, M. Sohif, M.H. Ruslan, *Darrieus vertical axis wind turbine for power generation I: Assessment of Darrieus VAWT configurations.* Renewable Energy, 75, **50-67** (2015)
7. W. Tjiu, T. Marnoto, M. Sohif, M.H. Ruslan, *Darrieus vertical axis wind turbine for power generation II: Challenges in HAWT and the opportunity of multi-megawatt Darrieus VAWT development.* Renewable Energy, 75, **560-571** (2015)
8. J. Xin, Zh. Gaoyuan, G. KeJun, Ju Wenbin, *Darrieus vertical axis wind turbine: Basic research methods.* Renewable and Sustainable Energy Reviews, 42, **212-225** (2015)
9. M. Shaheen, Sh. Abdallah, *Development of efficient vertical axis wind turbine clustered farms.* Renewable and Sustainable Energy Reviews, 63, **237-244** (2016)
10. D. Mohamed, A. Zeroual, R. Rabehi, N. Allam, *Wind energy systems: Analysis of the self-starting physics of vertical axis wind turbine.* Renewable and Sustainable Energy Reviews, 81(1), **1602-1610** (2017)
11. C.M. Vivek, P. Gopikrishnan, R. Murugesh, R. Raja Mohamed, *A review on vertical and horizontal axis wind turbine.* International Research Journal of Engineering and Technology (IRJET), 04(04), **247-250** (2017)
12. R. Dommeti, A. Kathi, M. Pasumarthi, *A Design for High-Torque, Low-Speed Vertical Axis Wind Turbine.* In.: Advances in Smart Grid and Renewable Energy, S. SenGupta et al. (eds.). Springer Nature Singapore Pte. Ltd., **203-213** (2018)
13. R. Kumar, K. Raahemifar, A.S. Fung, *A critical review of vertical axis wind turbines for urban applications.* Renewable and Sustainable Energy Reviews, 89(C), **281-291** (2018)

14. B. Govind, *Increasing the operational capability of a horizontal axis wind turbine by its integration with a vertical axis wind turbine.* Applied Energy, 199, **479-494** (2017)
15. S.R. Shah, R. Kumar, K. Raahemifar, A.S. Fung, *Design, modeling and economic performance of a vertical axis wind turbine*. Energy Reports, 4, **619-623** (2018)
16. Mahdi Moghimi, Hadi Motawej, *Developed DMST model for performance analysis and parametric evaluation of Gorlov vertical axis wind turbines.* Sustainable Energy Technologies and Assessments, 37, **100616** (2020)
17. B. Hand, A. Cashman, *A review on the historical development of the lift-type vertical axis wind turbine: From onshore to offshore floating application.* Sustainable Energy Technologies and Assessments, 38, **100646** (2020)
18. A.S. Pustovoitov, M.A. Chernov, D.O. Pavlov, L.O. Zemlyansky, N.V. Alexandrov, *Overview of the different types of wind turbines in use around the world.* Eurasian Scientific Association, 9-2(67), **124-127** (2020)
19. E.V. Solomin, *Comparative characteristics of vertical-axis wind turbines.* International Scientific Journal for Alternative Energy and Ecology, 1(81), **48-53** (2010)
20. F.D. Bayramov, N.S. Galimov, V.A. Ivanov, *The ways to increas efficiency rotor-type windmills with vertical axis of rotation in the megalopolis.* Scientific and Technical Volga region Bulletin, 2, **99-102** (2014)
21. A.A. Bubenchikov, R.A. Daichman, E.Yu. Artamonova, T.V. Bubenchikova, *Calculation of the profitability of an autonomous power supply system based on a wind power plant with a Darrieus rotor.* Russia is young: advanced technologies go to industry, 1, **149-154** (2015)
22. A.V. Nikitin, *Increasing the power of the wind flow with a wind generator with a diffuser amplifier.* Agricultural innovations, 3(8), **198-202** (2014)
23. A.V. Serebryakov, O.V. Kryukov, Intelligent wind power plant for autonomous power supply systems (Nizhniy Novgorod, Nizhniy Novgorod State Technical University n.a. R.E. Alekseev, 2014)
24. F.M. Mitenkov, A.S. Chistov, V.F. Ovchinnikov, M.Ya. Nikolaev, E.V. Kiryushina, V.N. Litvinov, E.V. Faleeva, O.G. Savikhin, *Electromagnetic suspension in vertical axial wind-driven generators.* Problems of Mechanical Engineering and Machine Reliability, 3, **3-9** (2015)
25. E.V. Solomin, E.A. Sirotkin, E E. Solomin, *The results of testing and operation of vertical axis wind turbines.* PNRPU Bulletin. Electrotechnics, Informational Technologies, Control Systems, 15, **70-83** (2015)
26. D.V. Korobatov, S.V. Kozlov, E.A. Sirotkin, *Historic and economic analysis of wind turbines and control systems.* International Scientific Journal Alternative Energy and Ecology, 15-18, **54-66** (2016)
27. A.A. Bubenchikov, A.E. Belodedov, I.S. Bulychev, A.O. Shepelev, *The study of aerodynamics and power characteristics of Savonius rotor.* International research journal, 12-3(54), **28-34** (2016)
28. V.A. Kostyukov, M.Yu. Medvedev, A.M. Mayevsky, N.K. Poluyanovich, V.V. Savchenko, *Study on advanced aerogenerator with "rotor-in-socket" assembly type.* Vestnik of Don State Technical University. Ser. Machine Building and Machine Science, 1(88), **85-91** (2017)
29. B.P. Khoziainov, *The ways to achieve leadership in wind energy.* International Scientific Journal for Alternative Energy and Ecology, 22-24(270-272), **59-67** (2018)

30. V.A. Galkovsky, M.Sh. Khabibullayeva, A.Kh. Saforzoda, *Calculation of indicators of energy efficiency of wind-driven electric plants of various construction.* Energy saving and water treatment, 5(115), **51-55** (2018)
31. S.N. Chizhma, S.V. Molchanov, A.I. Zakharov, *Criteria for choosing the type of wind turbines for mobile wind-solar power plants.* Bulletin of Baltic Federal University named after I. Kant. Series: Physical-Mathematical and Technical Sciences, 1, **53-62** (2018)
32. M.V. Deremov, N.V. Rudenko, V.V. Yershov, G.Z. Makhauri, *Analysis of the possibility of using wind power plants for power supply of autonomous communication facilities of the Far North.* Proceedings of the North Caucasus Branch of the Moscow Technical University of Communications and Informatics, 1, **295-301** (2019)
33. N.D. Shishkin, R.A. Ilyin, D.I. Atdaev, *The Use of Environmentally Friendly Vertical-Axis Wind Power Plants for Nature Reserves and National Parks in Southern Russia*. Ecology and Industry of Russia, vol. 23, 11, **43-49** (2019)
34. N.D. Shishkin, I.S. Terentyev, Screw-shaped sucker rod pumping units driven by vertical axis wind turbine for oil extraction. Vestnik of Astrakhan State Technical University, 2(62), **11-16** (2016)
35. N.D. Shishkin, R.A. Ilyin, *Experimental study of parameters of vertical-axial wind-power plants for propeller drives on small ships.* Vestnik of Astrakhan State Technical University, 2, **93-100** (2019)
36. Ch. Wilson, A. Grubler, K.S. Gallagher, G.F. Nemet, *Marginalization of end-use technologies in energy innovation for climate protection.* Nature climate change, 2, **780-788** (2012)
37. Å. Lindman, P. Söderholm, *Wind energy and green economy in Europe: Measuring policy-induced innovation using patent data.* Applied Energy, 179(C), **1351-1359** (2016)
38. M.Van Geenhuizen, R. Nejabat, *Municipalities' Policy on Innovation and Market Introduction in Sustainable Energy: A Focus on Local Young Technology Firms.* Energies, 14(4), **1094** (2021)
39. W.E. Kilbourne, *Green Marketing: A Theoretical Perspective*. Journal of Marketing Management, 14(6), **641-655** (1998)
40. Dan Wang, Member IEEE, Liu Liu, Hongjie Jia, Member IEEE, Weiliang Wang, Yunqiang Zhi, Zhengji Meng, and Bingyu Zhou, Review of Key Problems Related to Integrated Energy Distribution Systems., CSEE JOURNAL OF POWER AND ENERGY SYSTEMS, VOL. 4, NO. 2, JUNE 2018 DOI:10.17775/CSEEJPES.2018.00570
41. Abhishek Kumar, Nand K. Meena, Arvind R. Singh, Yan Deng, Xiangning He, R.C. Bansal, Praveen Kumar, Strategic integration of battery energy storage systems with the provision of distributed ancillary services in active distribution systems, , Applied Energy 253 (2019) 113503, doi.org/10.1016/j.apenergy.2019.113503
42. Farihan Mohamad, Jiashen Teh, Ching-Ming Lai and Liang-Rui Chen, Development of Energy Storage Systems for Power Network Reliability: A Review, , Energies 2018, 11, 2278; doi:10.3390/en11092278
43. Omar J. Guerra, Jiazi Zhang, Joshua Eichman, Paul Denholm, Jennifer Kurtz, and Bri-Mathias Hodge, The Value of Seasonal Energy Storage Technologies for the

Integration of Wind and Solar Power, , Energy & Environmental Science, 2020, DOI:10.1039/D0EE00771D

44. Felix Keck, Manfred Lenzen, Anthony Vassallo, Mengyu Li ,The impact of battery energy storage for renewable energy power grids in Australia, , Energy 173 (2019) 647e657, doi.org/10.1016/j.energy.2019.02.053