

PAPER • OPEN ACCESS

Backup Mechanical Brake System of the Wind Turbine

To cite this article: E A Sirotkin *et al* 2018 *J. Phys.: Conf. Ser.* **944** 012109

View the [article online](#) for updates and enhancements.

You may also like

- [Study on Braking Characteristics of Regenerative Brake-By-Wire System Based on Mechanical-Electron-Magnetism Integration for Electric Vehicles](#)
Zhongfu Zhang, Changran He, Jun Xu et al.
- [Simulated Braking Performance Comparison of an Electric Drum Brake and a Hydraulic Drum Brake Systems](#)
A Kittirattanachai and S Watechagit
- [Control of Electronic Mechanical Brake System on Automobile Electromechanical Brake](#)
Yiqing Chen and Youtong Li



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Backup Mechanical Brake System of the Wind Turbine

E A Sirotkin¹, E V Solomin¹ and S A Gandzha¹, I M Kirpichnikova¹

¹International innovative centre «Alternative Energy», South Ural State University (National Research University), 76a, Lenina prospect, Chelyabinsk, 454080, Russia

E-mail: easirotkin@susu.ru

Abstract. Paper clarifies the necessity of the emergency mechanical brake systems usage for wind turbines. We made a deep analysis of the wind turbine braking methods available on the market, identifying their strengths and weaknesses. The electromechanical braking appeared the most technically reasonable and economically attractive. We described the developed combined electromechanical brake system for vertical axis wind turbine driven from electric drive with variable torque enough to brake over the turbine even on the storm wind speed up to 45 m/s. The progress was made due to the development of specific kinematic brake system diagram and intelligent control system managed by special operation algorithm.

1. Introduction

During the last decade several countries have been actively engaged in the development of the Arctic territories. The northern territories are full of undiscovered mineral deposits, and that was the main reason of this activity. According to the UN estimates, the cost of the mineral reserves on the RF Arctic territories comprises over 21 trillion dollars [1, 2]. About 90 % of the Russian gas are produced on the Yamal [3, 4]. Besides, the Arctic territories are treated as strategic locations. Military facilities (for example, air defense complexes) or navigation facilities (GLONASS stations) can be placed there [5]. The Yamal peninsula is also unique because it is equidistant from Paris and Beijing. Thus, in the existing geopolitical environment the region can become a central link in the energy reserves supply chain throughout the entire continent.

Currently, two thirds of the Russian territory are still not electrified by the centralized network. [6, 7]. It can be easily explained economically – the cost of installing power electric lines and their operation and maintenance expenses will be very high, and it may take too long for them to pay back. However, it should be noted that even now the territories connected to the common electric grid are to a certain extent covered by decentralized and self-contained power supply. Yet, the cost of 1 kW-h at some facilities can reach 100 rubles and more [8–10]. Such a high price is predetermined by a low development level of the applied energy technologies. According to different estimates, from 10 to 25 mln. people live on the energetically decentralized territory of the country [11–14]. Over 50 regions are considered energy-deficient, which jeopardizes their own energy security [15].

Figure 1 shows a night satellite image of the Eurasian continent [16]. It is clear from the image that the European (western) and the southern parts of Russia are most electrified, while «the darkest» are the northern and the far-eastern territories. For a stable development of these territories it is necessary to have a relevant infrastructure with a sufficient power supply. Currently, diesel fuel is the main energy carrier in these regions [17]. However, this type is environmentally harmful, and the fuel transportation cost increases the cost of 1 kW-h making it swollen [18].





Figure 1. Eurasian continent screenshot during nighttime.

The noted problem can be solved by using wind turbines (WT). Moreover, it will be expedient to use small wind turbines with the power of up to 100 kW, which can operate under self-sustainment (in a non-networked mode) [19]. Figure 2 shows the distribution of the average annual wind speeds on the RF territory and the adjacent territories [20]. If we compare figure 1 and 2, we can see that the maximum average annual wind speeds are registered on the «unilluminated» northern and far-eastern territories. The northern coastal regions of the continent are within the green area of the wind load, which corresponds to the wind speed range of 5...10 m/s. Some far-eastern regions, in particular, the Kamchatka peninsula, are within the area of stably high wind speeds of 10...15 m/s (marked yellow). Thus, the use of wind turbines on the said territories will be maximally profitable for the economic and technical reasons.

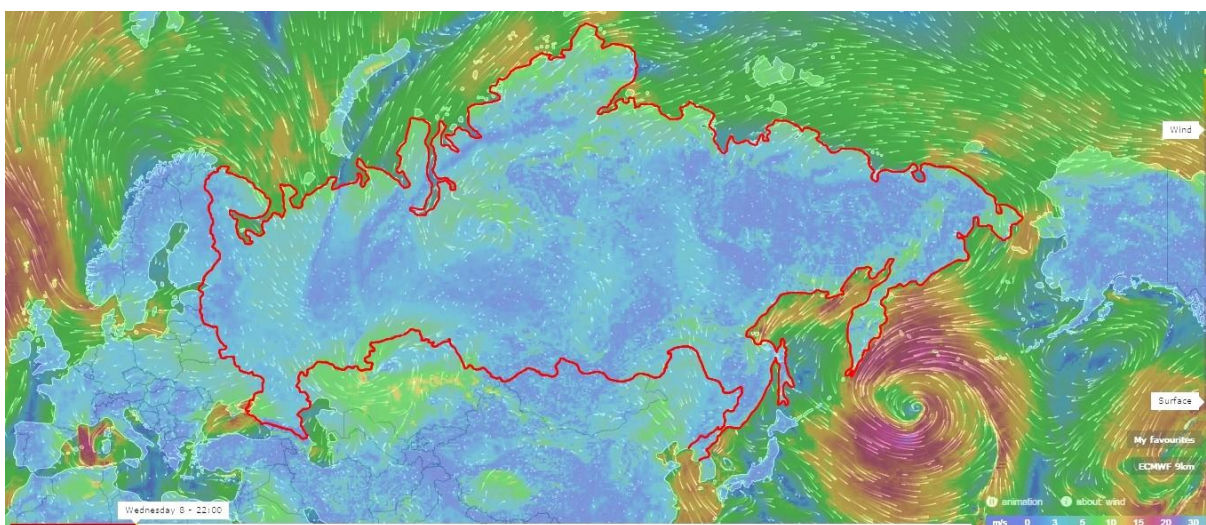


Figure 2. Annual wind speeds spherical map covering Eurasian continent (RF border is marked red).

2. Methods of the WT Power Control

An overwhelming majority of wind turbine manufacturers design their products in such a way, that

the nominal power is generated at the wind speed of 11 m/s [21]. At the same time, they do not consider climatic and geographical factors of the future wind turbine operation. Based on such design features of wind turbines, at the wind speed of over 11 m/s it is necessary to limit power at the wind wheel [22].

To date, there are several traditional ways to limit power at the wind turbine rotor:

1. Increase of the electric load on the generator. When the wind speed grows, the WT controller increases the electric load on the generator, thus, decreasing the rotor speed [23]. This power control method is most energy-efficient from the perspective of power takeoff, however, it is not meant for operation at continuous high wind speeds [24]. It is because the generator windings will be heated with an increasing electric load and at some time reach the critical temperature, after which they have to be cooled down. Periods of a high wind load generally last from one day to several weeks.

2. Closure of the generator windings using the pulse-width modulation. Such braking method enables to brake the wind turbine rotor within the necessary rotation frequency ranges. However, a weak point of this method is a quick overheating of the electrical generator, whereas the kinetic energy of the wind wheel is generated into the heat energy on the generator windings [25]. As a result, this method can be used only for a short period.

3. Airbraking. There are many configurations of aerodynamic regulators, including: blades rotating around the flap axis, special brake blades, which turn around depending on the rotation frequency, devices moving the wind wheel away from the approach flow. However, in practice such regulators were efficient only at large megawatt-class WTs.

4. Mechanical brake systems. This type of systems is most primitive out of all the above-listed. However, at this technical and technological development stage it is most reliable and most economically sound. Firstly, mechanical braking of the wind wheel implies turning of the kinetic energy into the heat one generated on the brake shoes. Modern friction materials preserve their operational characteristics at the temperatures of up to 800 °C, while it is not recommended to heat the generator windings above 100 °C [26]. Secondly, such mechanisms have maximum maintainability, whereas worked-out mechanical parts can be replaced without opening the wind turbine body. Thirdly, mechanical brake systems play the part of a compulsory backup brake system. According to the standards, all the WT, which power exceeds 5 kW, must be fitted with at least one backup brake system [27].

3. WT Electromechanical Brake System

This paper considers an electromechanical brake system with an actuating mechanism in the form of a three-pawl unit for a 3 kW vertical-axis WT. The strong points of such wind turbine include a lack of necessity for wind orientation, low vibration and acoustic irradiation indices, relatively high wind energy efficiency (up to 0,4) [28].

The electromechanical brake system is integrated into the WT structure in the mating place of the mast and the hub. Figure 3 shows a 3-d model of the actuating three-pawl mechanism directly used for braking. Each pawl is fitted with a replaceable friction lining. A limit switch for timely system disabling in the reverse mode is located inside the pawl body.

Due to the multiplicity of advantages of this wind turbine can be installed near residential properties. And also, it may be mounted on the roof of the building. In this case the structure will not threaten the vibrational oscillations of the wind turbine. Given the close location of wind turbines to the residential infrastructure necessary to provide adequate operational safety equipment. First and foremost, we need to prevent the destruction of the windmill blades, since the rotor speed 180 rpm variation of the blades can be up to 50 m in radius. Therefore, the braking system should prevent such situations and to ensure safe work of the personnel.

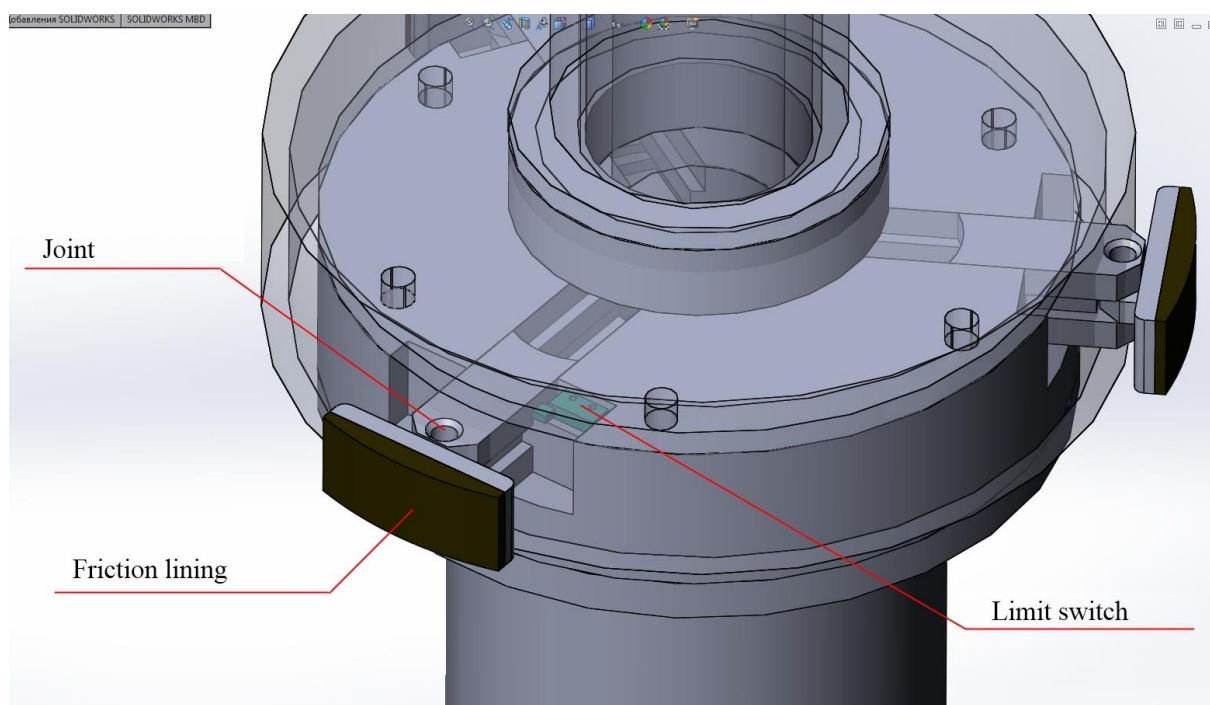


Figure 3. Computer model of the actuating three-pawl assembly of braking system.

Figure 4 shows a kinematic diagram of the entire brake system. When the permissible rotation frequency of the WT rotor or the generator's maximum operating temperature is exceeded, or in case of vibrations, the system's electric drive is activated. Then, power is supplied from the drive through the planetary reduction gear to the scroll gear (with an Archimedian spiral). The scroll gear is fitted with friction pawls with special combs cut in the bottom part. When the scroll gear rotates, the pawl combs begin to move along the spiral, and the pawls move radially. The pawls moving from the center to the periphery bump into the contact wall, which is fixed on the hub and rotates together with it. Thus, when the pawls touch the contact wall, the sliding friction process begins, and the wind wheel brakes.

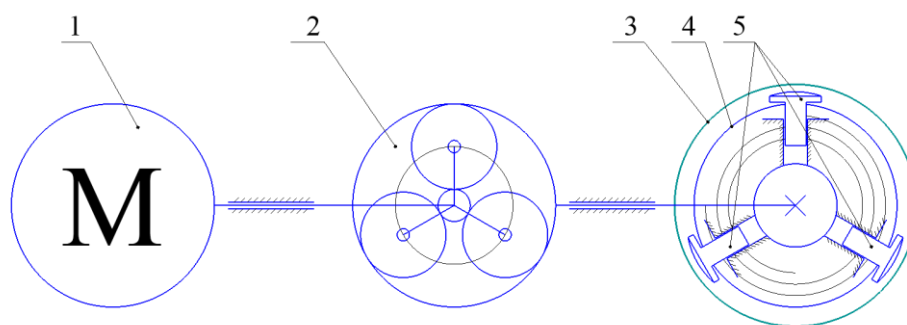


Figure 4. Kinematic diagram of electromechanical braking system: 1 – electric drive; 2 – planetary reduction gear; 3 – contact wall on the hub; 4 – scroll gear; 5 – friction pawls.

Such electromechanical brake system is to be used when the regular control system is unable to carry out the control process (for example, in case of a hurricane force wind) or in case of emergency [29]. These can be technical failures of the regular control system and external effects (lightning stroke or influence of electrical appliances) [30]. Therefore, the designated microcontroller, being a part of the top-level controller, is meant to control the system, however, it can also operate under self-sustainment. Besides, this controller and the system's electric drive are also fed by a separate

autonomous accumulator. The charge of this accumulator passes parallel to the charge of the main accumulator bank, being a part of the entire energy complex.

The control system tracks the status of the WT's three main parameters: generator temperature, wind wheel rotation speed and metal structure's vibration oscillations. If necessary, the system activates the brake's electric drive as per the algorithm and scheme shown in fig. 5 and 6.

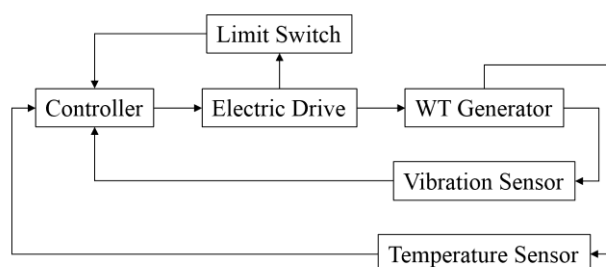


Figure 5. The flow chart of interconnection between braking system electric components.

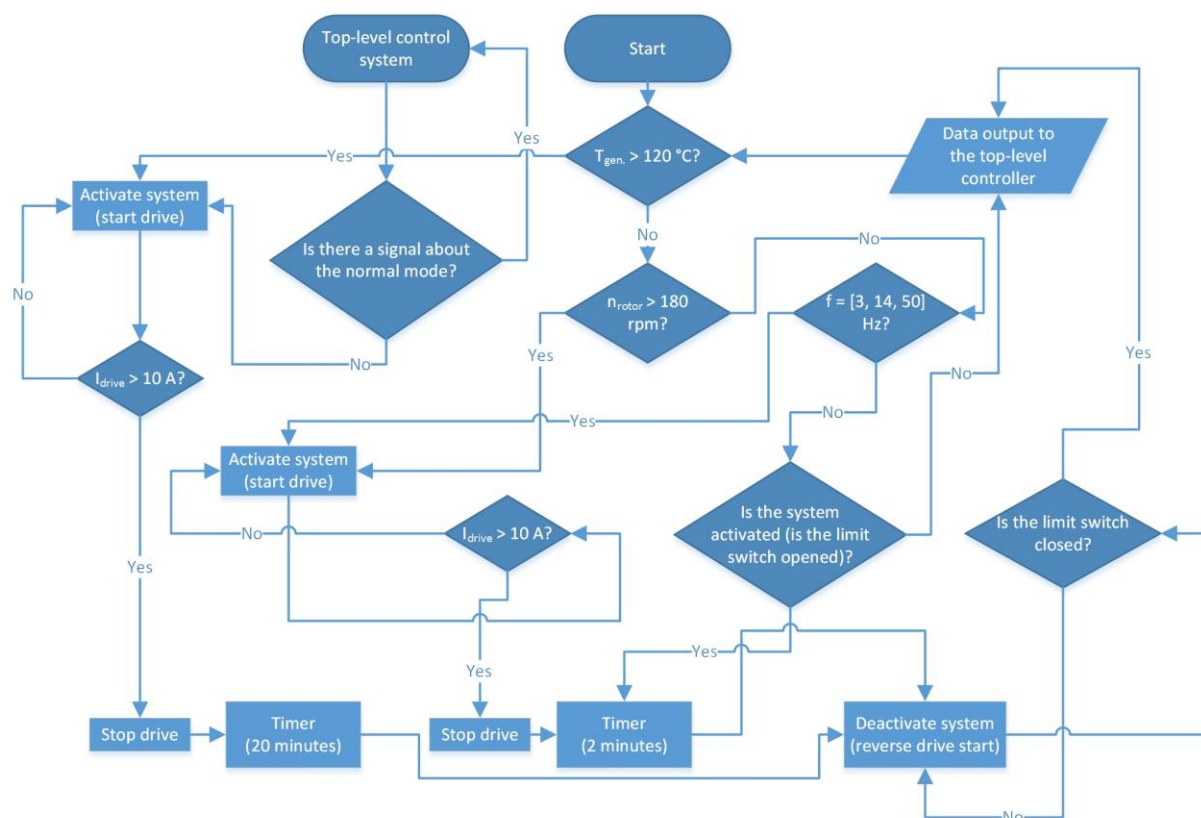


Figure 6. Electromechanical braking system operation algorithm.

Actuation and operation of the electric drive continue, until the current intensity in the drive reaches 10 A. It proves that the pawls press the contact wall with the force of 30,000 N. Such pressure must be applied to brake the vertical-axis wind turbine. Then, the rotor stops, and the system waits for 2 minutes, after which the electric drive is re-activated but in the reverse mode. The drive keeps operating, until the pawls return to the initial position and press the limit switch. A brake signal can be given to the electromechanical brake control system from the top-level control system (for example, it can be user-activated remote braking of the WT).

4. Conclusion

The considered electromechanical brake system has the outstanding competitive advantages both on economic and technical sides. Reliable mechanical links withstand high temperature loads absorbing more excessive power at the WT rotor area, comparing with analogs. The mechanical links are operable at a high load long term operation, which enables braking of the wind turbine even at storm wind speeds. Thus, at this technological development stage, the electromechanical method (as a duplicating one) is most reasonable.

5. Acknowledgments

The work was supported by Act 211 Government of the Russian Federation, contract №02.A03.21.0011.

References

- [1] Gogoberidze G, Abramov V M, Karlin L N, Lednova J and Malakhova J 2014 Marine economic potential assessment for environmental management in the Russian arctic and subarctic coastal regions *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management SGEM* 3 (5) pp 253–260
- [2] Tatarkin A I and Loginov V G 2015 Estimation of potential for natural resources and production in northern and Arctic areas: Conditions and prospects for use *Studies on Russian Economic Development* 26 (1) pp 22–31
- [3] Dudin M N, Sekerin V D, Gorohova A E, Bank SV and Danko T P 2016 Arctic zone: Global strategic priorities for integrated development and infrastructure policy (Man in India) 96 (7) pp 2297–2313
- [4] Yoon J R and Kim Y 2001 Reviews on Natural Resources in the Arctic: Petroleum, Gas, Gas Hydrates and Minerals *Ocean and Polar Research* 23 (1) pp 51–62
- [5] Dudin M N, Ivashchenko N P, Frolova E E, Abashidze A H and Smbatyan A S 2016 Innovative approach to the development of the logistics system of supply of the Arctic region space *International Journal of Economics and Financial Issues* 6 (4) pp 1965–1972
- [6] Boute A 2013 Renewable energy federalism in Russia: Regions as new actors for the promotion of clean energy *Journal of Environmental Law* 25 (2) pp 261–291
- [7] Milov V, Coburn L L and Danchenko I 2006 Russia's energy policy 1992–2005 *Eurasian Geography and Economics* 47 (3) pp 285–313
- [8] Gore O, Viljainen S, Makkonen M and Kuleshov D 2012 Russian electricity market reform: Deregulation or re-regulation? *Energy Policy* 41 pp 676–685
- [9] Bashmakov I 2009 Resource of energy efficiency in Russia: Scale, costs, and benefits *Energy Efficiency* 2 (4) pp 369–386
- [10] Lombardi P, Sokolnikova T, Suslov K, Voropai N and Styczynski Z A 2016 Isolated power system in Russia: A chance for renewable energies? *Renewable Energy* 90 pp 532–541
- [11] Larionov A and Nezhnikova E 2016 Role of energy efficiency in improving the quality of housing projects *International Journal of Applied Engineering Research* 11 (6) pp 4433–4439
- [12] Larionov A and Nezhnikova E 2016 Energy efficiency and the quality of housing projects *ARPN Journal of Engineering and Applied Sciences* 11 (3) pp 2023–2029
- [13] Boute A 2016 Off-grid renewable energy in remote Arctic areas: An analysis of the Russian Far East *Renewable and Sustainable Energy Reviews* 59 pp 1029–1037
- [14] Efendiev A M, Nikolaev Y E, Evstaf'ev D P 2016 Opportunities of energy supply of farm holdings on the basis of small-scale renewable energy sources *Thermal Engineering* (English translation of Teploenergetika) 63 (2) pp 114–121
- [15] Runkle B R K, Wille C, Gažovič M, Wilmking M and Kutzbach L 2014 The surface energy balance and its drivers in a boreal peatland fen of northwestern Russia *Journal of Hydrology* 511 pp 359–373
- [16] https://www.nasa.gov/mission_pages/NPP/news/earth-at-night.html
- [17] Overland I 2010 2017 Russia's Arctic energy policy *International Journal* 65 (4) pp 865–878

- [18] Sevastyanov S and Kravchuk A 2017 The Russian approach to national security in the arctic *Korean Journal of Defense Analysis* 29 (1) pp 131–150
- [19] Morais H, Kádár P, Faria P, Vale Z A and Khodr H M 2010 Optimal scheduling of a renewable micro-grid in an isolated load area using mixed-integer linear programming *Renewable Energy* 35 (1) pp 151–156
- [20] <http://explorer.worldwind.earth/>
- [21] Khan M J and Iqbal M T 2005 Dynamic modeling and simulation of a small wind-fuel cell hybrid energy system *Renewable Energy* 30 (3) pp 421–439
- [22] Datta R and Ranganathan V T 2003 A method of tracking the peak power points for a variable speed wind energy conversion system *IEEE Transactions on Energy Conversion* 18 (1) pp 163–168
- [23] Hansen A D, Sørensen P, Iov F and Blaabjerg F 2006 Centralised power control of wind farm with doubly fed induction generators *Renewable Energy* 31 (7) pp 935–951
- [24] Bossanyi E A 2003 Wind turbine control for load reduction *Wind Energy* 6 (3) pp 229–244
- [25] Teodorescu R and Blaabjerg F 2004 Flexible control of small wind turbines with grid failure detection operating in stand-alone and grid-connected mode *IEEE Transactions on Power Electronics* 19 (5) pp 1323–1332
- [26] Abrahamsen A B, Mijatovic N, Seiler E, Sørensen M P, Koch M, Nørgard P B, Pedersen N F, Træholt C, Andersen N H and Østergard J 2009 Design study of 10 kW superconducting generator for wind turbine applications *IEEE Transactions on Applied Superconductivity* 19 (3), art. no. 5067256, pp 1678–1682
- [27] Solomin E V, Sirotkin E A and Martyanov A S , 2015 Adaptive control over the permanent characteristics of a wind turbine *Procedia Engineering* 129 pp 640–646
- [28] Korobotov D V, Sirotkin E A, Troickiy A O and Solomin E V 2017 Wind turbine power plant control *2016 Dynamics of Systems, Mechanisms and Machines, Dynamics 2016* art. no. 7819031
- [29] Wang K, Hansen M O L and Moan T 2014 Dynamic analysis of a floating vertical axis wind turbine under emergency shutdown using hydrodynamic brake *Energy Procedia* 53 (C) pp 56–69
- [30] Yankov P V, Van Den Bossche A and Valchev V C 2010 Successive resistive braking circuit for permanent magnet wind turbine generators *Proceedings of EPE-PEMC 2010 - 14th International Power Electronics and Motion Control Conference* art. no. 5606915 pp T1127-T1131