

1. Serhiy SYROTYUK¹, 2. Vitaliy BOYARCHUK¹, 3. Serhii KOROBKA¹, 4. Vadym PTASHNYK¹,
5. Serhii BARANOVYCH¹, 6. Roman SHEREMETA¹, 7. Hanna SYROTYUK²,
8. Viktor CHUMAKEVYCH³, 9. Jan GIEŁŻECKI⁴, 10. Tomasz JAKUBOWSKI⁴, 11. Paweł SOKOŁOWSKI

Lviv National Environmental University, Department of Energy (1), Lviv National Environmental University, Department of Economics (2), Lviv Polytechnic National University, Department of Engineering Geodesy (3), University of Agriculture in Krakow, Faculty of Production and Power Engineering (4), University of Agriculture in Krakow, Faculty of Environmental Engineering and Land Surveying (5)
ORCID: 1. 0000-0001-9966-6299; 2. 0000-0001-8294-8759; 3. 0000-0002-4717-509X; 4. 0000-0002-1018-1138;
5. 0000-0001-8671-6517; 6. 0000-0002-7331-3118; 7. 0000-0002-8740-7959; 8. 0000-0002-5773-393X;
9. 0000-0002-4996-4252; 10. 0000-0002-5141-2705; 11. 0000-0002-5774-281X

doi:10.15199/48.2024.04.58

Design and Research of Computer Model of Wind Turbine Using LabVIEW

Streszczenie. Problematyka modelowania przepływu wiatru i elektromechaniki turbiny wiatrowej cieszy się dużym zainteresowaniem. Praca dotyczy projektowania i badania modelu turbiny wiatrowej. Wyniki badań dynamiki elektryczno-mechanicznego układu opracowano za pomocą oprogramowania LabVIEW. Opracowany model komputerowy turbiny wiatrowej umożliwia prowadzenie badań jej dynamiki przy stochastycznej zmianie prędkości wiatru.

Abstract. The issues of wind flow modeling and wind turbine electromechanics are of great interest. The work concerns the design and testing of a wind turbine model. The results of the study of the electro-mechanical dynamics of the system were developed using the LabVIEW software. The developed computer model of the wind turbine enables the study of its dynamics with stochastic changes in wind speed. (**Projektowanie i badanie komputerowego modelu turbiny wiatrowej z wykorzystaniem LabVIEW**).

Słowa kluczowe: model komputerowy, przepływ wiatru, turbina wiatrowa, zintegrowane środowisko programistyczne LabVIEW.

Keywords: computer model, wind flow, wind turbine, LabVIEW integrated development environment.

Introduction

The development of wind power engineering requires the constant improvement of both technology and converting the wind power usually into electrical energy, which is not possible without a deep study of electromechanical processes occurring in a turbine. To minimize the costs and time for development and improvement of the design of wind turbines as well as systems of their control, the methods of computer simulation are used. This modelling can be implemented using up-to-date mathematical apparatus, methods of investigation, and applied software. Traditionally, the technology of computer simulation is realized in MATLAB/Simulink [1–3], less often using other software [4–7]. Apart from the design and improvement of the construction of a wind power turbine, one of the objectives of computer simulation is forecasting power generation with existing turbines [8–9].

One of the possible ways of computer simulation is the use of virtual tools in the LabVIEW software environment made by National Instruments. This software has several advantages, in particular: the programming is based on the means of graphic G-programming, which is close to the nature of the activities of scientific and engineering personnel; user-friendly and informative user interface; the features of using the external data input/output devices, etc. Due to this, we applied this software.

Simulation of wind turbines can be performed using a continuous signal of input data on wind speed from anemometers or using a computer model of stationary and variable wind flows. The first of them is not convenient due to weather conditions, i.e. it is uncontrolled. The second one allows us to perform the research within a wide range of wind speeds, both stationary and stochastically variable.

Therefore, two models are used in the simulation - the model of the electromechanical part of the wind turbine and the model of the wind flow which is the main input parameter.

The issue of modelling the wind flow and the electromechanics of the wind turbine has attracted

significant attention, as evidenced by a significant number of publications [8–11]. In particular, in the work [12] a simplified model of a wind turbine operating in low winds is considered. In the article [13] in the Matlab/Simulink, the computer model of a wind turbine for research of its control system is developed. It is characteristic that the incoming wind flow is formed in the form of flutter-driven perturbation. A similar problem in the Matlab/Simulink is solved in the article [14], where the wind flow model is presented in the form of a submodule, the development of which was presented in [15].

Wind Flow Model

To generalize empirical dependences and convenience of their processing by methods of probability theory, the set of experimental values of wind flow Φ_V within the full range of velocities from 0 to V_m is approximated by a similar analytical dependence $\Phi(V)$ (usually by a two-parameter function of the Weibull distribution) [16–18]:

$$(1) \quad \Phi(V) = \frac{k}{c} \left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^k\right]$$

where: k is the curve shape parameter; c is the scale parameter close to the average velocity.

However, based on statistical estimation of wind flow velocity using the laws of its distribution, it is not possible to carry out a dynamic estimation of wind flow velocity, and accordingly the dynamics of wind power turbines.

Therefore, the need arises to construct mathematical models of wind flow dynamics, which are usually based on two main methods – concerning time [8] and concerning spectral characteristics [10, 19–22]. In addition, there are models of wind flow, which are formed taking into account such meteorological conditions as ambient temperature, humidity, atmospheric pressure, etc. [9, 23–26].

The value of the wind velocity in its simulation can either be applied as constants or as given within certain dynamic ranges of change. This allows the simulation of wind turbines in static and dynamic modes. The wind velocity can

be written as the sum of the average and variable wind velocities [24].

We took an approach based on the spectral method as a methodical basis for the development of the mathematical model of a wind flow. Applying the spectral method of wind flow modelling, in which the spectral density of wind power $V_w = f(S)$ in the entire frequency range depends on the degree of wind turbulence [27].

We have adapted the mathematical model implemented in [27] in the Mathcad for use in the LabVIEW software package. The front panel and block diagram of the computer model of wind flow implemented in the LabVIEW are given in figures 1 and 2.



Fig. 1. Front panel of the computer model of wind flow implemented in the LabVIEW

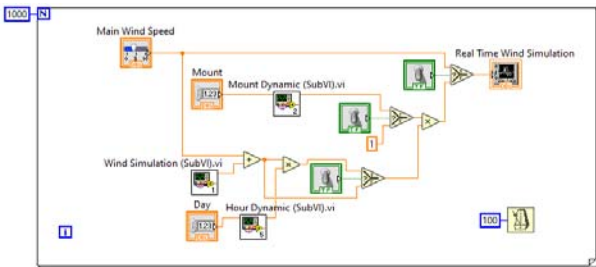


Fig. 2. Block diagram of the computer model of wind flow implemented in the LabVIEW

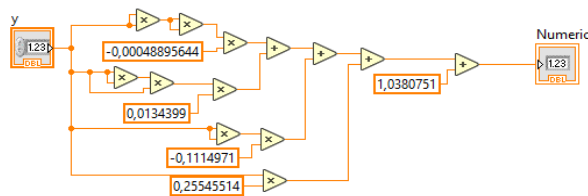


Fig. 3. Block diagram of the Mount Dynamic submodule (Sub VI.vi) of the computer model of wind flow

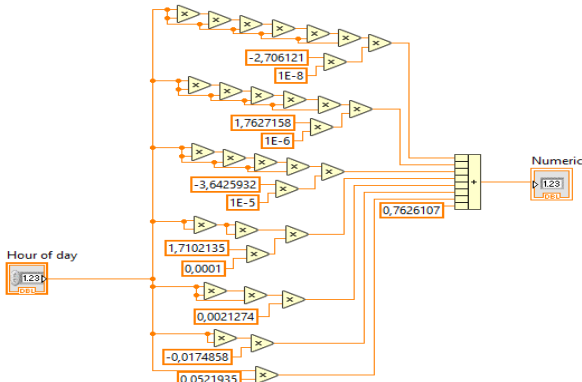


Fig. 4. Block diagram of the Hour Dynamic submodule (Sub VI.vi) of the computer model of wind flow

This model includes the submodules of additional dynamic components that reflect the daily change (Fig. 3) and seasonal change (Fig. 4) in the average wind velocity.

The dynamics of changes in the average wind velocity in the daily and seasonal cycles are shown in Figures 5 and 6.

Wind Power Turbine Model

The dynamics of changes in the average wind velocity in the daily and seasonal cycles are shown in Figures 5 and 6.

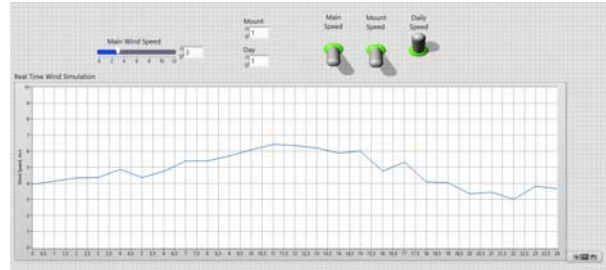


Fig. 5. Front panel of the computer model of wind flow in the mode of switching on the Hour Dynamic submodule (Sub VI)

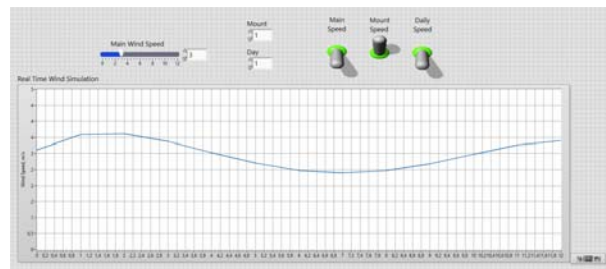


Fig. 6. Front panel of the computer model of wind flow in the mode of switching on the submodule Mount Dynamic (Sub VI)

An autonomous low-power wind turbine is a complex electromechanical system. It consists of a wind turbine, which receives the energy of the translational wind flow and converts it into a rotating motion of the main shaft of the turbine, which is connected directly or through the transmitting device to the generator. Usually, to agree on the kinematic characteristics of the wind turbine and the generator, a multiplier is used, the expediency of installation of which is determined based on functional and cost analyses [28-30].

To ensure the high efficiency of wind energy application by the wind turbine and the stability of its operation, it is necessary to ensure the consistency of the input energy of the wind flow with the extraction of energy produced by the wind turbine. First of all, it is necessary to provide a mode of energy extraction from the wind turbine, in which the operating point on the wind turbine characteristic would be to the right of the maximum value of wind energy consumption at a certain distance due to the wind flow and load dynamics.

The agreement on the parameters of the individual structural elements of the wind power turbine can be performed based on modelling its operation in the entire range of changes in the influencing factors.

The issue of modelling wind power turbines, in particular, the development of computer simulation models allowing carrying out the simulation research of complex systems attracts considerable attention. The development of computer models allows carrying out the development of control systems for operating modes of wind power turbines [15, 16].

The structure of the developed model of wind power turbine includes the following subsystems: input parameters of wind flow; determining the current value of the wind turbine torque; determining the current value of the angular

velocity of the wind turbine; modelling of parameters of the electric generator; determination of the current power of the wind turbine; parameters of the multiplier; modelling the characteristics of the wind turbine (Fig. 7).

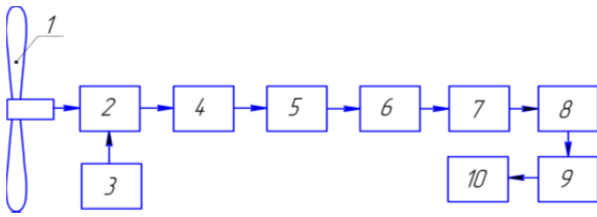


Fig. 7. Block diagram of autonomous wind power turbine: 1 – wind turbine; 2 – braking subsystem; 3 – subsystem of wind turbine orientation on wind and its output out of the wind; 4 – multiplier; 5 – electric generator; 6 – rectifier; 7 – battery charge controller; 8 – rechargeable battery; 9 – inverter; 10 – electricity consumers

The developed model allows carrying out modelling of operating modes of wind power turbine, and also to carry out archiving of the generated databases.

Visualization of the current values of the researched parameters is provided by virtual devices (oscilloscopes, digital displays, controllers), which are mounted on the virtual front panel (Fig. 8).

The load at the output of the generator was changed manually by changing the load resistance using a virtual device (Pointer Slide). The rhythm of the research was given using a virtual device (Wait Until Next ms Multiple).

The theoretical basis of the developed model of the wind rotor subsystem of a wind power turbine is the equation of the moment it develops by receiving the wind flow [18]:

$$(2) \quad M = \int_{r_0}^R dM = \int_{r_0}^R 4\pi \cdot r^2 \cdot \rho \frac{e}{1+e} v^2 \frac{1-\mu z_v}{z_v + \mu} dr$$

The solution to this equation is the expression

$$(3) \quad M = \frac{4e}{Z} \frac{1-e}{1+e} \left[1 - \frac{r_0^2}{R^2} - 2\mu \left(\frac{z_v}{3} + \frac{1 \cdot \frac{r_0}{R}}{z_v} - \frac{1 - \frac{r_0^2}{R^2}}{2} \right) \right] \pi R^3 \frac{\rho [v(t)]^2}{2}$$

where e is the airflow inhibition coefficient ($e = v_1/v$); v_1 is the velocity caused by the action of the torque of the wind turbine blades, m/s; $v(t)$ is the wind velocity, m/s; Z is the modularity of the wind turbine ($Z = \omega R/v$); r_0 is the radius of the beginning of the working area of the blade, m; r is the wind turbine radius, m; μ is a parameter corresponding to the inverse of the blade quality ratio ($\mu = C_x/C_y$); C_x and C_y are the resistance of the blade in its plane and the lifting force, respectively; z_v is the modularity corresponding to a certain radius of the wind turbine bracket; ρ is the air density, kgm^{-3} . The theoretical basis for modelling the generator of wind power turbine is the following system of equations

$$(4) \quad \begin{cases} di(t)/dt = 1/L_0 (C_1 \cdot \omega(t) - (R_0 + R_i(t)) \cdot i(t)) \\ M(t) = C_2 \cdot I \\ U = C_1 \cdot \omega(t) + (R_0 + R_i(t)) \cdot I \\ t = k \cdot dt \end{cases}$$

where $i(t)$ is the momentary value of the current in the armature circuit of the generator, A; dt is the increase in time, s; R_0 and $R_i(t)$ are active resistances of the armature winding and load, respectively, Ω ; ω is the angular velocity of the generator armature, rad/s ; L_0 is the total inductance of the electric circuit, H; C_1 and C_2 are the structure constants of the generator; t is the final value of the integration time, s.

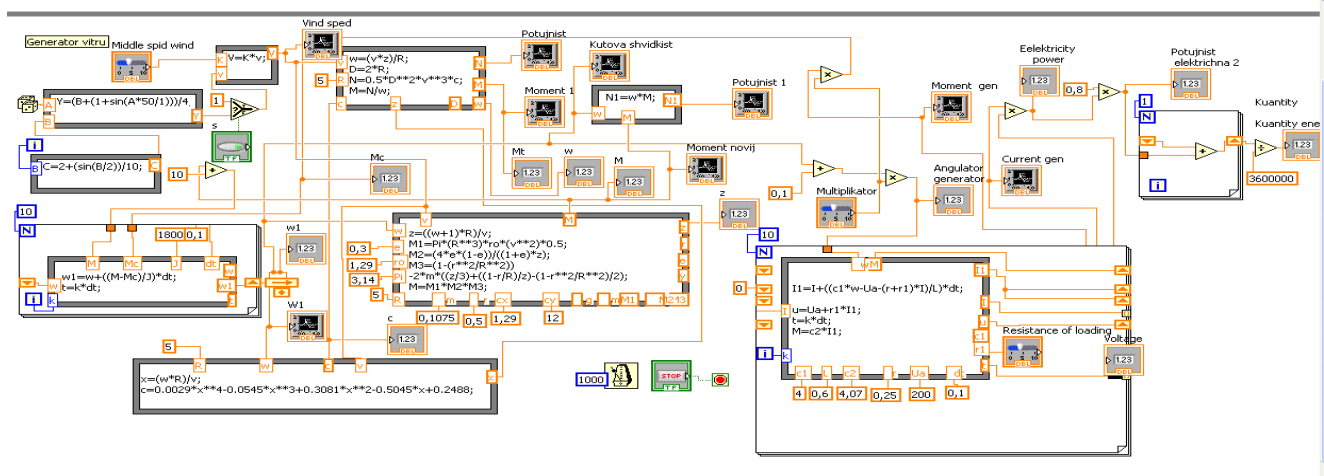


Fig. 8. Fragment of the front panel of the computer model of the wind power turbine

The subsystem of the wind turbine dynamics is modelled by the following equation:

$$(5) \quad J \frac{d\omega}{dt} = M - M_c$$

where J is the moment of inertia of the wind turbine and the rotational mass of the transmission transmitted to the main shaft, kgm^2 ; M is the moment developing the wind rotor transmitted to the main shaft, Nm; M_c is the moment of resistance on the generator shaft (electromagnetic moment) transmitted to the main shaft and the moments of friction resistance, Nm.

The basis of the subsystem for the formation of the characteristics of the wind turbine was the empirical equation for approximating the curve of the coefficient of consumption of wind energy from the velocity turbine by a polynomial of power 4 in the form:

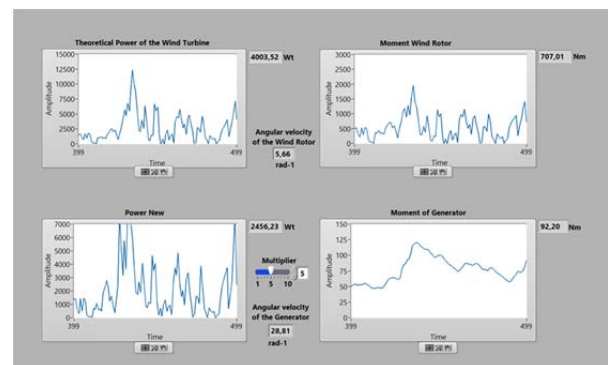


Fig. 9. Fragment of a block diagram of the computer model of a wind turbine

$$(6) \square C = 0.0029z^4 - 0.0545z^3 + 0.3081z^2 - 0.5045z + 0.2488$$

The block of diagrams of the computer model of the wind power turbine is given in Figure 9.

Summary

The computer model of wind flow adapted for LabVIEW software has been improved with the introduction of daily and seasonal non-uniformity of its change, which brings it as close as possible to the real wind flow.

The developed computer model of wind electric turbines allows carrying out the research of its dynamics by the stochastic change of wind speed.

The use of switches of the wind flow formation modes allows us to study the behaviour of the wind power turbine in statics and dynamics.

The long-term study of the developed computer model of wind flow may provide for its improvement using correcting the elements based on comparison with the data of meteorological measurements of wind speed.

The developed computer model of wind power turbine can be considered as a basis for its further improvement by introduction of additional submodules, for example, a system of storage of the electric power; the independent, network or hybrid inverter; PVM and MPPT controllers; a system of the orientation of the rotor on wind and output out of it, etc.

Another direction that would allow for a broader presentation of results (e.g. 3D maps) seems to be interesting, which would be possible by implementing a dedicated graphical interface as used in the work [31].

Authors: Dr. Eng., Serhiy Syrotyuk, Lviv National Environmental University, Faculty of Mechanics, Energy and Information Technologies, Vol. Velykogo str., 1, 80381, Dubliany-Lviv, Ukraine, E-mail: syrotyuksv@lnup.edu.ua; Dr. Eng., Vitaliy Boyarchuk, Lviv National Environmental University, Faculty of Mechanics, Energy and Information Technologies, Vol. Velykogo str., 1, 80381, Dubliany-Lviv, Ukraine, E-mail: boyarchukvm@lnup.edu.ua; Dr. Eng., Serhii Korobka, Lviv National Environmental University, Faculty of Mechanics, Energy and Information Technologies, Vol. Velykogo str., 1, 80381, Dubliany-Lviv, Ukraine, E-mail: korobkasv@lnup.edu.ua; Dr. Eng., Vadym Ptashnyk, Lviv National Environmental University, Faculty of Mechanics, Energy and Information Technologies, Vol. Velykogo str., 1, 80381, Dubliany-Lviv, Ukraine, E-mail: ptashnykproject@gmail.com; Dr. Eng., Serhii Baranovych, Lviv National Environmental University, Faculty of Mechanics, Energy and Information Technologies, Vol. Velykogo str., 1, 80381, Dubliany-Lviv, Ukraine, E-mail: baranovychsm@lnup.edu.ua; Dr. Eng., Roman Sheremeta, Lviv National Environmental University, Faculty of Mechanics, Energy and Information Technologies, Vol. Velykogo str., 1, 80381, Dubliany-Lviv, Ukraine, E-mail: sheremetarb@lnup.edu.ua; Dr. Econ., Hanna Syrotyuk, Lviv National Environmental University, Faculty of Management, Economics and Law, Vol. Velykogo str., 1, 80381, Dubliany-Lviv, Ukraine, E-mail: syrotyukgv@lnup.edu.ua; Dr. Eng., Viktor Chumakevych, Lviv Polytechnic National University, Institute of Geodesy, 6 Karpinskoho str., 79013, Lviv, Ukraine, E-mail: chumakevich@ukr.net; Dr. Eng. Jan Gielzecki, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Al. Mickiewicza 21, 31-120 Krakow, Poland, E-mail: jan.gielzecki@urk.edu.pl; Dr. Eng. Tomasz Jakubowski, prof. URK, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Al. Mickiewicza 21, 31-120 Krakow, Poland, E-mail: tomasz.jakubowski@urk.edu.pl.; Dr. Eng. Paweł Sokółowski, University of Agriculture in Krakow, Faculty of Environmental Engineering and Land Surveying, Al. Mickiewicza 21, 31-120 Krakow, Poland, E-mail: pawel.sokolowski@urk.edu.pl.

REFERENCES

- [1] Gielzecki J., Jakubowski T. The Simulation of Temperature Distribution in a Ground Heat Exchanger-GHE Using the Autodesk CFD Simulation Program, *4th International Conference on Renewable Energy Sources (ICORES)*, (2018)
- [2] Johnson B., Pike G.E., Preparation of Papers for Transactions, *IEEE Trans. Magn.*, 50 (2002), No. 5, 133-137
- [1] Koley I., Dey S., Sain C., Matlab modeling and simulation of DFIG with dump resistor during faulty condition, *International Journal of Engineering Inventions*, 4 (2014), 1, 11–17
- [2] Mozafarpour-Khoshrodi S.-H., Shahgholian G., Improvement of perturb and observe method for maximum power point tracking in wind energy conversion system using fuzzy controller, *Energy Equipment and Systems*, 4 (2016), No 2, 111–122
- [3] Oleynikov A., Matveev Yu., Kanov L., Modeling of a low-power wind plant mode, *Electrical Engineering & Electromechanics*, (2010), No 2, 16–20
- [4] Ayhan D., Saglam S., A technical review of building-mounted wind power systems and a sample simulation model, *Renewable and Sustainable Energy Reviews*, 16 (2012), 1040–1049
- [5] Beltran B., Ahmed-Ali T., El Hachemi Benbouzid M., Sliding mode power control of variable-speed wind energy conversion systems, *IEEE Transactions on energy conversion*, 23 (2008), No. 2, 551–558
- [6] Hansen A., Jauch C., Sorensen P., Iov F., Blaabjerg F., Dynamic wind turbine models in power system simulation tool DlgSILENT, Roskilde: Rise National Laboratory, (2003)
- [7] Singh M., Santoso S., Dynamic models for wind turbines and wind power plants, Golden: National Renewable Energy Laboratory, (2011)
- [8] El-Fouly T., El-Saadany E., Salama M., One day ahead prediction of wind speed using annual trends, *IEEE Power Engineering Society General Meeting*, (2006), 1–7
- [9] Foley A., Leahy P., Marvuglia A., McKeogh E., Current methods and advances in forecasting of wind power generation, *Renewable Energy*, 37 (2012), 1–8
- [10] Neammanee B., Sirisumrannukul S., Chatratana S., Development of a wind turbine simulator for wind generator testing, *Internatoinal energy journal*, (2007), No 8, 21–28
- [11] Kumar D., Chatterjee K., A review of conventional and advanced MPPT algorithms for wind energy systems, *Renewable and Sustainable Energy Reviews*, 55 (2016), 957–970
- [12] Eisenhut C., Krug F., Eisenhut C., Wind-turbine model for system simulations near cut-in wind speed, *IEEE Trans. on Energy Conversion*, 22 (2007), No. 2, 414–420
- [13] Subota A., Dybska I., Zabolotniy O., Control system of wind-driven power plant, *Radioelectronic and Computer Systems*, 37 (2009), No 3, 61–67
- [14] Lozynsky A., Shchur V., Control system for wind turbine based on fuzzy logic controller in view of aerodynamic changes of wind rotor parameters, *Electromechanical and energy saving systems*, 31 (2015), No. 3, 10–21
- [15] Shchur V., Mathematical model of turbulent wind flow for computer and physical modeling of wind turbines, *Electromechanical and energy systems, methods of modeling and optimization*, (2012), 199–200
- [16] Bianchi F., Battista H., Mantz R., Wind turbine control systems: principles, modelling and gain scheduling design, London: Springer, (2007)
- [17] Anaya-Lara O., Jenkins N., Ekanayake J., Cartwright P., Hughes M., Wind energy generation: modelling and control, West Sussex: Wiley, (2009)
- [18] Syrotyuk S., Boyarchuk V., Halchak V., Alternative Energy Sources. Wind energy, Lviv: Magnolia, (2017)
- [19] Nichita C., Luca D., Dayko B., Ceanga E., Large band simulation of the wind speed for real time wind turbine simulators, *IEEE Trans. on Energy Conversion*, 17 (2002), No. 4, 523–529
- [20] Tankari M., Camara M., Dakyo B., Nichita C., Wind power integration in hybrid power system with active energy management, *International Journal of Computations and Mathematics in Electrical*, 30 (2011), No 1, 1–6
- [21] Babazadeh H., Gao W., Cheng L., Lin J., An hour ahead wind speed prediction by Kalman filter, *Power Electronics and Machines in Wind Applications*, (2012), 1–6

- [22] Nichita C., Luca D., Dakyo B., Ceanga E., Cutululis N., Modelling non-stationary wind speed for renewable energy systems control, *The Annals of Dunarea de JOS: Electrotechnics Electronics Automatic Control and Informatics*, (2001), 29–34
- [23] Carta J., A continuous bivariate model for wind power density and wind turbine energy output estimations, *Energy Conversion and Management*, 48 (2007), 420–432
- [24] Lange M., Focken U., *Physical approach to short-term wind power prediction*, New York: Springer, (2005)
- [25] Xin L., Bin L., Jianyuan X., Yun T., A novel power predicting model of wind farm based on double ANNs, *Power and Energy Engineering Conference*, (2010), 1–4
- [26] Jaehnert S., Aigner T., Doorman G., Gjengedal T., Impact of large scale wind integration on power system balancing, *Power Tech IEEE Trondheim*, (2011), 1–6
- [27] Shchur I., Shchur V., Optimal control of wind turbines of different power in turbulent winds, *Electrical Power and Electromechanical Systems*, (2012), No 736, 146–152
- [28] Syrotiuk V., Boyarchuk V., Vorobkevych V., Syrotiuk S., Halchak V., Furman A., Substantiation of the structure of transmission devices of agricultural wind turbines, *Motrol. Motorization and power industry in agriculture*, 14 (2012), No 4, 75–83
- [29] Tadeusiewicz R., Tylek P., Adamczyk F., Kielbasa P., Jabłoński M., Bubiński Z., Grabska-Chrząstowska J., Kaliniewicz Z., Walczyk J., Szczepaniak J., Juliszewski T., Szaroleta M. Assessment of selected parameters of the automatic scarification device as an example of a device for sustainable forest management. *Sustainability*, (2017), 9 (12), 2370
- [30] Trzyniec K., Kowalewski A. Use of an artificial neural network to assess the degree of training of an operator of selected devices used in precision agriculture. *Energies*, (2020), 13(23)
- [31] Mączka M., Effective Simulations of Electronic Transport in 2D Structures Based on Semiconductor Superlattice Infinite Model. *Electronics*, (2020), 9, 1845.
<https://doi.org/10.3390/electronics9111845>