Scientific Papers of
the Department of Electrical Power Engineering of
the Wrocław University of Science and Technology

PRESENT PROBLEMS OF POWER SYSTEM CONTROL

9

Wrocław 2018

Printed in the camera ready form

Department of Electrical Power Engineering
Wrocław University of Science and Technology
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
phone: +48 71 320 35 41
www: http://www.weny.pwr.edu.pl/instytuty,52.dhtml; http://www.psc.pwr.edu.pl
e-mail: wydz.elektryczny@pwr.edu.pl

OFICYNA WYDAWNICZA POLITECHNIKI WROCŁAWSKIEJ
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław
http://www.oficyna.pwr.edu.pl
e-mail: oficwyd@pwr.edu.pl
zamawianie.ksiazek@pwr.edu.pl

ISSN 2084-2201

Print and binding: beta-druk, www.betadruk.pl

CONTENTS

Yu. KOZHUSHKO, T. KARBIVSKA, D. ZINCHENKO, D. PAVKOVIĆ, E. ROSOLOWSKI, O. BONDARENKO, Charging Device of Capacitive Energy Storage for Micro Resistance Welding 5

B. KASZTENNY, A. GUZMÁN, M. V. MYNAM, T. JOSHI, Controlling Autoreclosing on Overhead Lines with Underground Cable Sections Using Traveling-Wave Fault Location Based on Measurements from Line Terminals Only 19

K. KLEN, V. ZHUIKOV, Approximation and Prediction of the Wind Speed Change Function 35

J. SZAFRAN, E. ROSOŁOWSKI, Dynamically Corrected Fast Estimators of Active and Reactive Power and Their Performance 47

Present Problems of Power System Control. 9, 2018

distributed generation, wind generator,
Heisenberg's uncertainty principle,
linear approximation,
Walsh functions, regression analysis

Kateryna KLEN*
Valery ZHUIKOV*

APPROXIMATION AND PREDICTION OF THE WIND SPEED CHANGE FUNCTION

In the article the features of energy summation from two wind generators, located at a certain dis-tance from each other, are considered. The method of calculating the correlation function between the wind flow speed change functions in the direction of wind distribution is presented. The formulas for describing the fluctuation components of energy at the output of the wind generator are given for two cases: when the phases of the fluctuations of the wind flow on two wind generators are the same and when the fluctuations of the wind flow are in the antiphases. It is shown that to increase the energy level that can be taken from the wind power plant it is necessary to control the phase shift between the energy fluctuations at the output of the wind generators and use the energy of the storages; and to use linear approximations to approximate the wind speed change function. Under the condition of a linear change of the internal resistance of the wind generator in time, it is advisable to introduce the wind speed change function with linear approximations. The system of orthonormal linear functions based on Walsh functions is given. A table with formulas and graphs describing the first 8 functions, which are arranged in order of increasing the number of their sign alternating on the interval of functions definition, is presented. The result of the approximation of the wind speed change function with a system of 8 linear functions based on Walsh functions is shown. Decomposition coefficients, mean-square and average relative approximation errors for such approximation are calculated. In order to find the parameters of multiple linear regression the method of least squares is applied. The regression equation in matrix form is given. An example of application of linear regression prediction method to simple functions is shown. The restoration result for wind speed change function is shown. Decomposition coefficients, mean-square and average relative approximation errors for restoration of wind speed change function with linear regression method are calculated.

* National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Peremohy Ave. 37, 03056 Kyiv, Ukraine, e-mail: ekateryna.osypenko@gmail.com

1. INTRODUCTION

The share of electrical energy, generated by renewable energy sources, on the territory of Ukraine is about 2% of the total amount of electrical energy produced [1]. The energy strategy approved by the Government of Ukraine foresees that by 2035 year the share of renewable energy sources in the energy sector will be 11% [2]. The largest share in renewable energy sources in Ukraine is occupied by wind power plants, which in 2016 produced 925 GW*h of power [3]. A significant increase in the total capacity of wind power plants in Ukraine (more than 100 MW in the last year) requires a case study on increasing of energy efficiency of wind power plants.

The application of Heisenberg's uncertainty principle [4] indicates that in order to maximize the efficiency of wind power plants operation, it is necessary to implement two-channel control: on a basic interval to provide the required level of energy for the charge of the storage (the duration of the basic interval is determined on the basis of specific conditions); on the minimum duration of the observation interval to provide the required level of maximum energy that can be taken from the wind power plants. To implement the selection of maximum energy from a wind power plant it is necessary to take into account the distance between individual wind generators and their mutual influence. The dynamic change in the magnitude and direction of the wind flow speed and, consequently, the internal resistance of the equivalent wind generators source leads to changes in conditions for the maximum energy selection, the basis of which is based on the assumption that the parameters of the source linearly change in time [5]. Effective work of the power plant is realized by predictive control on the basic interval according to the predictor–corrector method [6]. On the n-th interval there is a prediction of the wind speed change function, and on the $(n + 1)$-st interval a correction of values is made, for which one must know the wind speed change function, which requires its approximation with orthogonal functions with the minimum approximation error [7]. In this regard, it is necessary: firstly, to investigate the influence of the distance between the wind generators on conditions for the maximum energy selection; and secondly, to predict wind speed change function considering it's representation by linear approximations.

2. CORRELATION BETWEEN WIND SPEED CHANGE FUNCTIONS

Let us consider a simplified scheme of the wind generators 1 ... j placement (Fig. 1) at a distance from each other, both in the coordinate Ox and in the coordinate Oy. In Fig. 1 two possible directions of wind flow are given. In case I, the wind generator 1 is the first on the way to the front of the wind flow, and in the case II, the wind generator j is be the first. Each wind generator is connected to the energy summation unit Σ via converter and storage C_i.

Let us determine the conditions under which, in the case of fluctuations in the wind flow, the selection of maximum energy is ensured. In order to ensure the selection of maximum energy from a wind power plant, it is necessary to consider the mutual influence of the distance between the wind generators on the selection of energy from each of them. For example of two wind generators (1 and 2), with distance S between them in the direction of propagation of the wind flow. In given case the wind flow is considered uniform with fluctuations relative to some average wind speed. For the consistent work of wind generators a significant correlation function $C(\tau)$ for the functions of the wind speed V_1 and V_2 is given:

$$C(\tau) = \frac{1}{T}\int_0^T V_1(t)V_2(t+\tau)dt \quad (1).$$

This function is close to the autocorrelation function with shift τ, provided that $V_1 \approx V_2$.

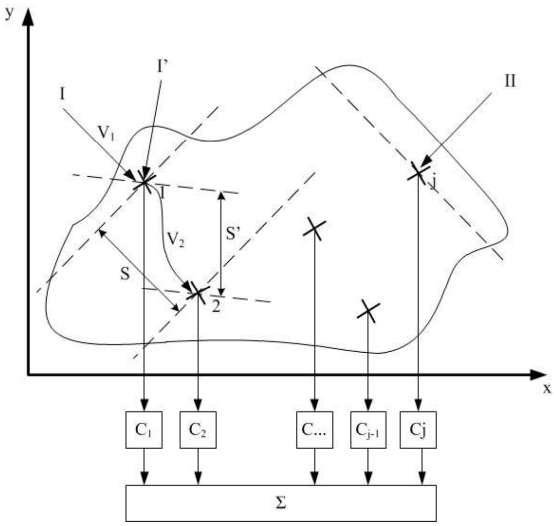


Fig. 1. Simplified scheme of a wind power plant placement

To simplify the calculations, we assume that the wind flow passes distance S for time t_s and fluctuations of the wind flow are described by the function f_f in the sinusoidal law with amplitude A_m and frequency $\Omega = 2\pi/T$; $f_f = A_m \sin\Omega t$. Then the correlation function is determined by the following equation:

$$C(t_s) = \frac{1}{T}\int_0^T A_m \sin \Omega t \cdot A_m \sin \Omega(t + t_s)dt$$
$$= \frac{A_m^{\;2}}{4T\Omega}\left(\sin \Omega t_s - \sin\left(2\Omega T + \Omega t_s\right) + 2\Omega T \cos \Omega t_s\right) \quad (2).$$

Correlation function will be equal to 1 if the phases of the fluctuations of the wind flow V_1 and V_2 on the wind generators 1 and 2 are the same. Then the total energy from the two wind generators will be proportional to the wind speed in $W_w \sim V_3$, and the total value of the fluctuation energy component at the output of the wind generator f_W is described as following:

$$f_W = \frac{3}{2}A_m^{\;3} \sin \Omega t - \frac{1}{2}A_m^{\;3} \sin 3\Omega t \quad (3).$$

Since the correlation function depends on the time interval τ, then for certain values of this interval, for example, for $\tau = \pi/2$, the wind speed change function on the second wind generator will vary according to the cosine law. Then the total value of the fluctuation energy component at the output of the wind generator is described as following:

$$f'_W = \frac{3\sqrt{2}}{4}A_m^{\;3} \sin\left(\Omega t + 45°\right) + \frac{\sqrt{2}}{4}A_m^{\;3} \sin\left(3\Omega t - 45°\right) \quad (4).$$

Thus, the amplitude of the energy from the fluctuation component decreases in $\sqrt{2}/2$ times, the pulsation amplitude also decreases, but harmonic pulsations with a frequency of 3Ω appear. In order to increase the energy that can be taken from a wind power plant, it is necessary to control the phase shift between the energy fluctuations at the output of the wind generators. The energy of the storages can be used to provide the necessary phase and suppress harmonics with a frequency of 3Ω that can be generated in the supply network.

When changing the direction of the wind (case I′), the distance between the wind generators S changes accordingly, but the method for estimating the level of energy and pulsations remains the same.

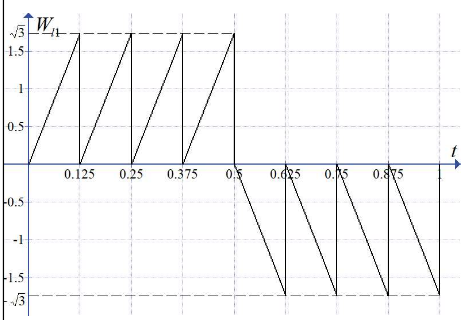
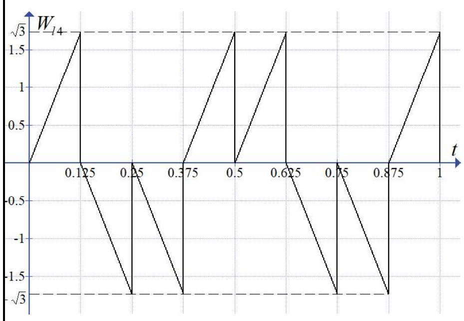
3. APPROXIMATION OF WIND SPEED CHANGE FUNCTION

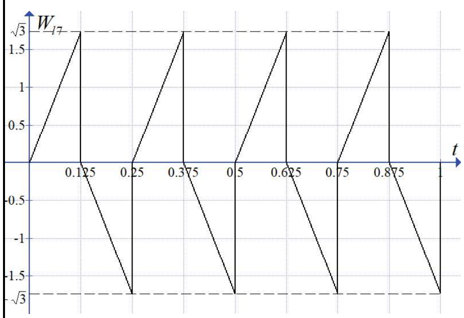
It is known from the approximation theory that with the appropriate choice of approximating functions, the approximation with orthogonal functions provides the least error. Since it is necessary to provide a linear approximation of the wind speed change function, it is expedient to select orthogonal functions that provide such approximation. These functions, in particular, include orthonormal functions of Franklin [8]. But, given their non-periodicity and asymmetry, it is expedient to construct a system of orthonormalized functions W_{linear} based on Walsh functions, which are constructed in accordance to the following equations:

$$\begin{cases} W_{linear0}(t) = 1 \\ W_{linear\ i}(t) = \left(n\sqrt{3} - k\sqrt{3}\right) wal_{nk}(t) \end{cases} \quad (5),$$

where i – number of piecewise-linear function, i = 0, ..., n; n – system dimension; k – number of partitioning interval; $wal_{nk}(t)$ – value of i-th Walsh function at the k-th partitioning interval; $\{n, k\} = 0 \ldots 2^m - 1$. Given system of functions satisfies the conditions of Gram-Schmidt orthogonalization. These functions, as well as Walsh functions, can be arranged in different ways: by Hadamard, by Rademacher, by Pelley [9]. Table 1 shows the expressions that describe first, fourth and seventh linear functions based on Walsh functions, which are arranged in order of increasing the number of their sign changes in the interval of the functions definition.

Table 1. The system of linear functions based on Walsh functions

Function number, i	Formula	Graphical representation
1	**2**	**3**
1	$\begin{cases} 8\sqrt{3}t, & 0 \le t \le 0{,}125 \\ 8\sqrt{3}t - \sqrt{3}, & 0{,}125 \le t \le 0{,}25 \\ 8\sqrt{3}t - 2\sqrt{3}, & 0{,}25 \le t \le 0{,}375 \\ 8\sqrt{3}t - 3\sqrt{3}, & 0{,}375 \le t \le 0{,}5 \\ -8\sqrt{3}t + 4\sqrt{3}, & 0{,}5 \le t \le 0{,}625 \\ -8\sqrt{3}t + 5\sqrt{3}, & 0{,}625 \le t \le 0{,}75 \\ -8\sqrt{3}t + 6\sqrt{3}, & 0{,}75 \le t \le 0{,}875 \\ -8\sqrt{3}t + 7\sqrt{3}, & 0{,}875 \le t \le 1 \end{cases}$	
4	$\begin{cases} 8\sqrt{3}t, & 0 \le t \le 0{,}125 \\ -8\sqrt{3}t + \sqrt{3}, & 0{,}125 \le t \le 0{,}25 \\ -8\sqrt{3}t + 2\sqrt{3}, & 0{,}25 \le t \le 0{,}375 \\ 8\sqrt{3}t - 3\sqrt{3}, & 0{,}375 \le t \le 0{,}5 \\ 8\sqrt{3}t - 4\sqrt{3}, & 0{,}5 \le t \le 0{,}625 \\ -8\sqrt{3}t + 5\sqrt{3}, & 0{,}625 \le t \le 0{,}75 \\ -8\sqrt{3}t + 6\sqrt{3}, & 0{,}75 \le t \le 0{,}875 \\ 8\sqrt{3}t - 7\sqrt{3}, & 0{,}875 \le t \le 1 \end{cases}$	

1	2	3
7	$\begin{cases} 8\sqrt{3}t, & 0 \le t \le 0{,}125 \\ -8\sqrt{3}t+\sqrt{3}, & 0{,}125 \le t \le 0{,}25 \\ 8\sqrt{3}t-2\sqrt{3}, & 0{,}25 \le t \le 0{,}375 \\ -8\sqrt{3}t+3\sqrt{3}, & 0{,}375 \le t \le 0{,}5 \\ 8\sqrt{3}t-4\sqrt{3}, & 0{,}5 \le t \le 0{,}625 \\ -8\sqrt{3}t+5\sqrt{3}, & 0{,}625 \le t \le 0{,}75 \\ 8\sqrt{3}t-6\sqrt{3}, & 0{,}75 \le t \le 0{,}875 \\ -8\sqrt{3}t+7\sqrt{3}, & 0{,}875 \le t \le 1 \end{cases}$	

The equation of a function approximated by linear functions based on Walsh functions has the following form [10]:

$$y(t) = \sum_{i=0}^{N-1} c_i W_{linear\ i}\left(\frac{t}{T}\right) \quad (6),$$

where $c_i = \frac{1}{T}\int_0^1 y(t) W_{linear\ i}\left(\frac{t}{T}\right) dt$ – decomposition coefficients for a series of linear functions based on Walsh functions.

In order to coincide the break points of empirical data and approximating functions, it is expedient to use a system of 8 linear functions based on Walsh functions for approximation.

To predict the wind speed change function, let's apply the approximation with linear functions based on Walsh functions to the data obtained from [11]. Table 2, as an example, shows the wind speed values for the period from August 31, 2018 to September 7, 2018, which are obtained every 3 hours.

Table 2. Wind speed data, m/s

Time / Date	00:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00	00:00
08/31	1	1	2	3	2	2	1	1	1
09/01	1	1	2	3	2	3	2	3	3
…	…	…	…	…	…	…	…	…	…
09/06	1	2	2	3	4	2	2	2	2
09/07	2	2	2	3	1	2	3	1	0

Figure 2 shows the result of the approximation of the wind speed change function on September 7, 2018, with a system of 8 linear functions based on Walsh functions according to equation (6).

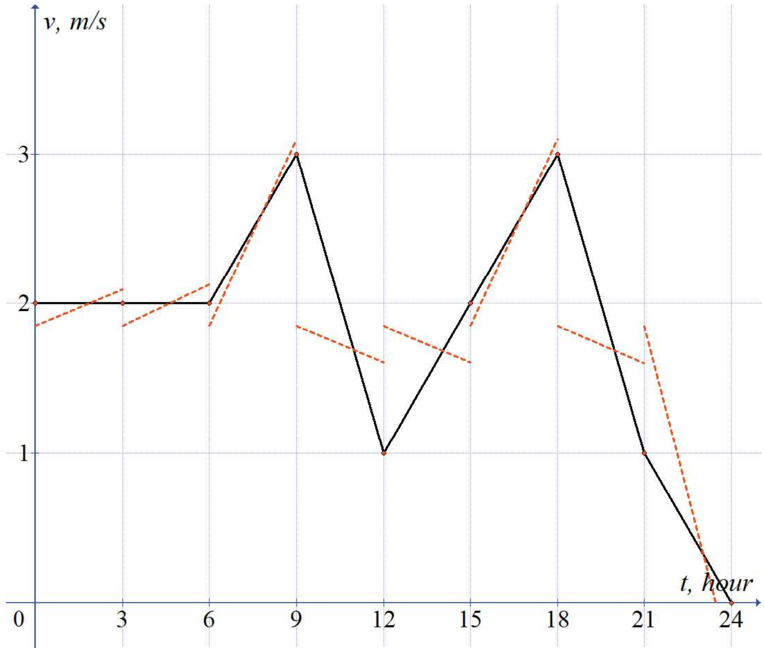


Fig. 2. The result of the approximation of the wind speed change function on September 7, 2018 by a system of 8 linear functions based on Walsh functions

Mean-square approximation error for such decomposition is 79% and average relative approximation error $\Delta = \frac{1}{N}\sum_{i}^{N-1}\Delta_i$ in approximation nodes is 30%.

Table 3 shows the values of decomposition coefficients for wind speed change function values given in Table 2.

Table 3. The values of decomposition coefficients for wind speed change function

Coefficient / Date	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
08/31	1.63	0.04	–0.11	–0.04	0.25	–0.11	–0.40	–0.18
09/01	2.25	–0.04	–0.32	–0.04	–0.32	–0.04	–0.18	–0.18
…	…	…	…	…	…	…	…	…
09/06	2.31	–0.07	–0.22	0.14	0.14	–0.22	–0.36	0
09/07	1.88	0.14	0.22	–0.36	0.22	0.07	–0.29	0.14

To predict the wind speed change function, let's predict the decomposition coefficients for a series of linear functions based on Walsh functions. For this regression analysis is applied, and comparison with results of approximation of corresponding empirical data is made.

4. APPLICATION OF REGRESSION ANALYSIS

In order to find the parameters of multiple linear regression let's apply the method of least squares, according to which the decomposition coefficients of a series are calculated by the following equation [12]:

$$B = \left(C_{in}^{T} \cdot C_{in}\right)^{-1} C_{in}^{T} \cdot C_{out}, \quad (7),$$

where C_{out} – coefficients of a series obtained on $(n + 1)$-th observation interval; C_{in} – coefficients of the series obtained on the n-th observation interval; B – coefficients of regression. All coefficients of the equation (4) are presented in the form of the following matrix:

$$C_{out} = \begin{pmatrix} C_1 \\ C_2 \\ \dots \\ C_n \end{pmatrix}, C_{in} = \begin{pmatrix} C_{11}C_{12}\dots C_{1n} \\ C_{21}C_{22}\dots C_{2n} \\ \dots\dots\dots\dots\dots \\ C_{n1}C_{n2}\dots C_{nn} \end{pmatrix}, B = \begin{pmatrix} b_0 \\ b_1 \\ \dots \\ b_n \end{pmatrix}.$$

By solving this system of equations, the matrix-column B of coefficients of the linear multiple regression is obtained, while the mutual influence of the coefficients was not taken into account.

The system of equations for regression analysis is built as follows. Since the coefficients of the series depend on their values on the previous observation intervals, for each coefficient as input data C_{in} the coefficients for given number of previous observation intervals and the corresponding coefficient C_{out} on the current interval were taken. These data form the first equation of the system. Next equations were formed on a similar principle with the displacement of the observation interval to the right. The system of equations is built each time when it is necessary to make a prediction for new empirical data.

With this prediction method for example for 7-th day (September 6, 2018), matrixes C_{in} and C_{out} will look as follows:

$$C_{in} = \begin{pmatrix} C_1C_2C_3 \\ C_2C_3C_4 \\ C_3C_4C_5 \end{pmatrix}, C_{out} = \begin{pmatrix} C_4 \\ C_5 \\ C_6 \end{pmatrix}.$$

When obtained the matrix of regression coefficients B and substituting values ($C_4C_5C_6$) into the regression equation, we obtain values for the 7-th day. For the 9-th day (September 8, 2018) the calculation will be similar. The only difference is that the matrix will have a dimension of 4 × 4. According to the predicted decomposition coefficients for the 7-th and 9-th days, the decomposition coefficients for the 8-th day (September 7, 2018) is determined as the arithmetic mean of the obtained values (Table 4).

Table 4. Predicted decomposition coefficients for 7-th, 8-th and 9-th days

Date \ Coefficient	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
09/06	–0.49	0.13	–0.22	–3.60	0.39	2.23	–0.84	0.01
09/08	2.90	–0.58	27.70	–1.37	0.04	–3.11	3.98	–151.1
09/07	**1.21**	**–0.22**	**13.74**	**–2.49**	**0.21**	**–0.44**	**1.57**	**–75.53**

In order to avoid false values in prediction and increase its efficiency, all values out of bounds 3σ are considered as false. Instead we use values 3σ with a sign corresponding to the sign of the predicted value. Statistical parameters, such as expected value and mean square deviation for 7-th day are given in Table 5.

Table 5. Statistical parameters of decomposition coefficients

Parameter \ Coefficient	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
M	2.08	–0.01	–0.15	0.06	–0.03	–0.12	–0.29	–0.05
σ	0.65	0.11	0.24	0.05	0.25	0.17	0.32	0.18
$M-3\sigma$	0.13	–0.34	–0.87	–0.09	–0.78	–0.63	–1.25	–0.59
$M+3\sigma$	4.03	0.32	0.57	0.21	0.72	0.39	0.67	0.49

Given this predicted decomposition coefficients for the 7-th, 8-th and 9-th days are shown in Table 6.

Table 6. Corrected predicted decomposition coefficients for 7-th, 8-th and 9-th days

Date \ Coefficient	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
09/06	0.13	0.13	–0.22	–0.09	0.39	0.39	–0.84	0.01
09/08	2.90	–0.34	0.57	–0.09	0.04	–0.63	0.67	–0.59
09/07	**1.52**	**–0.11**	**0.17**	**–0.09**	**0.21**	**–0.12**	**–0.09**	**–0.29**

The regression equations for the corresponding decomposition coefficients are summarized in Table 7. C_i is the predictive value of the coefficient, and $C_{i-1} \div C_{i-4}$ are the values on the previous observation intervals.

Table 7. Regression equations for the corresponding decomposition coefficients

Coefficient	Equation
C_0	$C_{0i} = 1.15 \cdot C_{0(i-4)} - 0.09 \cdot C_{0(i-3)} + 0.02 \cdot C_{0(i-2)} - 0.05 \cdot C_{0(i-1)}$
C_1	$C_{1i} = 2.11 \cdot C_{1(i-4)} - 0.42 \cdot C_{1(i-3)} - 1.14 \cdot C_{1(i-2)} - 1.2 \cdot C_{1(i-1)}$
C_2	$C_{2i} = -33.4 \cdot C_{2(i-4)} - 0.9 \cdot C_{2(i-3)} + 12.23 \cdot C_{2(i-2)} + 31.68 \cdot C_{2(i-1)}$
C_3	$C_{3i} = -7.42 \cdot C_{3(i-4)} + 0.37 \cdot C_{3(i-3)} + -0.75 \cdot C_{3(i-2)} + 0.61 \cdot C_{3(i-1)}$
C_4	$C_{4i} = -0.23 \cdot C_{4(i-4)} - 0.23 \cdot C_{4(i-3)} - 0.49 \cdot C_{4(i-2)} + 0.25 \cdot C_{4(i-1)}$
C_5	$C_{5i} = 4.79 \cdot C_{5(i-4)} - 4.83 \cdot C_{5(i-3)} + 2.17 \cdot C_{5(i-2)} - 0.28 \cdot C_{5(i-1)}$
C_6	$C_{6i} = -1.54 \cdot C_{6(i-4)} + 1.21 \cdot C_{6(i-3)} + 2.02 \cdot C_{6(i-2)} + 1.77 \cdot C_{6(i-1)}$
C_7	$C_{7i} = 298.85 \cdot C_{7(i-4)} - 97.25 \cdot C_{7(i-3)} - 261.04 \cdot C_{7(i-2)} - 153.6 \cdot C_{7(i-1)}$

According to predicted values of decomposition coefficients, let's restore the wind speed change function for the 8-th day (September 7, 2018). The restoration result is shown in Fig. 3, where the dashed line denotes a function restored by the predicted coefficients, solid line denotes empirical data.

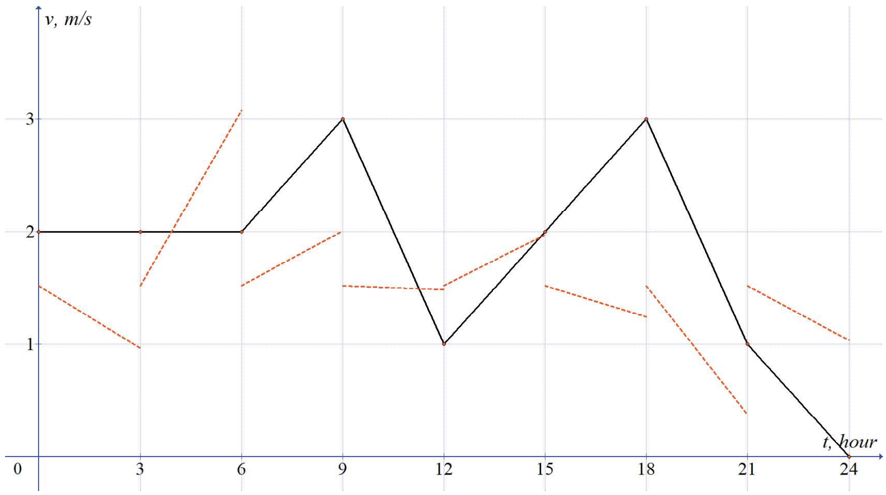


Fig. 3. The restoration result for wind speed change function for the 8-th day (September 7, 2018)

In general, the approximate function can be used to observe the main trend (character of change) of the function on each approximation interval.

Mean-square approximation error for such restoration is 88% and average relative approximation error in approximation nodes is 40%.

The graph shows that at the ends of the interval, the deviations of approximating values are maximum. This is similar to the Gibbs phenomenon [13]. Taking it into account, the mean square approximation error decreases to 33%, and the average relative approximation error in approximation nodes decreases to 23%. Approximation error can be reduced by correction the predicted decomposition coefficients according to a form of wind speed change function.

5. CONCLUSIONS

Thus, in order to increase the energy that can be taken from wind generators, it is necessary to fulfill several conditions. First, to control the phase shift between the functions of the energy fluctuations at their outputs. Second, to use the energy of converters and storages to suppress harmonics with a frequency of 3Ω that can be generated in the supply network. Third, to use linear approximations, for example, the linear functions based on Walsh functions, to approximate the wind speed change function. The application of regression analysis methods to the decomposition coefficients of a series of linear functions based on Walsh functions allows with error of not more than 33% to predict the wind speed change function with the possibility to reduce the value of error by correction the predicted coefficients according to a form of wind speed change function.

REFERENCES

[1] SUHODOLYA L., *Current state, problems and prospects of hydropower development in Ukraine*, National Institute for Strategic Studies, Analytical report, 2014.

[2] Ostap Semerak: *Ukraine pledged to increase its share of renewable energy up to 11% by 2035* [electronic resource] – Access to the resource: https://www.kmu.gov.ua/ua/news/ostap-semerak-ukrayina-zobovyazalasya-do-11-zbilshiti-chastku-vidnovlyuvanoyi-energetiki-do-2035-roku

[3] PRAHOVNYK A., *Harmony of Ukraine's energy and energy efficiency paths to world trends*, Knowledge, Kyiv 2003, p. 100.

[4] OSYPENKO K., ZHUIKOV V., *Heisenberg's uncertainty principle in evaluating the renewable sources power level*, Technical Electrodynamics, 2017, Vol. 1, pp. 10–16.

[5] ZHUIKOV V., OSYPENKO K., *Compensator currents form determination considering wind generator aerodynamic resistance*, 2014 IEEE International Conference on Intelligent Energy and Power Systems (IEPS), 2014, pp. 168–170.

[6] BUTCHER J. C., *Numerical Methods for Ordinary Differential Equations*, John Wiley & Sons, New York 2003.

[7] KORN G., KORN T., *Mathematical handbook for scientists and engineers*, Science, Moscow, USSR, 1974.

[8] OSYPENKO K., ZHUIKOV V., *The linearization of primary energy flow parameters change function Franklin discrete functions*, Electronics and Communication, 2016, Vol. 4, pp. 33–37.

[9] TRAHTMAN A., TRAHTMAN V., *The fundamentals of the theory of discrete signals on finite intervals*, Soviet radio, Moscow, USSR, 1975.
[10] DAGMAN E., *Fast discrete orthogonal transformations*, Science, Novosibirsk 1983.
[11] *The weather at the airports* [electronic resource] – Access to the resource: http://pogoda.by/avia/?icao=UKBB
[12] *Multiple linear regression. Improving the regression model* [electronic resource] – Access to the resource: https://function-x.ru/statistics_regression2.html
[13] BRILLOUIN L., *Science and the information theory*, State publishing house of physical and mathematical literature, Moscow, USSR, 1960.