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PREDICTION OF PRIMARY ENERGY FLOW CONSIDERING ITS STOCHASTIC NATURE

SYMULACJA PIERWOTNEGO PRZEPŁYWU ENERGII Z UWZGLĘDNIENIEM JEGO STOCHASTYCZNEJ NATURY

Abstract: In the article the prediction of wind speed values by Newton interpolation polynomials is made. It is mentioned that effective operation of the wind power station is realized by predictive control on the basic interval according to the predictor–corrector method. Equations for Newton interpolation polynomials are given. The fluctuations of the wind speed deviations occur random so can be described with Wiener process. An example of wind speed deviations, described with Wiener process, is shown. Equation to estimate the prediction error is given. The results of wind speed values prediction taking into ac-count the Wiener process that simulates its fluctuations are shown. The wind speed prediction for 1 hour in advance without taking into account the Wiener process is shown depending on the degree of the interpolation polynomial. The prediction errors at different degrees of the interpolation polynomials and the prediction for different number of hours in advance are given. It is noted that with the removal of a random component in the form of Wiener process, the average error of the prediction decreases.

Streszczenie: W artykule dokonano symulacji wartości prędkości wiatru na podstawie wielomianów interpolacyjnych Newtona. Wspomniano, że efektywna praca elektrowni wiatrowej realizowana jest poprzez kontrolę predykcyjną w podstawowym przedziale zgodnie z metodą predykcyjno-korektorową. Podano równania dla wielomianów interpolacyjnych Newtona. Fluktuacje odchyleń prędkości wiatru występują losowo, dlatego można je opisać w procesie Wienera. Pokazano przykład odchyleń prędkości wiatru, opisany w procesie Wienera. Podano równanie do oszacowania błędu prognozowania. Pokazano wyniki symulacji prędkości wiatru z uwzględnieniem procesu Wienera, który symuluje jego fluktuacje. Prognozę prędkości wiatru z 1-godzinnym wyprzedzeniem bez uwzględnienia procesu Wienera pokazano w zależności od stopnia wielomianu interpolacji. Podano błędy prognozowania dla różnych stopni wielomianów interpolacyjnych i przewidywania dla różnej liczby godzin wcześniej. Należy zauważyć, że wraz z usunięciem elementu losowego w postaci procesu Wienera zmniejsza się średni błąd prognozy..

Keywords: *distributed generation, wind generators, Heisenberg's uncertainty principle, prediction, Newton interpolation polynomials*
Słowa kluczowe: *generacja rozproszona, generatory wiatrowe, zasada nieoznaczoności Heisenberga, prognozy, wielomiany interpolacyjne Newtona*

1. Introduction

By 2035 year the share of renewable energy sources in the energy sector of Ukraine will be 11% as forecasted by energy strategy approved by the Government [1]. In 2018 Ukraine has installed 742.5 MW of new renewable energy sources capacity, which is 2.8 times more than a year ago. Thus, the total in-stalled capacity of renewable energy sources reached 2117 MW. The largest share in renewable energy sources in Ukraine is occupied by wind power stations, which in 2016 produced 925 GWh of power [2]. With the increasing number of installed wind power stations in distributed generation systems, there is a growing need to develop effective algorithms for system control. However, output power of wind power stations has variable and probabilistic nature. The amount of energy produced by wind power stations depends on the time of day, the wind speed, the amount of solar radiation and many other environmental factors. The application of Heisenberg's uncertainty principle [3] leads to the fact that in order to ensure maximum efficiency of wind power stations, it is necessary to implement two-channel control on basic and observation interval. Effective operation of the wind power station is realized by predictive control on the basic interval according to the predictor–corrector method [4]. On the nth interval there is a prediction of the wind speed change function, and on the (n + 1)th interval a correction of values and prediction on (n + 2)nd interval is made, for which one must know the wind speed change function, which requires its approximation with orthogonal functions with the slightest approximation error [5]. Thus, the prediction is made for a time interval τ that is equal to the interval of wind speed data receiving.

Therefore, the problem of predicting the of the wind speed change function on the basis of approximation by orthogonal functions using Newton interpolation polynomials arises.

2. Newton interpolation equations

The simplest interpolation problem is formulated as following: in certain interval [*a*; *b*], a set of *n+1* points $x_0, x_1, \ldots, x_n$ are given. These points are called interpolation nodes. Suppose that the function *f(x)* is defined at equidistant interpolation nodes x_0, $x_1 = x_0 + h$, …, $x_n = x_0 + nh$ such that:

$$f(x_0) = y_0, f(x_1) = y_1, \ldots, f(x_n) = y_n. \quad (1)$$

An interpolation function *F(x)* that takes the same values as *f(x)* at the interpolation nodes is built as:

$$F(x_0) = y_0, F(x_1) = y_1, \ldots, F(x_n) = y_n. \quad (2)$$

For interpolation at the end of the interval [*a*; *b*] the second Newton interpolation equation is used [6]:

$$P_n(x) = y_n + q\Delta y_{n-1} + \frac{q(q-1)}{2!}\Delta^2 y_{n-2} + \cdots + \frac{q(q-1)\ldots(q-n+1)}{n!}\Delta^n y_0, \quad (3)$$

where $q = \frac{x-x_0}{h}$, h is the step of interpolation, and in the case of extrapolation $q = \frac{x-x_0}{h} > 0$.

The interpolation error is determined by the equation:

$$R_n(x)\frac{f^{n+1}(z)}{(n+1)!}(x-x_0)(x-x_1)\ldots(x-x_n),$$

$$x \in [a; b]. \quad (4)$$

3. Wiener process

The fluctuations of the wind speed deviations occur random so can be described with Wiener process, which is a classic example of random processes with independent increments.

Weiner random process is a homogeneous Gaussian random process with independent increments that are distributed by Gaussian law with parameters $\{a(t_2 - t_1), \sigma\sqrt{t_2 - t_1}\}$ that are called wear and diffusion coefficient, respectively.

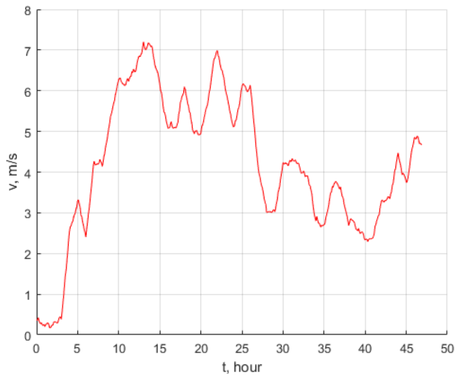

Fig. 1. An example of wind speed deviations, described with Wiener process

To simulate the change in wind speed between interpolation nodes, we use the Wiener process with mean value of 0 and a standard deviation of 1. A zero mean value makes the wind speed changes chaotic, not directed exclusively to increase or decrease, and the standard deviation equality to 1 partially counteracts the impact of Wiener process on prediction results.

Fig. 1 shows an example of wind speed deviations, described with Wiener process.

The presence of the Wiener process can significantly affect the operation stability of the system, so it is necessary to exclude random fluctuations from wind speed deviations.

4. Prediction results

We will use the weather station for 19.02.2019 - 27.02.2019 in Kyiv As initial data wind speed values received from weather station in Kyiv for February 19th – 27tht 2019 were taken.

Prediction is made with a range of 1-6 hours and varying degrees of interpolation polynomials. To estimate the prediction, we use the MAPE equation [7]:

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{e_i}{y_i}\right|, \quad (7)$$

where $e_i = y_i - \tilde{y}_i$ is the absolute prediction error, y_i is the actual value of *i*-th observation, $\tilde{y}_i$ is the predicted value of *i*-th observation.

Fig. 2 shows the results of wind speed values prediction taking into account the Wiener process that simulates its fluctuations.

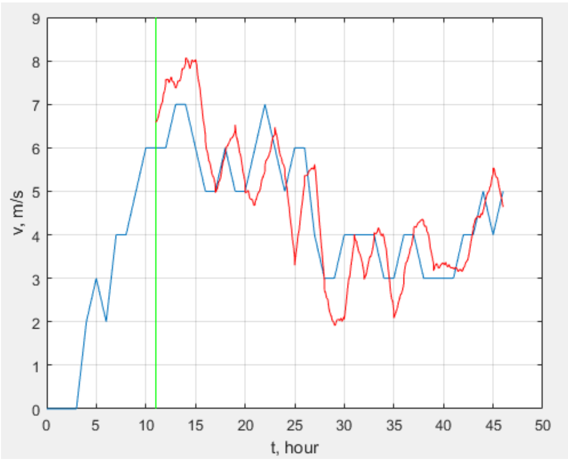

Fig. 2. The result of wind speed value prediction for 3 hours in advance taking into account Wiener process

The wind speed prediction for 1 hour in advance without taking into account the Wiener process is shown on Fig. 3 depending on the degree of the interpolation polynomial.

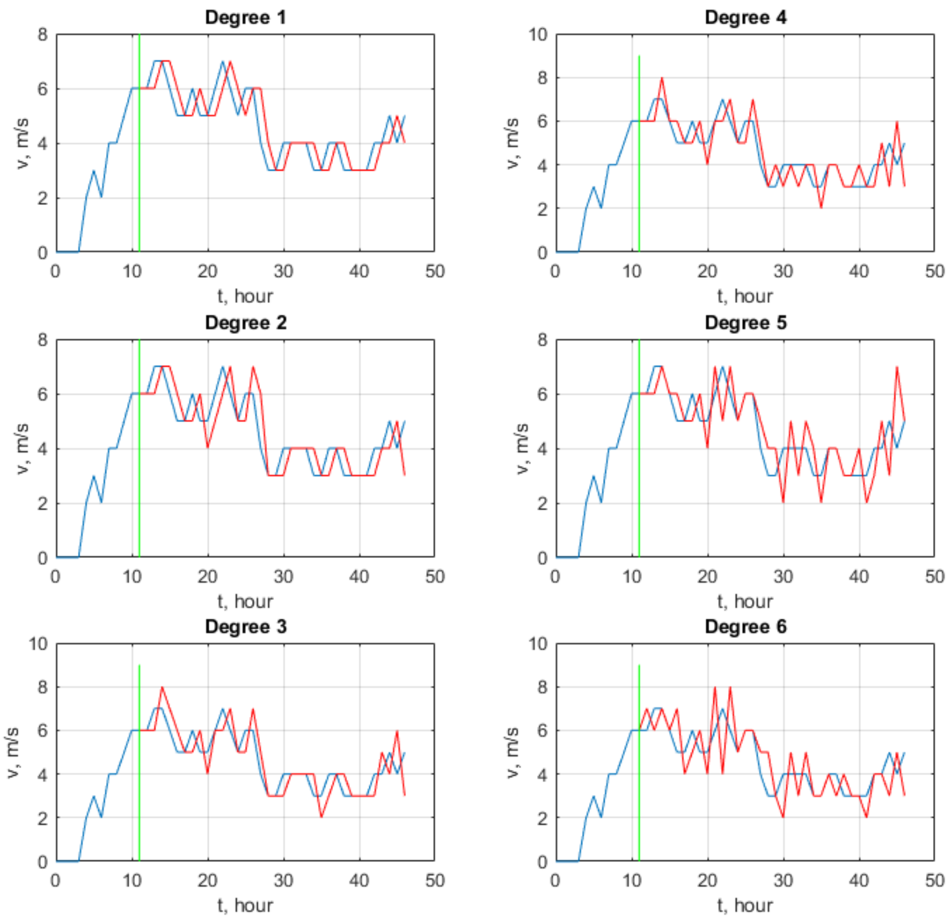

Fig. 3. The result of wind speed value prediction for 1 hour in advance without taking into account Wiener process

Table 1 and table 2 show the prediction errors at different degrees of the interpolation polynomials and the prediction for different number of hours in advance. In some predictions, the extreme points of the prediction were not taken into account when calculating the error according to the Gibbs effect [8].

From the tables it can be seen that with the removal of a random component in the form of Wiener process, the average error of the prediction decreases.

Tab. 1. Prediction error with taking into account the Wiener process

Prediction range, hours / Interpolation polynomials degree	1	2	3	4	5	6
1	17,2%	23,1%	26,2%	25,3%	28,9%	40,6%
2	16,1%	22,7%	27,2%	35,8%	31,9%	46,2%
3	18,6%	26,2%	27,7%	31,6%	35,3%	46,1%
4	21,1%	26,9%	32,7%	35,4%	40,9%	49,6%
5	22,1%	35,8%	35,3%	37,8%	42,3%	43,6%
6	31,8%	50,5%	44,8%	49,8%	54,3%	60,0%

Tab. 2. Prediction error without taking into account the Wiener process

Prediction range, hours / Interpolation polynomials degree	1	2	3	4	5	6
1	14%	16,7%	23,8%	18,6%	22%	20,8%
2	16,9%	19%	26,2%	21.9%	26,7%	20,4%
3	19,5%	20,2%	26,4%	32,1%	26,8%	20,3%
4	22,7%	23,5%	25%	34,7%	29,6%	32,5%
5	26,2%	34,9%	32,5%	30,6%	33,7%	44,3%
6	29,7%	48,3%	43,7%	31,9%	104,3%	53,8%

5. Conclusions

Thus, the application to the prediction of wind speed values of Newton interpolation polynomials allows with an error of no more than 27% to predict the value of wind speed for 3 hours in advance without taking into account the Wiener process and with an error of not more than 28% taking into account the Wiener process.

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