Short Term Prediction of Wind Farm Power Production

Sofija Nikolova[1] and Atanas Iliev[2]

Abstract – **This paper presents a method for prediction of wind farm power output. In order to predict wind farm production a source code in MATLAB is developed. The overall model is consisted of wind speed prediction model, wind turbine power curve model and wake effect model.**

Keywords – **Wind farm production, prediction, power curve, wind speed, wake effect.**

I. INTRODUCTION

The electric power generated by wind farms depends on external irregular source and that is the incident wind speed which does not always blow when electricity is needed. Some other factors that can influence the electric power variability of wind farms are the roughness of the terrain, orography of the terrain, obstacles, seasonal variations, local and regional weather patterns [1].

Because of the intermittent nature of wind and resulting power produced by wind farms, there is a great challenge to transmission system operator (TSO) for developing more accurate models for wind power generation prediction. The TSO, who is responsible to coordinate the power balance on the grid, determines the penalties that will be paid by independent power producers (IPPs) who missed in their obligations. In order to encourage wind power producers to participate into electricity market, certain countries have chosen a proper mechanism to handle the acceptance of wind power [2], [3].

Also a challenge is to quantify the requirements of reserve for compensating the eventual downfall of wind power production. The system must have enough reserve to operate in a reliable manner [4]. For compensating the intermittent nature of wind generation, an alternative is using energy storage devices. Various methods have been developed for operation and generation scheduling of such wind-storage combined systems [6], [7]. Pumped storage hydro power plants appears as a favorable option for improving wind farm operational economic profit and increase the controllability of the wind farm generation output [8].

Therefore, the prediction of wind farm production is an important process for the following aspects [5]:

- Power system generators scheduling;
- Optimal power flow between conventional units and wind farms;
- Electricity marketing bidding;
- Energy reserves and storages planning and scheduling;
- Maintenance of wind farms units.

There are three available categories of techniques for wind power forecasting [9]: numeric weather prediction (NWP) methods, statistical methods and methods based on the use of Artificial Neural Networks (ANNs).

NWP is an objective forecast which determines the future state of the atmosphere by the numerical solution of a set of equation describing the evolution of meteorological variables which together define the state of the atmosphere [10], [11]. Statistical method approaches [12], [13] are based on the time series of wind farm power measurements which are usually available on-line. The neural network based approaches [14] use large time series data sets to learn the relationship between the input data and output wind speeds. However, NWPs are used as the most accurate technique for the longer forecasts that might be required for wind power prediction, and statistical and neural network based methods are generally accepted for short-term predictions [9].

This paper presents a new method for prediction of wind farm power production. The model consists of the following submodels: model for wind speed prediction, model of wind turbine power curve and wake effect model.

II. WIND SPEED PREDICTION

When considering short term wind power prediction most important is to make decision about choosing parameter(s) which will be forecasted. That is forecaster's task, who should decide whether to predict wind speed alone or both wind speed and wind direction. Here we choose to predict wind speed alone.

In this paper the two year-based model is used for prediction of wind speed. The propose model is based on using n data points from the current year (N) and two previous years ($N-1$ and N-2) to develop linear predicting model. This model then is used with the next n data points from the two previous years to predict the next n data points for the current year. The two year-based model is represented by the following relation:

$$\hat{Y}_N(n+i) = a + bX_{N-1}(n+i) + c\,X_{N-2}(n+i) \quad \forall\ i = 1,2,...,n \qquad (1)$$

Where $\hat{Y}_N(i)$ are the predicted values for the N wind speed data series, $X_{N-1}(i)$ and $X_{N-2}(i)$ are the corresponding values for the $N-1$ and $N-2$ wind speed data series respectively, i represents the step, a, b, c are the model parameters. In order to estimate the model parameters the

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least square method is applied, and the following equation is derived:

$$\begin{bmatrix} n & \sum_{i=1}^{n} X_{N-1}(i) & \sum_{i=1}^{n} X_{N-2}(i) \\ \sum_{i=1}^{n} X_{N-1}(i) & \sum_{i=1}^{n} X_{N-1}^{2}(i) & \sum_{i=1}^{n} X_{N-1}(i)X_{N-2}(i) \\ \sum_{i=1}^{n} X_{N-2}(i) & \sum_{i=1}^{n} X_{N-1}(i)X_{N-2}(i) & \sum_{i=1}^{n} X_{N-2}^{2}(i) \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} Y_N(i) \\ \sum_{i=1}^{n} Y_N(i)X_{N-1}(i) \\ \sum_{i=1}^{n} Y_N(i)X_{N-2}(i) \end{bmatrix} \quad (2)$$

From (2) we can estimate a, b and c coefficients.

In order to predict wind speed a MATLAB source code is developed. As inputs in the program wind speed data series are used for three successive years, for the same period, from potential wind station Niew Beerta, Netherland [15] (as shown on Fig.1). Each of the series consists of 72 points. The wind speeds are measured at 10 m height and then these values are transformed to 60 m hub height with the following formula:

$$v = v_r \frac{\ln\left(\frac{h}{h_0}\right)}{\ln\left(\frac{h_r}{h_0}\right)} \quad (3)$$

Where v is wind speed at height h above ground level, v_r is reference speed at height h_r and h_0 is roughness length (in our case $h_0 = 0{,}02$ m).

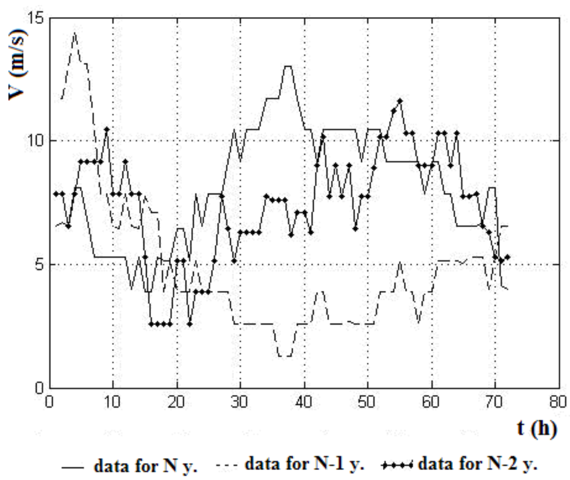

Fig.1. Wind speed data series for three successive years

The analysis is made for prediction horizon of 6 hours ahead. The results generated from the two year-based model are compared with those from the persistence model (which assumes that the forecasted wind speed will be the same as the last measured value) [11].

Fig.2 presents the actual and predicted wind speed time series from the two year-based model and the persistence model for analyzed prediction horizon.

The calculated average percentage error, the standard deviation and the coefficient of correlation for the two year-based model and the persistence model are given in Table I. The improvement over the results obtained from the persistence model is about 25,03 %.

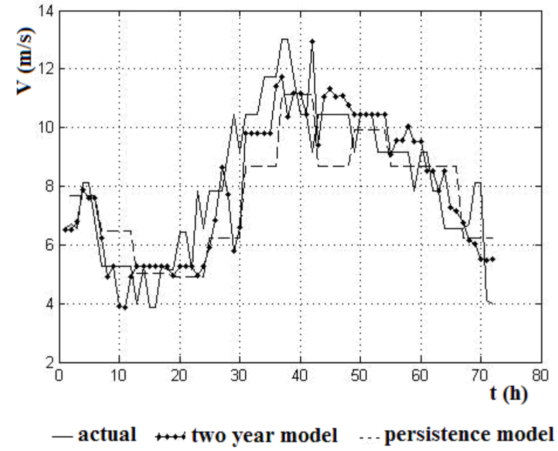

Fig.2. Predicted wind speed time series for 6 hours ahead from the two year-based model and the persistence model

TABLE I

AVERAGE PERCENTAGE ERROR, STANDARD DEVIATION AND COEFFICIENT OF CORRELATION

Horizon (h)	Persistence model			Two year-based model		
	$E\%$	σ	r	$E\%$	σ	r
$n = 6$	17,10	1,46	0,76	12,82	1,33	0,84

The presented results validate the effectiveness of the two year-based model for wind speed prediction.

III. MODELING OF THE WIND TURBINE POWER CURVE

The general relationship between wind turbine's power output and wind speed is given by:

$$P = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 \cdot C_p \quad (4)$$

where P is the output power, ρ is air density, A is swept blade area, V is wind speed of the wind perpendicular to the turbine and C_p is rotor coefficient of performance. Usually in practice rating power curves are used instead of the Eq. (4).

In order to predict wind farm power output a model of used wind turbine's power curves are needed. The modeling of wind turbine power curve is based on the data given by manufacturers. In our case, wind farm consists of wind turbines type G80-2000 kW [16]. Cut-in wind speed (V_I) of this type of wind turbine is 4 m/s, rated speed (V_R) is 17 m/s and cut-out wind speed (V_O) is 25 m/s. The modeled power curve is expressed by the following relationship:

$$Y = -3{,}3X^3 + 90{,}2X^2 - 552{,}7X + 1046{,}7 \quad (5)$$

where Y is output power (kW) and X is wind speed (m/s). Eq. (5) gives the power response of the turbine at wind speed which belongs to the region between V_I and V_R. Between V_R and V_O the turbine produce constant power which is equal to the rated power (2 MW).

The generated results for the predicted wind speed time series by the two year-based model is used as an input to the G80-2000 kW wind turbine power curve, to predict the wind power production for 6 hours ahead from the single wind turbine. The generated actual and predicted wind power time series, when the two-year based model is employed, are presented in Fig. 3.

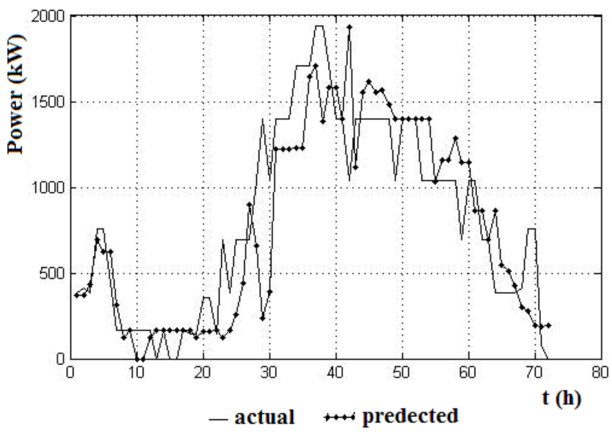

Fig.3. Wind power prediction for 6 h ahead from single wind turbine using two year-based model

IV. WAKE EFFECT MODEL

For developing more accurate wind field model of wind farm the wake effect is taken into consideration. The wake effect model, used in this study, is expressed by [17]:

$$V = U\left(1 - \frac{2}{3}\left(\frac{R}{R + \alpha X}\right)^2\right) \qquad (6)$$

V is wind speed in the wake at distance X, R is radius of the rotor, U is initial wind speed incident before the first wind turbines row and α is wake constant (assumed equal to 0,1).

V. WIND FARM POWER PREDICTION

In this section two cases of configuration of wind turbines into wind farm will be analyzed.

In the first one we are considering wind farm consisted of 20 wind turbines (type G80-2000 kW) that are arranged in 5 rows as it is shown on Fig.4.

Using the proper source code developed in MATLAB the power output of the wind farm is predicted. Fig.5 and Fig.6 present power produced by each of the wind turbines in one row and the total wind farm power output respectively.

In the second case wind farm is consisted of the same number as in the first one, and the same type of wind turbines, but the wind turbines are arranged in 4 rows (5 in a row) as it is shown on Fig.7.

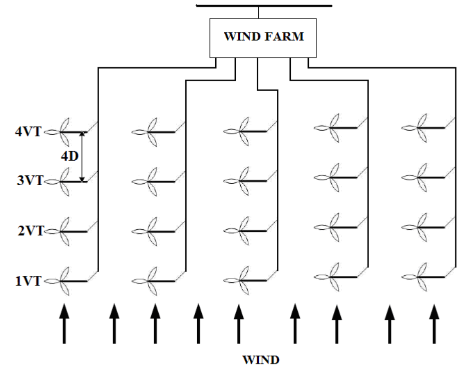

Fig.4. Wind farm configuration, case 1

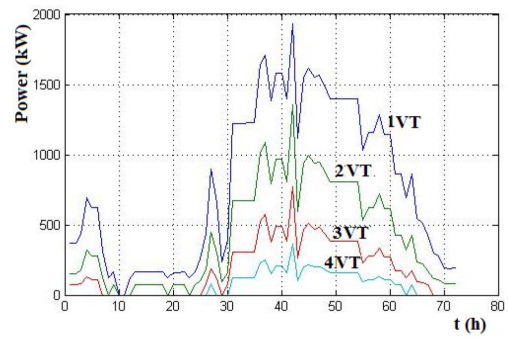

Fig.5 Power produced by each of the wind turbines in one row,case 1

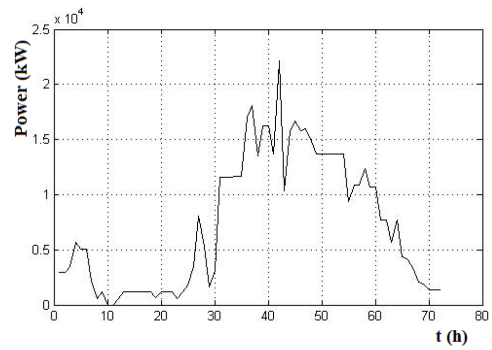

Fig.6. Predicted wind farm power output, case 1

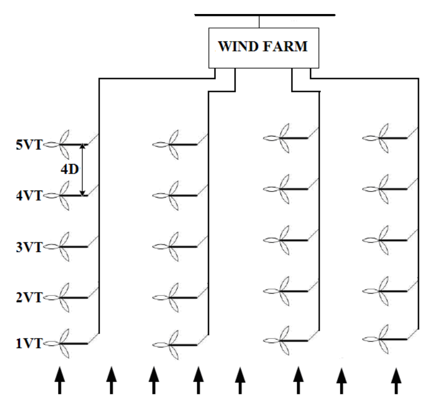

Fig.7. Wind farm configuration, 2-nd case

Fig.8 and Fig.9 present power produced by each of the wind turbines in one row and the total wind farm power output respectively, in second case.

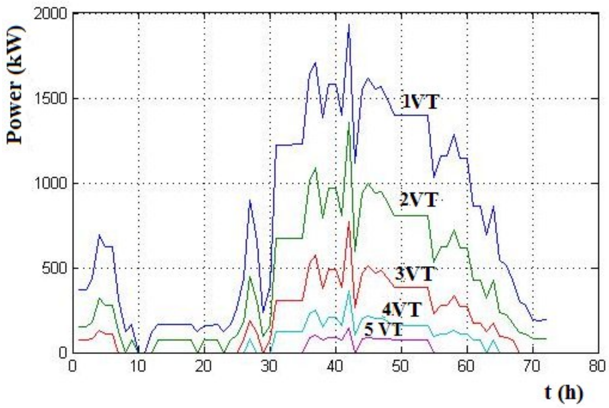

Fig.8. Power produced by each of the wind turbines in one row, 2-nd case

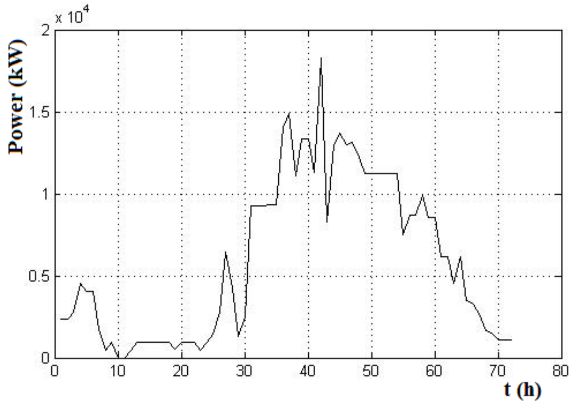

Fig.9. Predicted wind farm power output, 2-nd case

From the results of two analyzed cases of configuration of wind farms, with same wind direction, consisted of the same type and number of wind turbines, but arranged in different number of rows we can see that in the second one the wind farm generate lower power output. Practically the wind speed, because of wake effect, before 5^{th} wind turbine in one row is very small and generated power of the 5^{th} wind turbine of each row has very small part in the total generated power.

VI. CONCLUSION

In this paper a method for prediction of wind farm power production is presented. At first, a model for wind speed prediction is proposed. The used model relates the predicted interval to its corresponding two year old data. The accuracy of the model for predicting wind speeds for 6 hours ahead is investigated by using wind speed data series for three successive years, for the same period.

Obtained results from the two year model are compared with those from the persistence model. Table I reveals better accuracy of the two year-based model compared to the persistence model as illustrated by lower average percentage error, lower standard deviation and higher coefficient of correlation. Then a model of G80-2000 kW wind turbine power curve is gained. For more accurate prediction of wind farm power output a wake effect model is taken into consideration.

Finally, by integrating all mentioned models the wind farm production is predicted as illustrated in Fig.6. and Fig.9. Two wind farm configurations are analyzed. The purpose of this analysis is to determine how the wake effect affects the total generated power from the wind farm.

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