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Reliability and Predictions of Power Supplied by Wind Power Plants

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Abstract. The paper deals with the reliability analysis of electrical power supplies from renewable sources. It focuses primarily on wind power stations which provide variable, stochastic power supply to the distribution and transmission network. Results from application of wind power plant power flow measurement methodology are shown in this paper. We apply measurement methodology to two wind power plants in different localities and we analyze measured values. In the last part is a description of the prediction model developed at the Technical University of Ostrava

Key words

Wind power plants, power measurement, prediction model.

1. Introduction

Reliability of supply of electric power from renewable resources is important with respect to operators and electric power distribution and super grids.
Any unstable and stochastic supply of electric power results in higher requirements for controls backup volumes and the continuously increasing installed output of RES (Renewable Energy Resources) present a risk to the electric power networks.

Prediction of output from renewable resources then plays a specific role both from the prospective of operators of electric power distribution networks and super grids as well the operators of wind power plants. There are currently several prediction models in place, varying by different levels of prediction accuracy. The Technical University of Ostrava is concerned with development of the wind power plant simulator – Wind Power Forecast – which uses the output curve, wind speed and wind direction to predict the output volume for a specific wind power plant.

2. Reliability of Supply from Renewable Power Resources

Reliability is generally defined as an essential characteristic of a certain object comprising its ability to perform specific functions while maintaining the determined operation indicators within set limits and with adherence to timescales in compliance with defined technical conditions.
The reliability of supply of power from renewable power resources can be divided into two categories:

- Renewable power resources with the ability to ensure stable and continuous supply of power. This category might as well include the biomass, which allows for long-term accumulation (storage).
- Renewable resources with variable and stochastic nature of power supply. This category includes wind and solar power plants.

The reliability of power supply represents the ability of the transformation chain to supply the product of such quality as needed at a specific time, or even throughout a certain time period, and required by a specific appliance and it can be generally expressed as follows [1]:

$$R_{W,T} = \frac{W_{d,T}}{W_{est,T}} \quad (1)$$

where $W_{d,T}$ power actually supplied over the time period T
$W_{est,T}$ expected supply of power over the time period T

The reliability of power supply at the resource depends on the option for output prediction. Especially wind or solar power plants are resources with difficult output prediction options. These resources are associated with low probability output prediction based on monitoring and forecast of weather conditions.

The energy source efficiency can be best determined by means of basic utilization ratio coefficient [1]:

$$k_v = \frac{W_T}{P_i \cdot h} \tag{2}$$

where W_T volume of power produced (kWh)

P_i installed output (kW)

h hours

3. Wind Power Plants

Wind power has been considered the most rapidly growing electric power resource for a long time. The volume of power supplied from wind power plants should increase up to 12% [5] out of the total global consumption by the year 2020.

The Czech Republic has adopted a directive compiled to support utilisation of renewable energy resources, which assumes the average annual wind speed at the wind power plant location with the rotor axis height compliant with the designed wind power plant will be at least 6 m/s. The Fig. 1 shows a map of average wind speed at the height of 100 m above the ground.

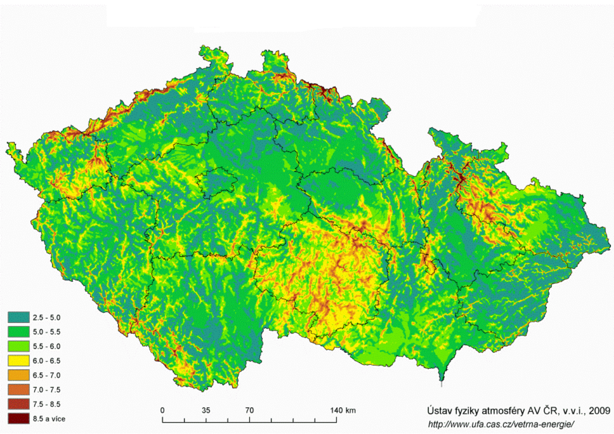


Fig. 1 Wind Map of Czech Republic [6]

4. Pchery Wind Power Plant

The wind power plant in Pchery is the largest wind power plant in the Czech Republic, with its installed output of 2x3MW. Turbines are driven using the D100 type rotors made by WinWinD, which are suitable mainly for inland projects with lower average wind speed.

Obr. 2 WPP Pchery

Table I. - Technical Parameters [2]

Locality	Pchery
Technology	WinWinD – WWD3
Type	3 blades, up-wind
Power control	Pitch, variable speed
Rated Power	3000 kW (grid side)
Rotor diameter	100 m
Cut-in wind speed	4 m/s
Rated wind speed	12.5 m/s
Cut-out wind speed	20 m/s
Rotor speed	5-15 m/s
Hub height	100 m
Generator	Synchronous generator with permanent magnets
Frequency converter	Located in nacelle IGBT-Bridges on both generator and grid side
Filter generator side	dU/dt-Filter and common-mode filter
Transformer	Located in nacelle

The Figure 3 shows the wind speed map across even flatland in the Czech Republic. The Pchery wind power plant is located within the area with the average wind speed around 6 – 6.5 m/s.

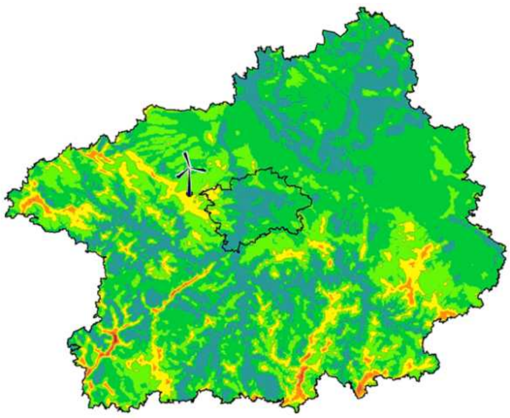


Fig. 3 Partial Wind Map of Czech Republic – Central Bohemia Region

Diagram showing connection of the Pchery wind power plant into the electric power distribution network is included in Figure 4. The wind power plant (WPP) supplies electric power to the 22kV distribution network, connected via the 0.4/22kV transformer with the output of 3.300 kVA.

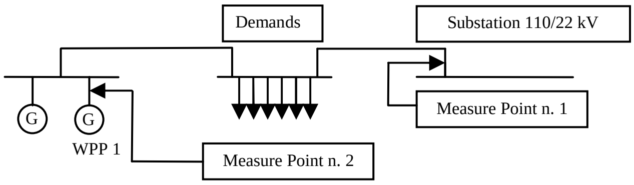


Fig. 4 WPP Pchery Connection scheme [2]

Figures 5 and 6 illustrate the supply of electric power from WPP Pchery. The wind power plant was put out of order in periods of 10.7.-15.7.2009 and 9.8.-12.9.2009. The wind speed reaches its least level in those periods. The Pchery wind power plant supplied P=293.2 MWh in July 2009 and the usage coefficient in that month was equal to k_v =13.13%. The output supplied from the WPP in August equalled to P=162.3 MWh, the usage coefficient was k_v =7.27%. The planned utility of the wind power site is 11 GWh/year.

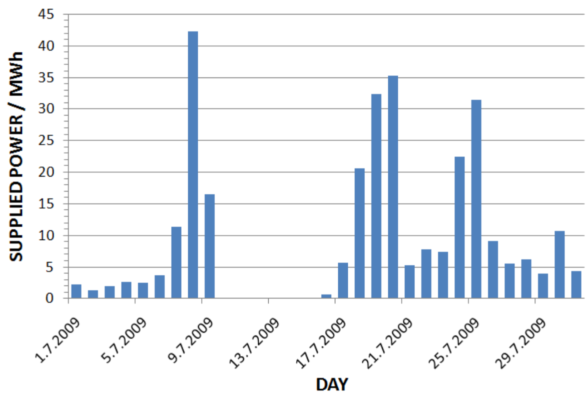


Fig. 5 Delivered power -July 2009

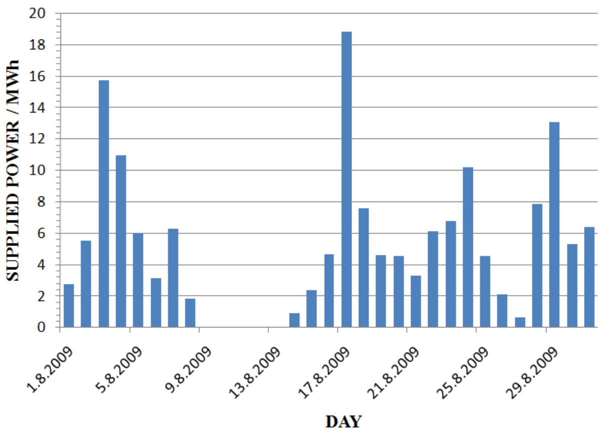


Fig. 6 Delivered power - August 2009

5. The Veselí u Oder Wind Power Plant

Table I. - Technical Parameters [2]

Locality	Veselí u Oder
Technology	VESTAS V-90
Type	3 blades, up-wind
Power control	Pitch, variable speed
Rated Power	2000 kW (grid side)
Rotor diameter	90 m
Cut-in wind speed	4 m/s
Rated wind speed	12 m/s
Cut-out wind speed	25 m/s
Rotor speed	9.3-16.6 rpm
Hub height	80 m
Generator	4-pole asynchronous with variable speed
Air Brake	Full blade feathering with 3 pitch cylinders
Gearbox	3-stage planetary/helical
Transformer	Located in nacelle

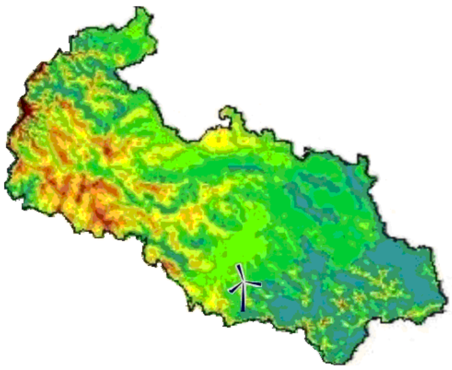


Fig. 7 Partial Wind Map of Czech Republic – North Moravian Region

The wind power plant in Veselí with the installed output of 2x2MW is located in the region with medium-range mountains. That is the VESTAS V90 type wind power plant. Refer to Table 2 for the exact technical parameters.

The wind power plant in Veselí is also connected to the 22kV network via a 0.4/22kV transformer featuring a radial branch connected to the 22/110kV network. For connection diagram see Fig. 8.

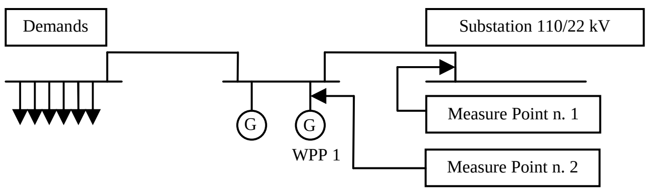


Fig. 8 WPP Pchery Connection scheme [2]

The largest production volume was achieved in the year 2008, when the power plant supplied P= 8.5 GWh of electric power, which is P= 4.25 GWh on average per wind power plant. Fig. 9 shows the total supply of electric power over individual months in the year 2008 per one wind power plant.

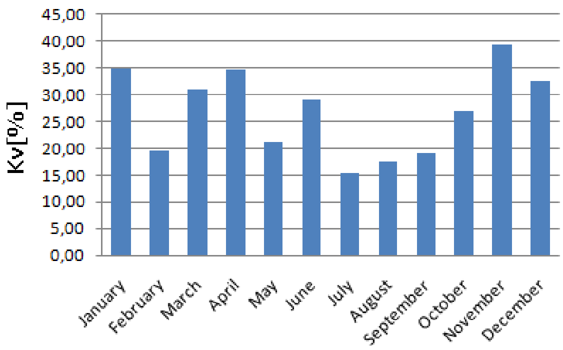
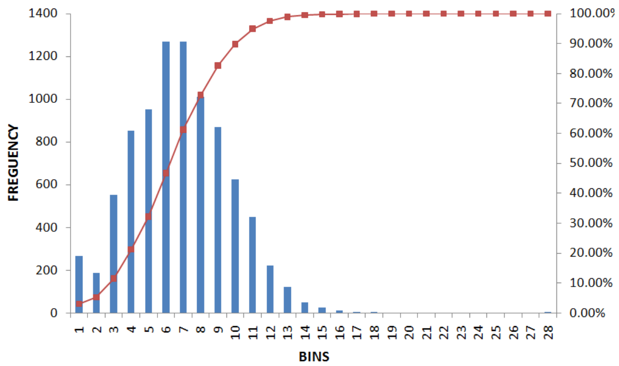


Fig. 9 The availability ratio

The average wind speed at the wind power plant location is 6-6.5 m/s, see Fig. 10.



Figr. 10 Histogram of wind speed

6. Wind Power Forecast Output Simulator

The Wind Power Forecast unit comprises of three modules [4]:

- Wind Power Forecast-Downloader – this is a module designed for regular updates and downloads of data associated with the forecast of direction and speed of the wind at the location subject to monitoring several times a day. The module activation intervals are defined by weather forecast schedules for particular modules.
- Wind Power Forecast-Run Time – forms the core of the prediction system and its task is to carry out the very prediction for electric power production,
- Wind Power Forecast-Post processing – serves for analysis and verification of the prediction system using the data predicted and data obtained through actual measuring.

The calculation algorithm in this simulator deals with assigning the WPP active output values to the existing wind speed [1]:

$$v_1, v_2, \ldots, v_i \rightarrow p_1, p_2, \ldots, p_i \qquad (3)$$

where v_1 refers to the wind speed
p percentual value of active output
i number of measured or predicted values

The existing active output of WPP is then defined by the formula [1]:

$$P_{WPP} = \frac{p_1 \cdot P_{RATED}}{100} \quad [MW] \qquad (4)$$

where P_{RATED} refers to the installed output of the WPP

The volume of electric power produced by WPP [2]:

$$W_{WPP} = \sum_{1}^{i} (P_{WPPx} \cdot t_x) = (P_{WPP1} \cdot t_1) + (P_{WPP2} \cdot t_2) + \ldots + (P_{WPPm} \cdot t_i) \quad [MWh] \qquad (5)$$

where t refers to simulation time interval

The existing active output of a wind power farm at any stage can be determined as follows [1]:

$$P_F = \sum_{1}^{n} P_{WPPx} = P_{WPP1} + P_{WPP2} + \ldots + P_{WPPn} \quad [MW] \qquad (6)$$

The volume of electric power produced by WPP farm [2]:

$$W_F = \sum_{1}^{m} W_{WPPx} = W_{WPP1} + W_{WPP2} + \ldots + W_{WPPn} \quad [MWh] \qquad (7)$$

The total output of wind power farms can be defined as [2]:

$$P_{TOTAL} = \sum_{1}^{m} P_{Fx} = P_{F1} + P_{F2} + \ldots + P_{Fm} \quad [MW] \qquad (8)$$

The total volume of electric power produced can be calculated as [1]:

$$W_{TOTAL} = \sum_{1}^{m} W_{Fx} = W_{F1} + W_{F2} + \ldots + W_{Fm} \quad [MWh] \qquad (9)$$

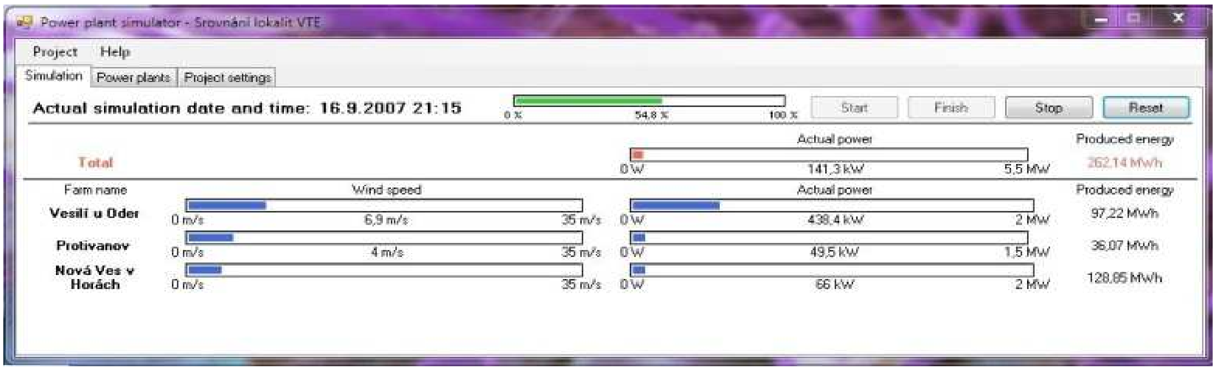


Fig. 11 Software WindPowerForecast

A. Measuring the WPP Output at a Location in Czech Republic

Fig. 12 shows the actually measured course of wind power plant production, using the plant at Veselí farm. The measurements were taken using the electric power quality analyser model BK-505. Apart from the voltage and current parameters, we were further interested in the course of active output and the volume of electric power produced in order to run a comparison of values measured with the values obtained from the simulator. The wind power plant produced 135 MWh of power during the measuring process. The usage coefficient reached the level of 20 %. The return on investment within the territory in Czech Republic is 10 years. [4]

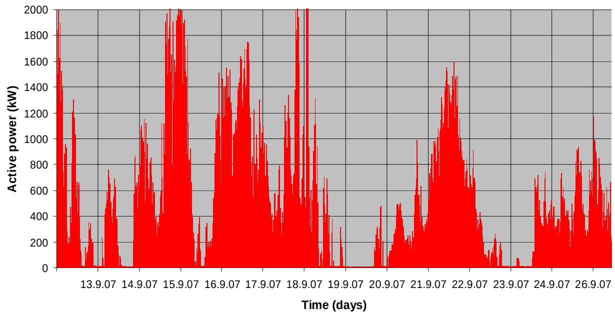


Fig. 12 Demonstration of active output measured [4]

Fig. 13 shows the course of measured output (green) and the graph obtained from simulator (red) at the wind power plant in Veselí subject to monitoring. The simulator produced the calculation result of 151 MWh of electric power, which meant good match with the actual course. The total deviation in determining the volume of electric power produced by the wind power plant was approximately 10%. [4]

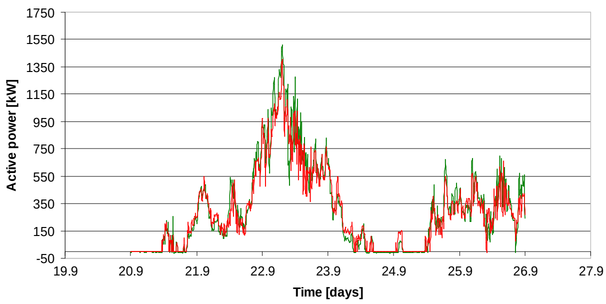


Fig. 13 Comparison between measured and simulation values [4]

Following the comparison of both course curves, we can say the simulated output shows very good match to the output actually supplied. Nevertheless, the deviation in determination of electric power volume develops in such cases, when the wind speed is below the start up speed required for commissioning of the WPP. In that case, the wind power plant behaves as an appliance consuming the active output and the simulator is unable to identify such status.

The output of WPP is then dependant on the cube power of the wind speed value [4]:

$$P = \rho \cdot \frac{v^3}{2} \cdot \pi \cdot \frac{D^2}{4} \cdot c_p = 0.125 \cdot \rho \cdot \pi \cdot v^3 \cdot D^2 \cdot c_p \qquad (10)$$

where c_p refers to the output coefficient

D rotor diameter

ρ atmospheric density

v wind speed

The steep dependence between the active output and the wind speed affects the simulation deviations. Higher speeds render greater deviation of the simulator as the simulated and actual deviations are proportional to the cube power of the value wind speed. [4]

Fig. 14 *Fig. 14* shows the course of the relative deviation of simulation over a certain time interval. It is evident that the deviation is in proportion with the active output. The average deviation is approximately 5%, rising to 20% in extreme situations. [4]
Cause of higher relative error for high active power is due to calculation of simulated active power from equation (10). There is size of active power proportional the cube of wind speed.

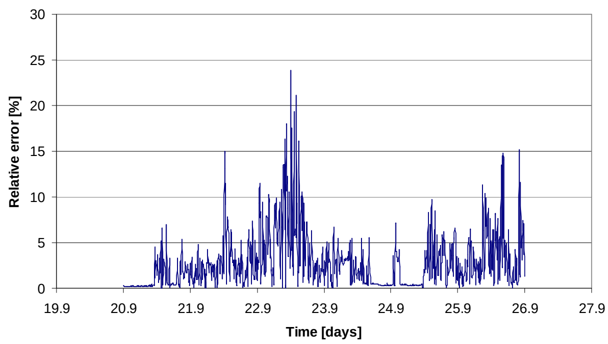


Fig. 14 Relative deviation in simulation [4]

The comparison of measured and simulated data was conducted by means of statistical data analysis. This analysis describes the simulation deviation. [4]

7. Conclusion

This article provides description of effects of stochastic production of electric power by wind power plants in the Czech Republic. There has been an analysis carried out with data measured at wind power plants from the different site in the Czech Republic, producing the output of 2x3MW and 2x2MW respectively.

Further description deals with the simulator of output of wind power plants – the Wind Power Forecast – developed at the Technical University of Ostrava – Czech Republic.

The values obtained by measurement were processed by the quality analyser at particular wind power plants and compared with the values simulated by the WPP based on the statistical data analysis.

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