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Efficiency of Modern Wind Turbines in Real Conditions

Kostiantyn Pokrovskyi*, Olgerd Mavrin, Andriy Muzychak

Lviv Polytechnic National University, 12, S. Bandery str., Lviv, 79013, Ukraine

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Abstract

One of the problems of wind energy is determined insufficient information available about the effectiveness of wind farms in the real life conditions, due in particular to commercial issues of use. On the one hand it is associated with the wind loads in effective areas, on the other – lasting licensed wind parameters measurement with difficult access conditions. The paper estimates the economic efficiency of wind farm generators of different capacities. It is shown that in this way we can calculate the wind power parameters necessary for the preliminary analysis of the economic efficiency of – annual electricity production, profitability and return on investment. As a result, the estimation of costs for wind turbines and their installation and operation, profit margins and payback period were estimated. The high efficiency of wind power in terms of the Carpathian region of Ukraine provided detailed characteristics of wind turbine choice for real parameters of wind loads has been shown.

Keywords: wind turbine; wind station; efficiency; productivity.

1. Problem definition

The global power industry, given the growing level of environmental requirements and technological advances, creates conditions for widespread use of alternative energy production technologies. The pace of the world's installed capacity of alternative energy sources, the volume of production consistently demonstrate positive dynamics. Along with this, wind energy shows significant growth impact on electricity production [1]. Use of wind power plants (WPP) reduces the consumption of traditional primary energy, promotes technological development of areas and creates jobs, reduces CO_2 emissions into the atmosphere.

The development of wind energy in Ukraine is characterized by dynamic parameters. Thus, in 2015 Ukraine WPP produced 974 thousand MWh of electricity, while the share of wind energy in the overall balance is 0.62 % and 0.9 % in installed capacity of generators, which reduces CO_2 emissions by 500 thousand tons. In 2016, the installed capacity of wind farms reached 525 MW in size in the production of energy of 925 thousand MWh and 49 % share in power alternative and renewable sources in Ukraine [2]. Consistent with this, in September 2016 "Eko-Optima" Ltd. launched the second stage of WPP "Staryi Sambir-1" with 6.6MW capacity to increase the power of generation. These facts confirm that wind energy development in Ukraine is promising, as its known benefits include reduced operating costs for electricity and cheaper equipment for the wind farms with the development of technology. Further development of wind power in Ukraine will contribute to the spread of additional information on the effectiveness of the establishment and operation of powerful WPP in power grid.

2. Analysis of the recent publications and research works

Features of the geographical location of WPP in Ukraine show that the main factors determining the possibility of wind electricity are weather conditions – WPP location taking into account the characteristics of the wind turbine, which determines its effectiveness given the wide range of proposals from manufacturers. High capacity power wind turbines by Vestas, Fuhrländer, Gamesa, Siemens, Aerodyn, Alstom and Guangdong

* Corresponding author. Email address: kpokrov@gmail.com

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MingYang, etc., differ in their characteristics, but are designed for maximum economic benefit in a wide range of wind loads. Evaluation of the WPP performance requires consideration of many factors to make design decisions arising from the existing legislation, the project engineering surveys (geological, surveying), expenses for arranging access and internal roads, especially in the mountains, data on the study of wind potential regional characteristics of existing grid connection for wind farms – energy infrastructure, land use requirements – availability of reserve land outside settlements, sufficient distance from the wind farm facilities to the existing buildings, the impact of wind farms on environmental and recreational conditions for the location of wind farms [3]. We should also include the special requirements of state law to obtain a "green tariff" based on the proportion of the use of domestic equipment. Sometimes under these circumstances, it is advisable to use a simplified algorithm for determining the performance of a WPP at the pre-project stage for the adoption of technical decisions, because the feasibility study of the wind power options requires significant financial investment.

The prospects of the Ukrainian Carpathians region to obtain industrial wind load can be confirmed according to expert assessment [3] and is determined by the average wind speed at the altitude of 80 m at 7.5–9 m/s. It is in this area that work on designing wind farms is conducted. First of all – "Eko-Optima" Ltd. in cooperation with the European Bank for Reconstruction and Development and Clean Technology Fund of the World Bank launched the first and second WPP "Staryi Sambir-1" with the installed capacity of 13.2 MW. [4] Also, in the area Drohobych Energy Ltd., Carpathian VES Ltd. and others are engaged in designing WPP. An important issue of site selection for the construction of WPP is the problem of wind measurements. Information expert assessments can be used to approximate estimates because according to current norms, calculation of wind turbines performance should be based on the results of long-term wind measurements, which leads to certain financial costs. However, results [4] of extended measurements in the western Ukrainian Carpathians have been published providing a similar average wind potential: 6.2–7.64 m / s at a height of 80m. Method [6] gives WPP productivity based on measured or expected wind power and WTG parameters. Change in wind parameters at the SH altitude can be determined by Hellman exponential law:

$$V_{h2} = V_{h1} \cdot \left(\frac{H_2}{H_1} \right)^b , \tag{1}$$

where H_2 – the altitude to which the reduction is made, H_1 – altitude for which wind measurements were carried out, V_{h1}, V_{h2} – appropriate wind speed, b – WTG installation terrain profile index (b = 0.14–0.30). For wind load data processing for future platform on the upper ridges in Turka region of Lviv oblast of Ukraine (coordinates investigated area – (lat., lon.) 49.2470; 22.8763), we can use the actual probability distribution of the known wind Weibull analytical division:

$$\Phi_V = \frac{k}{C} \left(\frac{V}{C} \right)^{k-1} \exp\left[\left(-\frac{V}{C} \right)^k \right], \tag{2}$$

where Φ_v – wind occurrence probability distribution function , %; k – coefficient of dispersion; C – coefficient scale determined by the average speed of the wind, approximately $C = 2A/\pi^{1/2}$; V – wind speed, in m/s.

This characteristic of wind loads of the specified area at A = 7.34 m/s and k = 2.16 m/s is shown in Fig. 1. To calculate the technical performance of the WPP, we choose types of wind turbines.

A common feature of today's installed capacity generators is the capacity of 2.5–3.3 MW. However, with the development of technologies, new capacities of 5–8 MW are launched at the market.

To evaluate the WPP performance, we will apply specifications (VG) Gamesa G132 5 MW [7] and Enercon E-126 5 MW [8] with working wind range 3–25 m/s. Options of the adopted generators are listed in Table 1.

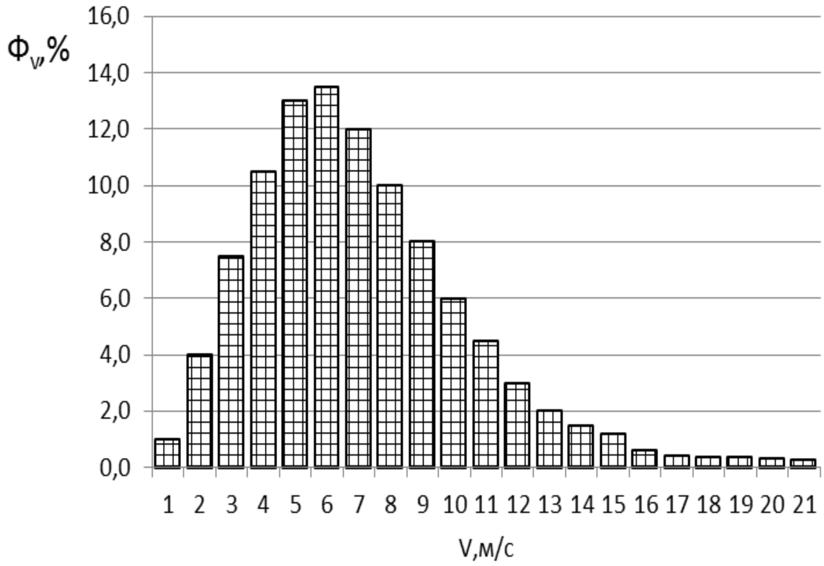

Fig. 1. Analytical Weibull distribution

Table 1. Parameters of WTG

Parameter	Enercon E-126	Gamesa G132
Rated power, MW	7,58	5,0
Rotor diameter, m	127	132
Hub height, m	135	95/120/140
Swept area, m^2	12668	13685

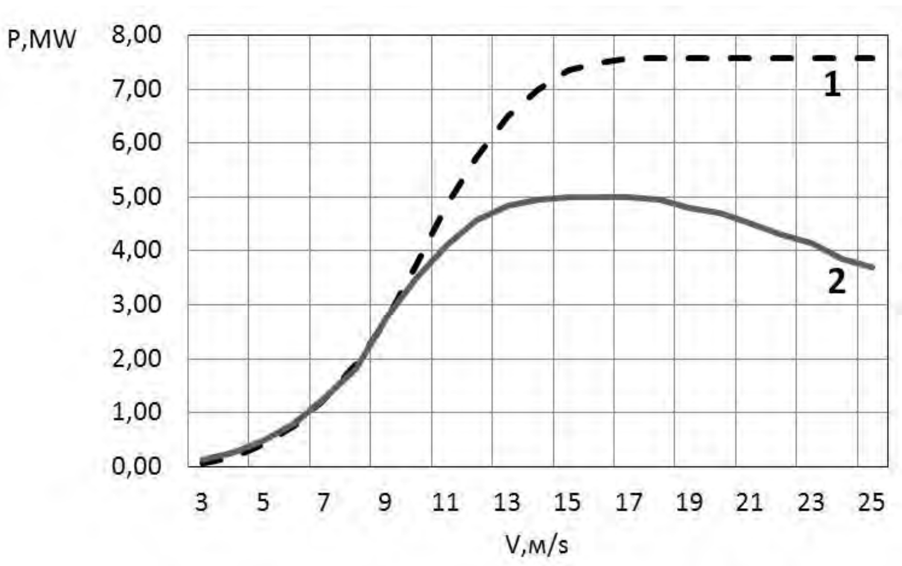

Fig. 2. Performance characteristics: 1 – Enercon E-126, 2 – Gamesa G132

WTG capacity is determined by the following parameters: average wind speed at the height of the rotor axis gondola, direction of wind, air density, the daily maximum and minimum wind speed [6].

$$P = k \cdot \rho \cdot V^3 \cdot S/2, \tag{3}$$

where k – coefficient of efficiency of the turbine; ρ – air density, kg/m³; V – wind speed, m/s; S – area of wind flow m². Performance characteristics for WTG models for the analysis are shown in Fig. 2.

Productivity of electricity can be defined [6] as follows:

$$E = \int_{v=0}^{n} \left[\tfrac{1}{2} rSV^3 C_p \Phi_V T\right] dV, \tag{4}$$

where ρ – density of air; S – area of propeller; C_p – parameter characterizing the efficiency of wind turbine energy wind flow (power coefficient) [7, 8].

3. Formulation of the goal of the paper

Preliminary considerations yield estimation parameters estimated from heterogeneous wind farms and wind turbines within the parameters of the actual wind load area. Method described in (1)–(4) allows us to get the following results for the 5-blocks imaginary WPP.

4. Presentation and discussion of the research results

Annual WTG productivity for specified areas in terms of the ridge with (1) and obtained by (2), (3) and (4) wind characteristics are as follows (Table 2):

Table 2. Characteristics of WPP performance

WTG type	Number of WTG	Average energy production (AEP), MWh
Enercon E-126	1	14082.262
Gamesa G132		12683.234

Electricity production for the year AEP is defined based on 2 % of energy consumption for power needs. Based on the indicators, we held an approximate assessment of the effectiveness of the WPP construction in the chosen area and the two types of WTG.

The cost of electricity generated at WPP in Ukraine is determined by the “green” tariff, which amounts to 0.11 €/kWh. We take into account the cost of one wind turbine in the amount of 0.61 million € per MW of installed capacity, corresponding to the expertise. We take into account that for 5 WTG-s cost of land acquisition, permitting and design documentation, license generation costs account for less than 1.9 mln. €, transportation costs, cost of construction and commissioning, including the cost of materials and switching devices – 30 % of the total cost, then we can get an approximate cost of WPP. Reactive power costs are not included in the calculation due to their absence for selected WTG [8]. Operating costs can be roughly estimated at 8.5 % – including wages, control service, depreciation, rent, investment contributions to development areas, taxes.

As a result, we can get the value of gross profit for the year of operation of imaginary power plant and payback period.

Table 3. Economic performance of WPP

Type of WTG	Number of WTG	"Green" tariff, €/kWh	Cost of construction and equipment, mln. €	Operational expenses, mln. €	Annual profit, mln. €	Payback, years.
Enercon E-126	5	0.11	30.612	0.634	7.456	4.5
Gamesa G132			20.839	0.571	6.715	3.4

5. Conclusions

The result shows that the wind turbine of lower capacity in terms of wind loads of the selected areas demonstrates lower payback period of the investment. This is due to the characteristics of wind areas stemming from Fig. 1. and Fig. 2 and is largely determined by higher volume of investment in equipment. This raises the possibility of finding the optimal ratio of cost and performance of wind turbines for specific wind conditions.

The results of wind farm performance should be considered as an assessment which can't be absolute because of the proximity of data and use of expertise and performance. Performance of 5-aggregate WPP shows slight differences from the published results of practical WPP, which suggests the adequacy of obtained characteristics and the possibility of evaluation of WPP performance in the Carpathian region of Ukraine.

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Ефективність новітніх вітрогенераторів у реальних умовах

Костянтин Покровський, Ольгерд Маврін, Андрій Музичак

Національний університет "Львівська політехніка", вул. С. Бандери, 12, м. Львів, 79013, Україна

Анотація

Проблемою розвитку вітроенергетики в Україні є недостатність доступної інформації про ефективність вітростанцій у реальних умовах застосування через комерціалізацію промислової інформації. З одного боку, це стосується показників вітрових навантажень в ефективних регіонах, з іншого – забезпечення тривалого ліцензованого вимірювання вітрових параметрів у складних за доступом умовах. Наведено результати оцінки економічної ефективності вітроелектростанції з генераторами різної потужності. Показано, що в такий спосіб можна розрахувати необхідні для попереднього аналізу економічної ефективності вітроелектростанції параметри – річне виробництво електроенергії, прибутковість та окупність інвестиції. В результаті проведено оцінку витрат на вітрогенератори та їхній монтаж та експлуатацію, оцінено розміри прибутку та терміну окупності. Показано високу ефективність впровадження вітроелектростанцій в умовах Карпатського регіону України за умови детального вибору характеристик вітрогенератора для реальних параметрів вітрових навантажень.

Ключові слова: вітрогенератор; вітростанція; ефективність; продуктивність.