Some aspects of technical, economical and wind simplified analysis for 18 MW wind farm in Poland

Waldemar DOLEGA
Institute of Electrical Power Engineering;
The Wroclaw University of Technology
Wybrzeze Wyspianskiego 27
Wroclaw, Poland

***Abstract*- In this paper, simplified analysis of different conditions of wind power expansion in Poland is shown. This analysis is made on basis of simplified computational example for 18 MW wind farm in Poland from the point of view different groups of parameters. Four groups of conditions: wind, geographical, technical and economical are taken into consideration.**

I. INTRODUCTION

Renewable energy sources as: wind, hydro, solar, biomass, biogas, geothermal and sea waves are of more and more fundamental importance in electricity production in countries of the European Union. This situation also ivolves Poland.

From renewable sources, the quickest and the greatest development concerns wind energy. Last years in the world just belongs to wind power energy. Now, there are wind turbines set with a total capacity of over 94000 MW in the world, at the territory of the Europe over 64900 MW [8]. Only in 2008, at the territory of the European Union countries there were in total wind turbines with capacity of 8484 MW set, which means 15% increase of installed capacity in comparison to the previous year [8].

Germany is still leader of the sector in the extent of market size, where the total installed capacity exceeds 23903 MW, the second place in the extent of installed capacity belongs to Spain - over 16754 MW [8]. Moreover, in six countries of the European Union the total installed capacity exceeds 2 GW – in Italy (3736 MW), France (3404 MW), Great Britain (3241 MW), Denmark (3180 MW), Portugal (2882 MW) and Holland (2225 MW) [8].

Wind energy in Poland is still in its early phase in comparison with other countries of the European Union. At country's territory there are 36 wind power plants (only 11 wind farms) with a total capacity of 442 MW [9]. Average capacity of a set turbine amounts to about 1,52 MW. Capacity installed in wind energy -per capita is 0,0037 kW, and per km^2 of land area 0,45 kW [9]. Wind energy density in Poland is one of the lowest in the Europe. A number of wind farms is very small in composition with fact that there are profitable wind conditions in 30 % area of Poland (Fig.1).

In 2006 total energy production in wind parks in Poland amounted to 388,4 GWh, which means that share of energy production from wind in production of energy in renewable energy sources in general amounted to 5,8% [4,9]. Share of wind generation in total country energy consumption in 2006 amounted to only 0,16 % [4,9].

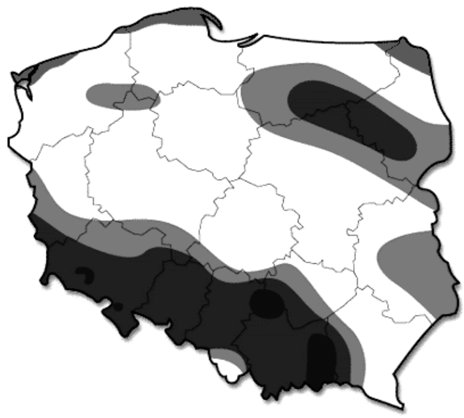

Figure 1. Wind resources in Poland (/colour – localisation/; grey - very profitable /north ends of Poland/; light grey - profitable; medium grey – enough profitable; dark grey – unfavourable /south part of Poland/; black – very unfavourable) [10]

In term 2004-2006, it was a dynamic increase of number and capacity of wind farms (almost 300%). It was installed 183,9 MW in wind farms installed power in this time [9].

A relatively quick development of renewables in Poland (especially wind farms) is connected with special consideration paid to renewables at the national level. It is determined in The Energy Law [1] and Decrees (Ordinances) of Ministers in charge of economic affairs [2,3]. This success was made mainly thanks to support given to renewables.

Support given to renewables in Poland are represented by: green certificate payment (market based), subvention to investment, additional benefits and limited fees for connection renewables to the grid [1-3].

According to The Energy Law and appropriate decrees (e.g. Ordinance of Ministry of Economy from 19.12.2005 about renewable energy purchase obligation [3]) the total balance of electricity in the gross national energy consumption in 2010 must contain 10.4 % share of renewable energy (and respectively: in 2009 – 8.7%). It means that any energy enterprise whose activity consists in electricity generation or trade in electricity, which sells the electricity to the final customers connected to the grid on the territory of Poland are obliged to purchase electricity from renewables – 8.7% in 2009 and 10.4 % in 2010 [3].

Additionally, polish government plans for 2020 concern installing 13600 MW in wind energy and 20 % share of wind generation in the national energy consumption [4]. It means that in 2009-2020 increase of capacity that is needed amounts to at least 13200 MW, at the same time connecting about 1200 MW a year.

Presently, this subject matter are specially important because of fact, wind energy in Poland is planned to develop very dynamic and in the near period is planed to build many wind farms [9,10].

II. Description of project

The main aim of this project was a realisation of computational example of 18 MW wind farm in Poland from point of view different groups of parameters. Four groups of conditions: wind, geographical, technical, and economical were taken into consideration.

First group of conditions were contained wind regime (consistent with mesoscale) as: yearly wind speed, specific yield and Weibull distribution. Yearly wind speed on level: 4, 4.5, 5, 5.5 and 6 m/s, profitable for wind power expansion in Poland, was considered in analysis. This range of values of wind speeds is fited to conditions which are occured in Poland (Fig.1.). Wind speed was qualified at a height - 30 m.p.g [10].

Simplification as wind regime for temperature of air - 15°C, pressure of air - 101.3 kPa /specific weight 1.225 kg/m^3/. Wind was modelled to use Weibull distribution with shape parameter equal 2. This model was a standard for polish wind conditions [10]. Wind speeds were related to geographical regions in Poland.

Second group of consider conditions were geographical conditions as: localisation of wind farm and surface class. Localisation of wind farm was qualified through connection with yearly wind speed. Surface class (roughness) was considered according to Danish elaboration on level: 0 (surface of water), 1 (open fields with single buildings), 2 (open fields with few buildings /distant about 500 m/) [5,11].

Third group of consider conditions were technical conditions as: unit of wind turbine, producer of wind turbine, rotor area, wind turbine power curve, characterised power of unit of wind turbine. In the frames of investigations some units of leader producers from Denmark are considered [11-13]. These producers are: BONUS, NEG MICON, NORDEX, VESTAS and WIND WORLD. Offer specification of turbine for each producers is taken into considerations [12,13].

For project simulation of wind power plant about 18 MW nominal power were used:

- 30 units about 600 kW nominal power each (Bonus 600/44 Mk IV, NEG Micon 600/43, Nordex N43/600, Vestas V44 600/44 and Wind World 600/42);
- 24 units about 750 kW each (NEG Micon 750/44, Wind World 750/48);
- 18 units about 1 MW each (NEG Micon 1000/60, Bonus 1000/54, Nordex N54/1000);
- 12 units about 1,5 MW each (NEG Micon 1500/72, Nordex S70/1500);
- 9 units about 2 MW nominal power each (Bonus 2000/76, NEG Micon 2000/72, Vestas V66 2000/66).

Fourth group of consider conditions were economical factors as: wind turbine price, installation cost of turbine, total investment cost of turbine, operational & maintenance cost, price per 1 kWh produced electricity, price of green certificate per 1 MWh produced electricity, inflation rate and rate of discount. All incurred costs and economical calculations were realised in EUR currency. Wind turbine prices was taken from offer specification of producers [12,13]. Installation cost of turbine was qualified as 30% wind turbine price [11]. Operational & maintenance cost was considered on level 1.5% wind turbine price yearly [11]. Period of exploitation was qualified as 25 years [5]. Rate of discount was qualified as 8 % [6,10]. Real rate of return was also qualified on level 8%. For simplification, price per kWh produced electricity was taken in calculations as constant in time on level 0.03, 0.04 and 0.05 EUR/kWh. Price of green certificate per 1 MWh produced electricity was qualified as 64.21 EUR/MWh [7]. For economical calculations all prizes, costs and counters (EUR/PLN, USD/PLN, EUR/USD, EUR/DKK) were taken as average level in 2007. Investment was qualified as totally realised from own financial sources. Quantity of subsidies was calculated as the aim to obtain of investment profitability. Economical calculations were realised with reference to hypothetical wind farm about 18 MW nominal power. For simulation, this farm is included from: 30 units about 600 kW nominal power each, 24 units about 750 kW each, 18 units about 1 MW each, 12 units about 1.5 MW each and 9 units about 2 MW nominal power each. All units in the wind farm were produced by the same producer.

III. Wind farm calculation

In frames this project two main groups of calculations were realised. These calculations were made with using two computer programs elaborated by author.

First group were calculations of year energy output for specified wind turbines, wind speeds, surface classes and Weibull shape parameter. In frames these calculations power input, power output, energy output and capacity factor were calculated.

Technical and economical calculations are related to five analysed configurations of wind farm, 15 basic units, profitable wind conditions (yearly wind speed: 4, 4.5, 5, 5.5 and 6 m/s) and different surface classes suitable for localisation of wind farm (surface class: 0,1 and 2). The main parameters of technical and economical estimate were: yearly total energy output from analysed wind farm, capacity factor of wind farm, total investment costs, total income per year (sale of electricity, sale of green certificates, inclusive), cost of 1 kWh produced electricity from analysed wind farm. Electricity price per kWh on assumed levels are determined as a limit of profitability, according to polish conditions [10].

Process of simulations and analysis was divided into two stages:

- selection of the best solution within given configuration of wind farm,
- selection of the best solution for wind farm.

IV. ANALYSIS OF WIND FARM

Conducted simulations and analysis for individual configurations of wind farm about 18 MW nominal power let to select the best variant for each configuration. Selection was based on three criterions: max. yearly energy output, min. cost of 1kWh produced electricity and max. total income per year from sale of electricity and green certificates. The best solutions for each configurations of wind farm are presented in table 1. The best composition of wind farm was selected of these configuration according to listed earlier criterions.

TABLE 1.
The best solutions inside individual configuration

Composition of wind farm	Producer of turbine	Type of turbine	Nominal power of turbine
30 x 600 kW	Nordex	N43/600	600 kW
24 x 750 kW	NEG Micon	750/48	750 kW
18 x 1MW	NEG Micon	1000/60	1 MW
12 x 1.5MW	Nordex	S70/1500	1.5 MW
9 x 2 MW	Bonus	2000/76	2 MW

Analysis of solutions for optimal localisation of wind farm (surface class – 0) from point of view total energy output for different yearly wind speeds leads to conclusion that the best solution is a wind farm included 18 units NEG Micon 1000/60.

Yearly wind speed has the greatest influence on total energy output of wind farm. A higher yearly wind speed in place of wind farm localisation means larger productivity of wind farm. Even slight deviation from assumed yearly wind speed results in differences in electricity production on level a few dozen or so, and even a few dozen percent. Differences between five considered solutions with reference to total energy output are presented in table 2. Solution with 1 MW units is the best for each analysed yearly wind speed, but in principle solutions with units about largest nominal power are the best.

TABLE 2.
Comparison of total energy output per year (MWh) for analysed 18 MW wind farm for different yearly wind speeds (surface class = 0)

Composition of wind farm	Yearly wind speed, m/s				
	4	4.5	5	5.5	6
30 x 600 kW	11838.9	16803.6	22914.0	29406.3	36280.5
24 x 750 kW	11421.0	16750.9	22842.1	29694.7	36928.1
18 x 1MW	14722.5	20968.3	27660.4	34798.5	42382.8
12 x 1.5MW	12954.4	19026.8	25908.9	33600.6	41292.3
9 x 2 MW	12168.6	17537.1	23621.4	30779.4	37937.3

For example, wind farm included 1 MW units produces 27660 MWh electricity for yearly wind speed on level 5 m/s and it brings in total inclusive income per year on level 2882489 EUR for price for sale of 1 kW produced electricity on level 0.04 EUR (tables 2, 6). The cost of 1 kWh produced electricity from analysed wind farm is equal 0.12 EUR (table7). This solution is on a limit of profitability, thanks to significant income from sale of green certificates. Solution with 750 kW units is the most disadvantageous. Such farm produces 17 % less electricity and total inclusive income per year decreases also 17 % i.e. 502113 EUR (tables 2, 6). Producing of 1 kWh electricity costs 0.02 EUR more (table 7).

Significant differences between solutions occur for yearly wind speed on level 6 m/s. The farm included 30 units Nordex N43/600 produces 14 % less electricity than farm included 18 units NEG Micon 1000/60 (table 2). Differences are smaller for other configurations of wind farm.

Similar correlations concern capacity factors for wind farm. Maximum values of capacity factors obtain for yearly wind speed on level 6 m/s. Than wind turbine NEG Micon 1000/60 has capacity factor on level 27 %, however turbines Nordex N43/600 and NEG Micon 750/48 have 23 % (table 3).

TABLE 3.
Comparison of capacity factor (%) for analysed 18 MW wind farm for different yearly wind speeds (surface class = 0)

Composition of wind farm	Producer of turbine	Type of turbine	Yearly wind speed, m/s				
			4	4.5	5	5.5	6
30 x 600 kW	Nordex	N43/600	8	11	15	19	23
24 x 750 kW	NEG Micon	750/48	7	11	14	19	23
18 x 1MW	NEG Micon	1000/60	9	13	18	22	27
12 x 1,5MW	Nordex	S70/1500	8	12	16	21	26
9 x 2 MW	Bonus	2000/76	8	11	15	20	24

Simplified economical analysis leads to conclusion that the wind farm included 18 units NEG Micon 1000/60 has the best economical parameters.

Total inclusive income for wind farm is obtained from sale of electricity and green certificates. It depends mainly on quantity of produced electricity as well as unit price for sale of electricity (1 kWh) and unit price for sale of green certificate (1 MWh). For example, wind farm included 1 MW units brings in total inclusive income per year on level 4416713 EUR for yearly wind speed 6 m/s, however it decreases 65% to level 1534230 EUR for yearly wind speed 4 m/s (table 6).

Influence of unit price for sale of electricity on total income of wind farm for example yearly wind speed 5 m/s is presented in table 4.

TABLE 4.
Comparison of total income per year (EUR) obtained from electricity sale in function of price for 1 kW produced electricity
(yearly wind speed = 5 m/s, surface class = 0)

Composition of wind farm	Producer of turbine	Type of turbine	Price for 1kWh, EUR		
			0.03	0.04	0.05
30x600 kW	Nordex	N43/600	687420	916560	1145700
24 x 750 kW	NEG Micon	750/48	685264	913685	1142106
18x1 MW	NEG Micon	1000/60	829811	1106415	1383018
12x1.5 MW	Nordex	S70/1500	777266	1036355	1295444
9 x 2 MW	Bonus	2000/76	708641	944855	1181068

Influence of unit price for sale of green certificate on total income of wind farm for different yearly wind speeds is presented in table 5. For example, wind farm included 1 MW units brings in total income from sale of green certificates per year on level 2721400 EUR for yearly wind speed 6 m/s, however it decreases 65% to level 945332 EUR for yearly wind speed 4 m/s (table 5).

TABLE 5.
Comparison of toal income per year (EUR) obtained from sale of green certificates for produced electricity for different yearly wind speeds (surface class = 0)

Composition of wind farm	Yearly wind speed, m/s				
	4	4.5	5	5.5	6
30 x 600kW	760176	1078959	1471308	1888179	2329571
24 x 750kW	733342	1075575	1466691	1906697	2371153
18 x 1MW	945332	1346375	1776074	2234412	2721400
12 x 1.5MW	831802	1221711	1663610	2157495	2651379
9 x 2 MW	781346	1126057	1516730	1976345	2435954

Profitability of wind farm depends strictly on cost of 1 kWh produced electricity. It is connected with yearly wind speed, higher speed means smaller cost (table 6). Cost of 1 kWh produced electricity should be smaller than price per kWh produced electricity. Analysed solutions aren't effective economicly even for the highest assumed level of unit price for sale of electricity (0.05 EUR) and yearly wind speed 6 m/s (table7). Effectiveness is obtained thanks to significant income from sale of green certificates.

Wind farm included 1 MW units has the smallest cost of 1 kWh produced electricity. However the largest cost is for wind farm included 750 kW units (table 7).

TABLE 6.
Comparison of total income per year (EUR) obtained from electricity sale and sale of green certificates for different yearly wind speeds (price for sale of 1 kW produced electricity - 0,04 EUR surface class = 0)

Composition of wind farm	Yearly wind speed, m/s				
	4	4.5	5	5.5	6
30 x 600 kW	1233732	1751103	2387868	3064431	3780791
24 x 750 kW	1190184	1745611	2380376	3094487	3848276
18 x 1MW	1534230	2185109	2882489	3626353	4416713
12 x 1.5MW	1349980	1982785	2699965	3501518	4303070
9 x 2 MW	1268089	1827540	2461585	3207519	3953448

TABLE 7.
Comparison of electricity cost per kWh for analysed wind farm for different yearly wind speeds (price for sale of 1 kW produced electricity - 0,04 EUR, surface class = 0)

Composition of wind farm	Producer of turbine	Type of turbine	Yearly wind speed, m/s				
			4	4.5	5	5.5	6
30 x 600 kW	Nordex	N43/600	0.27	0.19	0.14	0.11	0.09
24 x 750 kW	NEG Micon	750/48	0.28	0.19	0.14	0.11	0.09
18 x 1MW	NEG Micon	1000/60	0.22	0.15	0.12	0.09	0.075
12 x 1,5MW	Nordex	S70/1500	0.25	0.17	0.13	0.09	0.08
9 x 2 MW	Bonus	2000/76	0.26	0.18	0.135	0.10	0.08

V. Conclusions

A quick development of renewables (especially wind farms) in Poland in last years is closely related to good law and economic solutions.

The Energy Law [1] with Ordinances of Ministry of Economy [2,3] are key law acts in Poland for development of renewables.

Support given to renewables in Poland constitutes market based green certificate payment, subvention to investment, additional benefits and limited fees for connection renewables to the grid.

Green certificate payment (market based) and subvention to investment are key support means given to renewables in Poland.

Green certificate payment is the best solution for development of renewables applied in Poland.

Energy enterprises which generates electricity from renewables in Poland have two sources of income - from sale of physical electricity and - from sale of property rigths connecting with certificates of origin (green certificates).

Realised investigations enable to qualify a localisation of wind farm about 18 MW nominal power for different profitable yearly wind speeds, different surface classes and optimum selection of unit for wind farm.

Yearly wind speed has the greatest influence on total energy output of wind farm and electricity cost per kWh produced by it. Growth of yearly wind speed causes considerable growth of total energy output and considerable decrease electricity cost per kWh.

Surface class has considerable influence on total energy output and electricity cost per kWh.

Type of units applied in wind farm has a great influence on total energy output and electricity cost per kWh.

The best solution for analysed 18 MW wind power plant is farm consisted of 18 units NEG Micon 1000/60.

At present market mechanisms wind power farm investments are profitable for good localisations. The main causes of wind farm profitability are market based mechanism of green certificates and subvention to investment from different national and union funds.

References

[1] Act of 10 April.1997 – The Energy Law (Journal of Laws of 2003 No.153, Item 1504, No.203, Item 1966, of 2004 No.29, Item 257, No 34, Item 293, No.91, Item 875, No 96, Item 959, of 2005 No.62, Item 552). /in polish/

[2] Ordinance of Ministry of Economy from 4.05.2007 about detailed conditions of power system functions (Journal of Laws of 2007 No.93, Item 623). /in polish/

[3] Ordinance of Ministry of Economy from 19.12.2005 about renewable energy purchase obligation (Journal of Laws of 2005 No.261, Item 2187). /in polish/

[4] Energy policy of Poland up to 2030 – Project formulated by Ministry of Economy. Warsaw, september 2007. /in polish/

[5] T. Burton, D. Sharpe, N. Jenkins, E. Bossanyi: Wind Energy Handbook, John Wiley and Sons Ltd. Chichester, England, 2001.

[6] J.F. Manwell, J.G.McGowan, A.L. Rogers: Wind Energy Explained: Theory, Design and Application, John Wiley and Sons Ltd. Chichester, England, 2002.

www pages

[7] URE (Energy Regulatory Office) http://www.ure.gov.pl

[8] EWEA (European Wind Energy Association) http://www.ewea.org

[9] PWES (Polish Wind Energy Society) http://www.ptew.pl

[10] Wind Plants – News Bulletin http://www.elektrownie-wiatrowe.org.pl /in polish/

[11] Know how: Danish Wind Industry Association, www.windpower.org/en/tour.

[12] Wind energy: The World of Renewable Energy Industry, www.iwr.de.

[13] Wind turbine index: The International Portal for Wind Energy - Branch, www.windfair.net.