1. *www.elektrownie-wiatrowe.org.pl* *2.* *www.energy.sourceguides.com* *3.* *www.euwinet.iset.uni-kassel.de* *4.* *www.physik.uni-oldenburg.de/ehf/wind/* *5.* *www.uni-muenster.de/energie/wind* *6.* *www.windpower.dk* *7.* *www.windustry.com*

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ANALYSIS OF WIND FARM EXPANSION ON EXAMPLE POLAND

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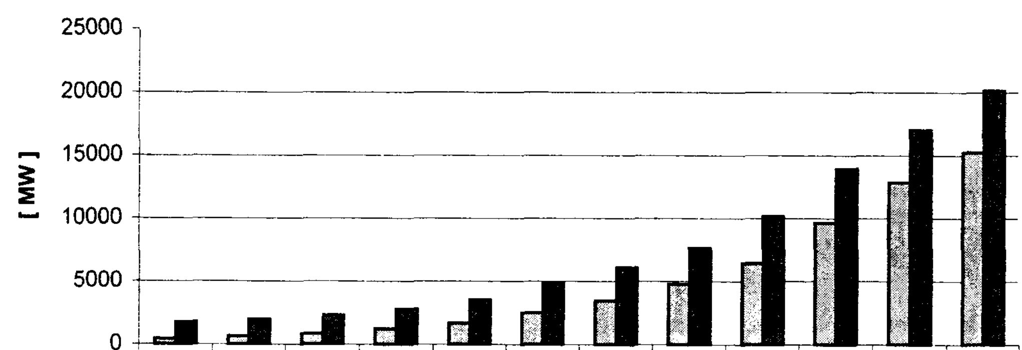
This paper describes a some elements of research project "Wind Farm" which was realised in Wroclaw University of Technology. In this paper, analysis of different conditions of wind power expansion in Poland is shown. This analysis is made on basis computational examples of 6 MW wind farm in Poland from the point of view of different groups of parameters. Four groups of conditions: wind, geographical, technical and economical are taken into consideration.

Introduction. Energy is one of the basic factors to necessary for economical, social and technical expansion. Further civilisation expansion of world will grow energy demand, which will entail to enlarge consumption of conventional fuels. It will have consequences as faster exhaustion of these supplies and increase the pollution of the environment. Solution of this problem may be using renewable resources as: wind, solar, biomass, geothermal and sea waves to energy produce. From these sources, one of fastest development has wind energy. Lately, wind energy energetic just scored a spectacular success in Europe (Fig. 1).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
□EU	439	629	844	1211	1683	2515	3463	4772	6458	9645	12822	15238
■World	1743	1983	2321	2801	3531	4821	6104	7636	10153	13932	17000	20158

Fig. 1. Growth of wind plants power in 1990 — 2001 [3]

Poland is only on the start of way for wind power expansion. Now, 17 mainly small wind power plants about 27 MW power work in Poland [1]. Localization of wind power plant is presented fig. 2. It is a very small amount of wind power plants in composition with fact that there are excellent wind conditions in two-thirds of Poland (Fig.3). These conditions are increased interest in renewable energy sources such as wind energy and are better than for example in Germany — the world leader in wind energetic[5]. Now, the problems 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 some wind farms[1].

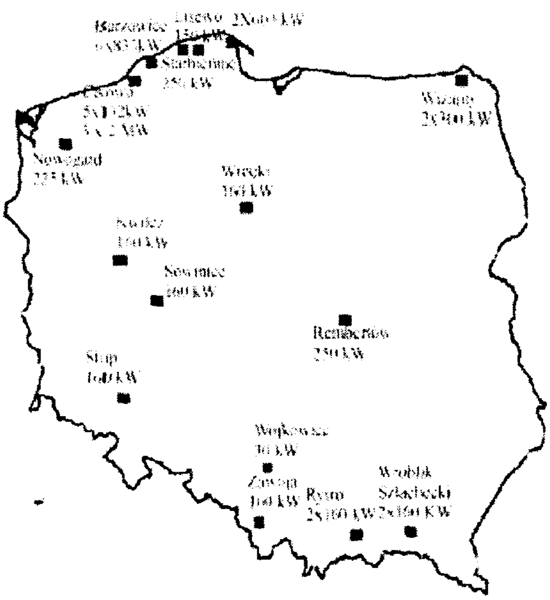


Fig. 2. Localization of wind power plants in Poland

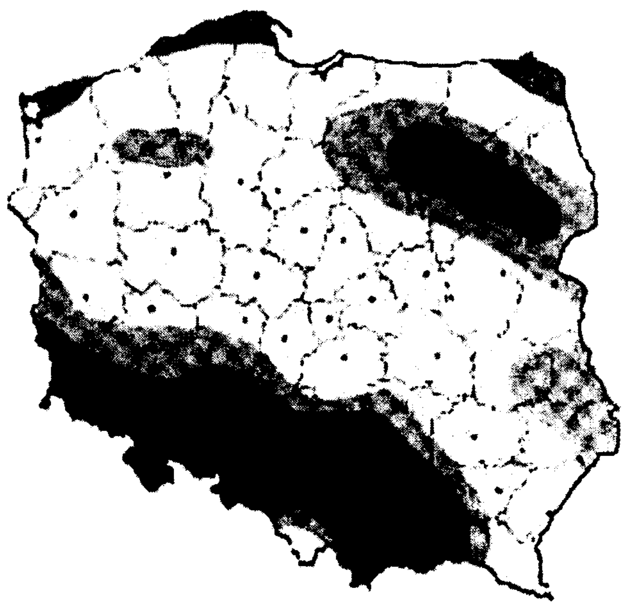


Fig. 3. Wind resources in Poland[1]

Description of project. "Wind Farm" was a subject of research project which was realised in Wroclaw University of Technology. The main aim of this project was a realisation of computational example of 6 MW wind farm in Poland from the point of view of different group 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; and 5.5 [m/s] , profitable for wind power expansion in Poland [1], was considered in analysis. This range of values of wind speeds is fited to conditions which are occured in two-thirds of Poland (Fig.3). Wind speed was qualified at a height 30 m.p.g and 50 m.p.g.

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[1]. Wind speeds were joined with geographical regions in Poland.

Second group of consider conditions were geographical conditions as: localisation of wind farm , surface class, roughness and height. 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)), 3 (villages, small towns, forest, uneven ground) [6].

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 [3,6,7]. These producers are: NEG MICON, NORDEX, VESTAS and WIND WORLD. Offer specification of turbine for each producers is taken into considerations [6, 7].

For project simulation of wind power plant about 6 MW nominal power were used:

- 12 units NEG Micon 500/43 (producer NEG Micon, unit nominal power 500 kW, wind turbine power curve — between 3 m/s and 25 m/s, rotor diameter 43 m, hub height 40 m);
- 6 units Nordex N54/1000 (producer Nordex, unit nominal power 1000 kW, wind turbine power curve — between 4 m/s and 25 m/s, rotor diameter 54 m, hub height 50 m);
- 4 units NEG Micon 1500/64 (producer NEG Micon, unit nominal power 1500 kW, wind turbine power curve — between 4 m/s and 25 m/s, rotor diameter 64 m, hub height 60 m);
- 10 units Vestas V44 600/44 64 (producer Vestas, unit nominal power 600 kW, wind turbine power curve — between 4 m/s and 20 m/s, rotor diameter 44 m, hub height 35 m);
- 10 units WIND WORLD 600/42 64 (producer WIND WORLD, unit nominal power 600 kW, wind turbine power curve — between 2,5 m/s and 20 m/s, rotor diameter 42 m, hub height 40 m);
- 10 units NORDEX N43/600 64 (producer NORDEX, unit nominal power 600 kW, wind turbine power curve — between 3 m/s and 25 m/s, rotor diameter 43 m, hub height 40 m).

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 kWh, inflation rate, rate of discount, distribution company tariffs. All incurred costs and economical calculations were realised in USD currency. Wind turbine prices was taken from offer specification of producers [3]. Installation cost of turbine was qualified as 30 % wind turbine price [6]. Operational & maintenance cost was considered on level 1.5 % wind turbine price yearly [6]. Period of exploitation was qualified as 20 years [6]. Rate of discount was qualified as 8 % [1]. Real rate of return was also qualified on level 8 % . For simplification, price per kWh was taken in calculations as constant in time on level 0.05 [USD/kWh] [1]. 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 6 MW nominal power. For simulation, this farm is included from: 12 units NEG Micon 500/43, 6 units Nordex N54/1000, 4 units NEG Micon 1500/64, 10 units Vestas V44 600/44, 10 units WIND WORLD 600/42 and 10 units NORDEX N43/600.

Some examples of wind farm calculations. 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 year energy output calculations for specified wind turbines, wind speeds and surface classes. In frames these calculations power input, power, power output , energy output and capacity factor were calculated. Example of calculations from first group are placed in table 1. These calculations are related to one of analysed wind farms — 10 units Vestas V44 600/44. Graphic presentation of results for wind farm consisting of units Vestas V44 600/44. and NORDEX N43/600 is on fig.2, 3.

Second group of calculations were electricity costs per kWh electric energy for analised wind farms including specified wind turbines, wind speeds and surface classes. In frames this group of calculation current income per year, total net income per year were qualified among other things. Example of economical calculations for wind farm about 6 MW nominal power are placed in table 2. Graphic presentation of economical results for wind farm consisting of units Vestas V44 600/44. and NORDEX N43/600 is on chart no.5 and no.6.

These calculations are related to six analysed wind farms, profitable wind conditions (wind speed: 4.0, 4.5; 5.0; 5.5 [m/s]) and different surface classes. The main parameter of economical estimate is electricity cost per kWh from analysed wind farms. Electricity price per kWh on level 0.05 [USD/kWh] is determined as a limit of profitability, according to Polish conditions [1].

Table 1

Results of calculations for wind farm including from 10 units Vestas V44 600/4

Surface class	Yearly wind speed	Power I input	Power output	Energy output	Capacity factor	Total energy output for 10 units
	m/s	[W/m^2] rotor area	[W/m^2] rotor area	kWh/year	%	KWh/year
Surface class = 0	4,0	70	22	293237	5,57	2932370
	4,5	100	34	453185	8,61	4531850
	5,0	137	48	639791	12,16	6397910
	5,5	183	63	839725	15,96	8397250
Surface class = 1	4,0	67	20	266579	5,07	2665790
	4,5	96	32	426527	8,11	4265270
	5,0	132	46	613133	11,66	6131330
	5,5	175	61	813067	15,46	8130670
Surface class = 2	4,0	66	20	266579	5,07	2665790
	4,5	94	31	413198	7,86	4131980
	5,0	129	45	599804	11,40	5998040
	5,5	172	59	786409	14,95	7864090
Surface class = 3	4,0	64	19	253250	4,82	2532500
	4,5	90	30	399869	7,60	3998690
	5,0	124	43	573146	10,89	5731460
	5,5	165	57	759751	14,45	7597510

Table 2

Results of economical calculations for wind farm including from 10 units Vestas V44 600/4

Surface class	Yearly wind speed	Total energy output for 10 units	Current income per year	Total net income per year	Electricity cost per KWh
	m/s	kWh/year	USD	USD	USD
Surface class = 0	4,0	2932370	146610	84360	0,2086
	4,5	4531850	226590	164330	0,1350
	5,0	6397910	319890	257630	0,0956
	5,5	8397250	419860	357600	0,0728
Surface class = 1	4,0	2665790	133280	71030	0,2295
	4,5	4265270	213260	151000	0,1434
	5,0	6131330	306560	244300	0,0997
	5,5	8130670	406530	344270	0,0752
Surface class = 2	4,0	2665790	133280	71030	0,2295
	4,5	4131980	206590	144340	0,1480
	5,0	5998040	299900	237640	0,1020
	5,5	7864090	393200	330940	0,0777
Surface class = 3	4,0	2532500	126620	64360	0,2415
	4,5	3998690	199930	137670	0,1530
	5,0	5731460	286570	224310	0,1067
	5,5	7597510	379870	317610	0,0805

Conclusions. Realised investigations enable to qualify a localisation of wind farm about 6 MW nominal power for different profitable yearly wind speed, 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. Received results from simulations indicate on units about the least nominal power from analised turbines as the most efficient units in producing electricity. Units: NEG Micon 500/43, NORDEX N43/600 and Vestas V44 600/44 are the most efficient in producing electricity for yearly wind speed in range 4 — 5.5 m/s (fig. 4, fig. 5). With reference to key economic factor of wind farm — electricity cost per kWh, the best units are in turn NORDEX N43/600 , Vestas V44 600/44 and NEG Micon 500/43 (fig. 8, 9).

The best economical solution for analyzed 6 MW wind power plant is farm consisted of 10 units NORDEX N43/600 or 10 units Vestas V44 600/44. or 12 units NEG Micon 500/43.

There are very good wind conditions in Poland for expansion of wind power. Regions with average year wind speed at least 4.0 m/s wind determine two-thirds of Poland. The best localisation of wind farms in Poland from point of view wind energy is seaside resort.

At present market mechanisms wind power farm investments isn't profitable now. The main causes of wind farm unprofitability are low price of electric energy for consumers, high price of wind turbine, expensive credits for private investors and poverty of state financial aid.

The main possibility of investment effectivity improvement is extra charges to preferential credits or subsidies from advisable funds: national budget, different ecological foundations, local autonomies, etc.

State should be introduce a system of economical and law encouragement for wind power.

[7]www.windustry.com

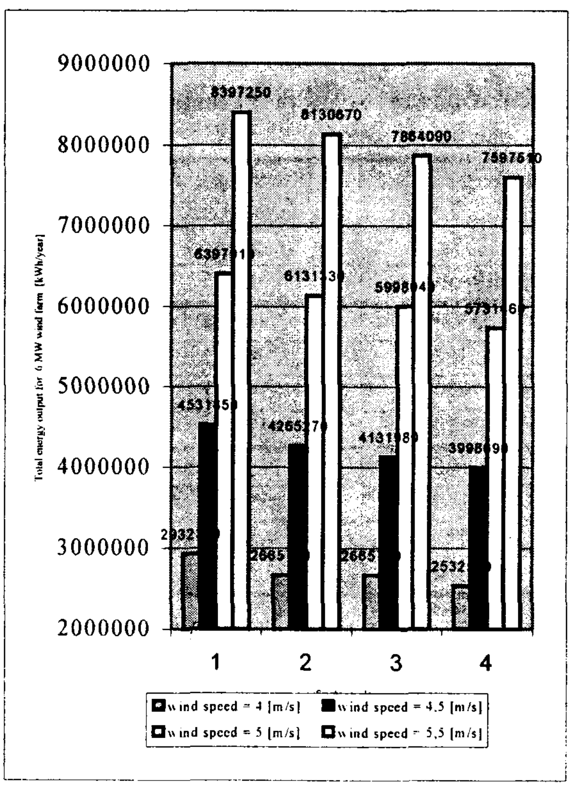


Fig. 2. *Total energy output per year for 6 MW wind farm including 10 units Vestas V44 600/44 in function of surface class.*

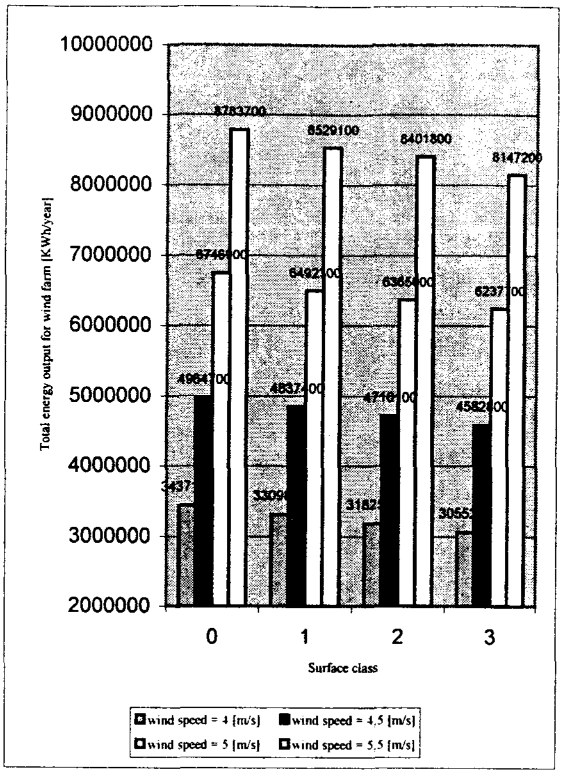


Fig. 3. Total energy output per year for 6 MW wind farm including 10 units NORDEX N43/600 in function of surface class

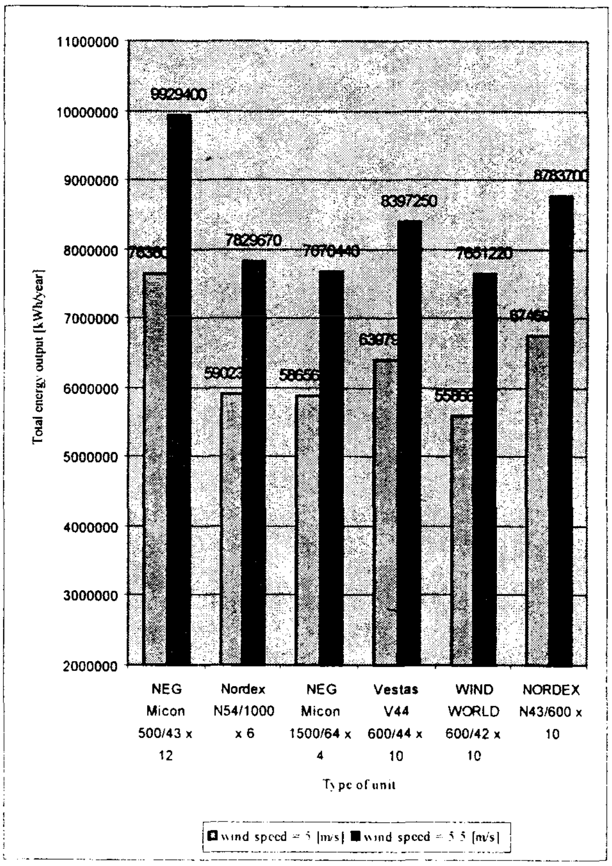


Fig. 4. Total energy output per year for analised 6 MW wind farm (surface class = 0)

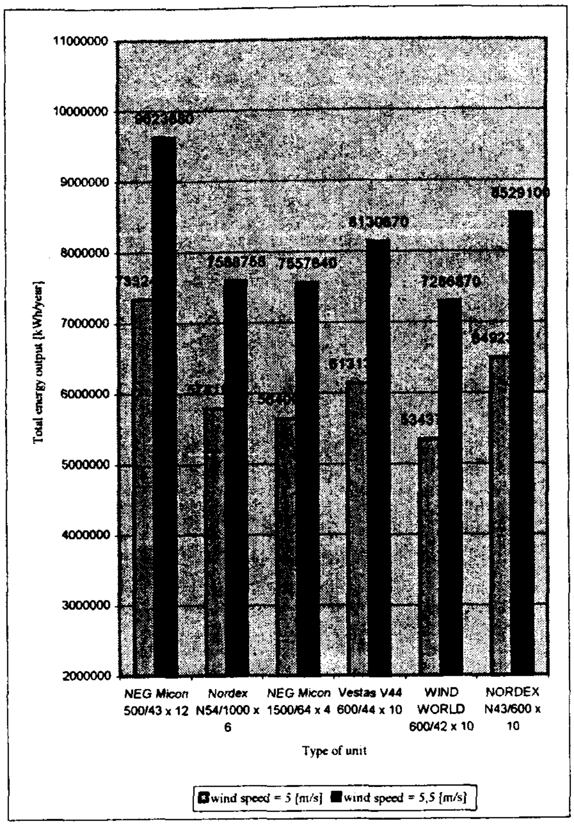


Fig. 5. Total energy output per year for analised 6 MW wind farm (surface class = 1)

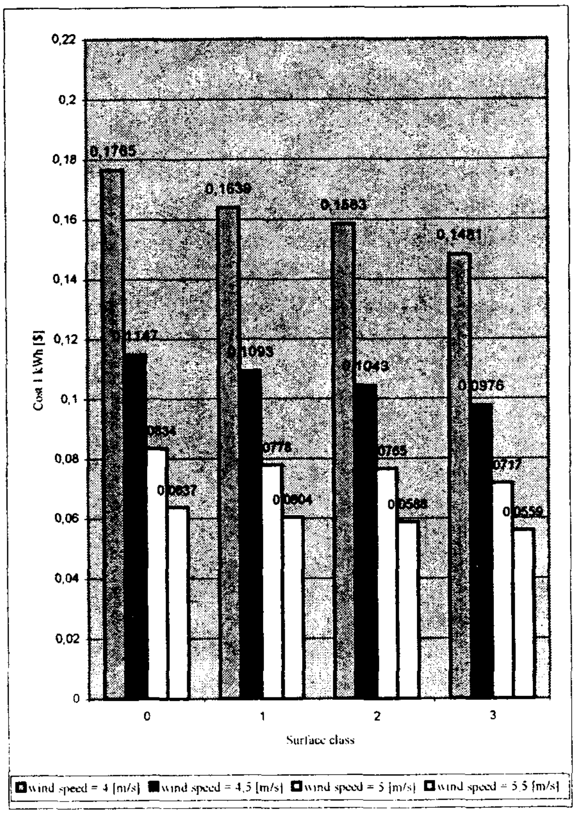


Fig. 6. Electricity cost per kWh in function surface class for 6 MW wind farm including 10 units Vestas V44 600/44

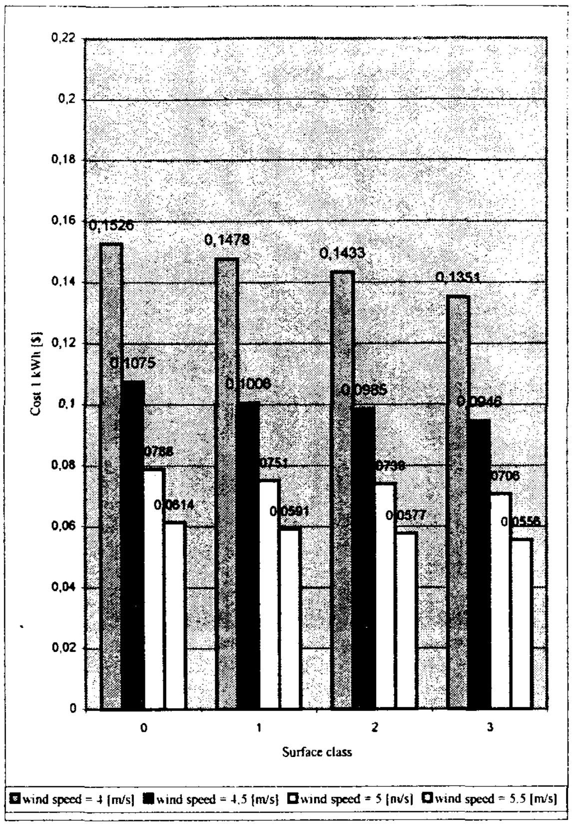


Fig. 7 Electricity cost per kWh in function surface class for 6 MW wind farm including 10 units NORDEX N43/600 x 10

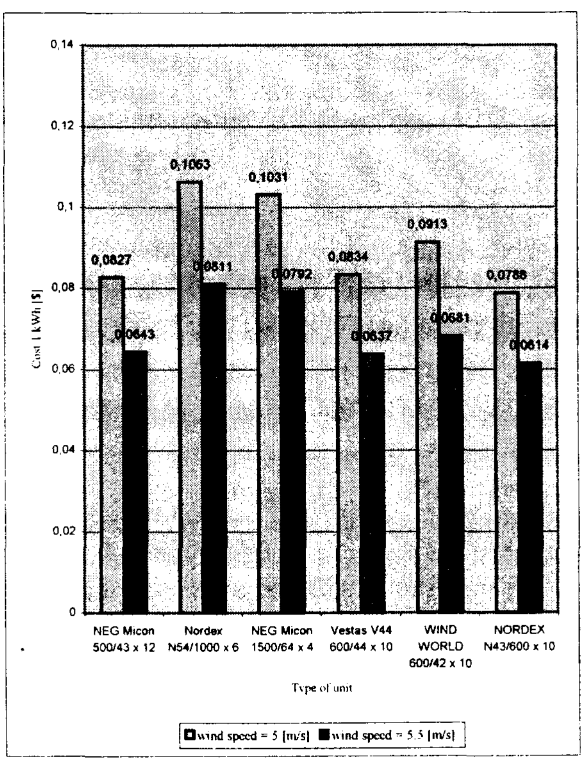


Fig. 8. Electricity cost per kWh for analised 6 MW wind farm (surface class = 0)

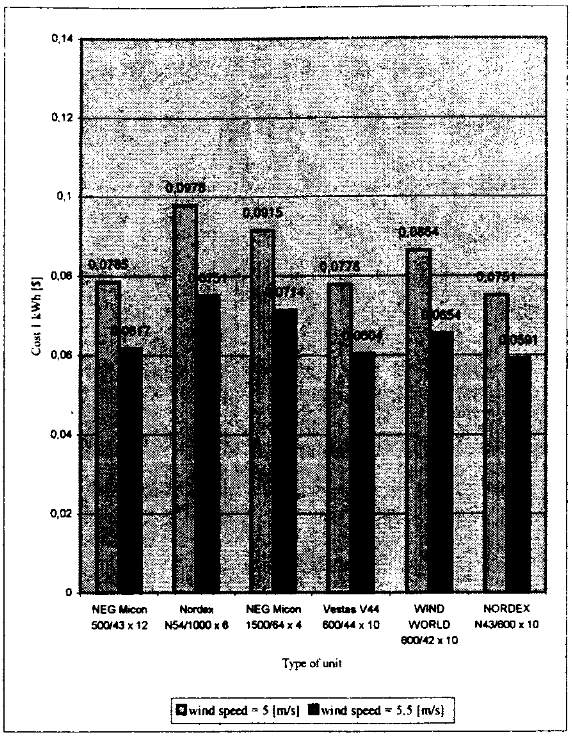


Fig. 9. Electricity cost per kWh for analised 6 MW wind farm (surface class = 1).

1. www.elektrownie-wiatrowe.org.pl 2. www.energy.sourceguides.com 3. www.euwinet.iset.uni-kassel.de 4. www.reisi.iset.uni-kassel.de/wind/ 5. www.uni-muenster.de/energie/wind 6. www.windpower.dk

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APPLICATION OF PHYSICAL MODELLING FOR AERODYNAMIC TEST OF FGD ABSORBER

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1. Introduction

Belchatow Power Plant is the Polish and European largest lignite fired conventional plant. It consists of 6 power units of 360 MW capacity and 6 units of 370 MW capacity, which gives the total of 4380 MW installed capacity. There are 6 flue gas desulphurization plants based on lime-gypsum method installed at Belchatow Power Plant and another two ones are under realization.

Commencement of the construction of Belchatow Power Plant, which took place in 1975, was of a great importance both to the Polish power system and to the Power Plant itself, as its development perspectives were very promising. Six years later, on 29th December 1981 the 1st Power Unit was synchronized with the National Power Grid and the last one — on 12th October 1988, reaching the total of 4320MW capacity, as it had been originally planned.