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WIND POWER PLANTS IN CZECH REPUBLIC

Abstract: The paper deals with history, state-of-the-art and future development of wind power plants (WPP) in Czech Republic. First units of this art occurred in CR in early fortieth of the last century namely in isolated places in the countryside and in mountains, where the electricity network has not yet been established. The boom of WPP started especially in times, when Europe and whole the world were looking for renewable sources of electrical energy. First powerful units in CR connected to the network were installed in the half of ninetieths. The gradual growth of number, types, power output and electrical energy produced by WPP in CR is briefly described. Some problems and difficulties going along with the building-up of WPP are discussed. The corresponding attention is devoted to the electrical part of WPP with regard to types of suitable generators and concepts of WPP arrangement with respect to their cooperation with electrical network.

1. Introduction

The whole world is for several last decades looking for renewable sources of electrical energy. Cole, gas and oil resources are limited and rising pollution levels have the negative impact on the world climate. After some periods of hesitation how to solve this problem, the utilization of wind and direct solar energy has been chosen as the resort. The immense potentials of wind and solar energy together with energy of water and biomass are now of great importance. The utilization of wind energy brings wide spectrum of problems, related to its physical fundamentals. The irregularity, accidentality and poor predictability of speed, force and direction of wind affects the full utilization of its energy. In the Central European and especially Czech conditions only about 10 % of wind energy can be effectively changed to electrical power. The infelicitous output of built-up capacities causes the economical losses in electrical energy production and serious problems in electrical network regulation. Those problems are now more complicated due to immense growth of solar photovoltaic power plants in Czech Republic.

2. Short history

Single small wind power turbines driving low power output generators occurred in CR already in times, when some mountain parts of the country have not yet been connected to the electricity network. As an example can be introduced small unit composed of wooden two blade propeller with 2,5 m diameter driving the rewound tractor dynamo giving the power output about 0.5 kW at 24 volts. This “wind energy power plant” was built by author of this paper in 1957 in Beskydy Mountains to supply the mountain chalet by electrical energy needed for light and radio.

Fig.1 Small Wind power plant in Beskydy moutains (1957)

In years 1948 to 2005 wind units were subsequently built-up in Bohemia, Moravia and Silesia with power output from several hundreds of wats, later hundreds of kilowatts, part of them by enthusiasts, later by domestic enterprisers and firms. Contemporary the majority of wind power plants (WPP) and wind power farms (WPF) in Czech Republic is built-up by foreign developers and companies or by Czech firms using foreign components (towers, turbines, gears, nacelles, generators, control systems). Till 2004 the growth of built-up WPP was comparatively slow. The total installed capacity did not exceed 12 MW with about 25 units connected to the grid. In the beginning of 2006 the installed capacity was increased to about 30 MW with 47 built-up units. In 2007 started the boom of building-up of WPP with 50 MW of total installed units cooperating with the network. In the middle of 2009 the total installed power output reached about 150 MW with about 120 unites installed. The majority of installed units have the power output 2 MW. The greatest wind energy power plants farm (WPF), including 21 units 2MW each (total power output of the farm 42 MW) was completed and connected to the grid in 2008. Last year two most powerful WPP were built-up with 3 MW each. Every unit has 88m high tower, with the rotor diameter 100 m. 3 MW generator is the synchronous machine with permanent magnets on the rotor. In CR there exist currently about 20 firms and companies dealing with WPP. Some of them are producing small units with the power output in tenths of kW, another firms cooperate with foreign producers and suppliers in building-up of WPP, some others act as producers and suppliers of parts and modules. The majority of individual installations and building-up of WPP farms is organized and realized by domestic and foreign developer companies. The wind power plants in CR produced in 2009 about 290 GWh of electrical energy [1]. According to Czech Wind Energy Society it can be expected, that the installed power output can increase to 1000 MW in next four years. Those capacities are able to produce about 2.5 TWh of electrical energy, what is the equivalent of total electrical power produced by all water power plants in CR. The survey of installed wind farms and units location in the Czech republic can be seen in Fig. 2, where the first figure is the number of WPP and second one presents nominal installed power [1].

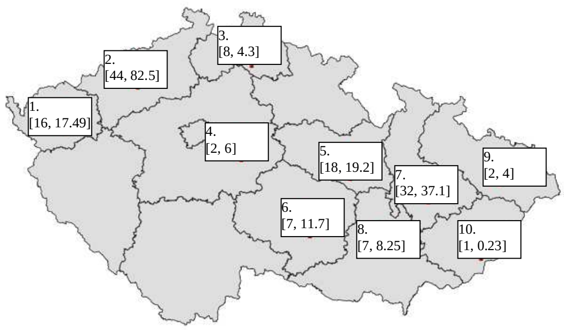

Fig. 2. Present installations of WPP in Czech Republic in respective regions (number of wind turbines, installed power in MW) [1]

The trend of building-up of wind turbines in Czech Republic can be seen in Fig.3. [2]. As usually, the grand planes of building-up of high numbers of wind turbines with higher and higher total power outputs were not fulfilled. One of the main problems from the point of view of wind utilization are the wind conditions in CR. Only very small part of the country is suitable for effective installation of WPP. The wind speeds are usually comparatively low, the wind blows rarely and unreliably. The average wind speed reaches only 2 - 4 m/s on the majority of CR territory. Only on highs it reaches 5 to 6 m/s and in frontier mountains more than 7 to 8 m/s (see Fig. 4).

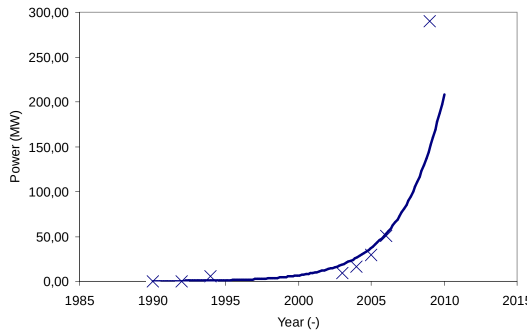

Fig. 3 The trend of building-up of wind turbines in Czech Republic.[2]

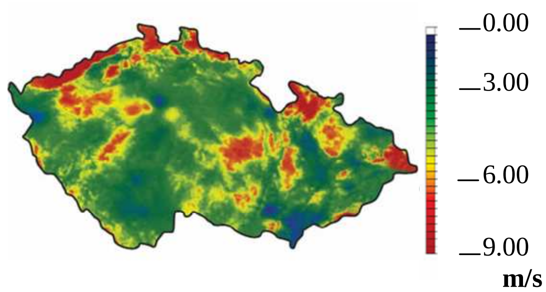

Fig. 4. The year average speed of wind in CR

Another problem of wind energetics in CR is caused by many existing Protected Natural Regions (NATURA 2000 and others) prohibiting the installation and operation of WPP in those regions. The serious problem is the aversion and opposition to WPP by inhabitants, municipalities and regions with arguments that WPP are noisy, dangerous, deteriorate the landscape and are not effective enough due to low coefficient of capacity utilization.

Tab. I. The share of WPP on the electrical energy production in CR

	2005	2008
Water power plants	2.88 %	2.42 %
Biomass	0.68 %	1.40 %
Biogas	0.19 %	0.32 %
Wind power plants	0.03 %	0.29 %
Solar power plants	0.00 %	0.02 %

In spite of given problems, the installed capacity of WPP in CR is still growing. The share of WPP on the total production of electrical energy in CR is shown in Tab. I with the comparison for 2005 and 2008 years [4]. Wind turbines are here compared with other renewable sources of energy.

When compared with Poland, CR has only less then one third of installed wind energy power plants. According to Polish Energetic Regulation Authority (Urzad Regulacji Energetiky) the power output of Polish up-to-date installed wind energy power plants reaches 666 MW (1/2010) with 282 units registered [17]. Poland has in comparison with CR very convenient conditions for wind energetics. Wide plains, borderline mountains and especially sea shore regions with everlasting wind enabled the effective exploitation of WPP.

3. General concepts of wind power plants

Some special problems of electrical generators used in wind power plants and their concepts with respect to the cooperation with the electrical grid are in the focus of our interest . The generator represents the load torque to the wind turbine driving the respective generator. For the conversion of mechanical energy to the electrical one almost exclusively synchronous or asynchronous generators with various arrangements are used. One of the reasons are the hard requirements on robust construction. Only in small units with DC power output different dynamos or special alternators found their utilization. The mechanical effects of shock moments to the drive train can propagate due to the machine anchoring. The electrical effects can also propagate through windings into the grid. Those effects are essentially dependent on the torque/rotational speed gradient of the generator. Therefore, mechanical/electrical converters that are flexible both in their speed of rotation and in the way in which they are linked to the drive train have an advantage for use in wind turbines. Most outstanding is the concept with completely separated turbine or rotor speed from the grid. In this way greater degree of efficiency can be obtained under partial loading or a lesser amount of power can be drawn from the wind when the amount of energy required is lower.

Delivery of energy from the generator and WPP as a whole should start at low wind speeds and should be capable of maintaining small base loads. To accomplish this, stand still and run-up torques must be kept low. Also dwell torques can arise mainly in permanent magnet generators due to reluctance effect. Further, the generator should have low no-load and exciting losses and keep the high efficiency, even under low loads.

The main components of the WPP system are shown in Fig.5. In general, WPP consists of the turbine rotor, gearbox, generator, transformer, power electronics. The turbine rotor converts the wind energy into mechanical one changed by means of generator into electrical energy which is transferred into the grid through a transformer and transmission lines. For megawatt range the rotational speed of rotor can be 10-15 rpm. The low speed can be converted by means of gearbox to higher speed of generator, where higher efficiency and lower dimensions can be achieved. For modern wind turbine systems, each WPP has its own transformer to convert the 400 or 690 VAC to the grid voltage. Only small wind turbines are connected directly to the low-voltage line without a transformer.

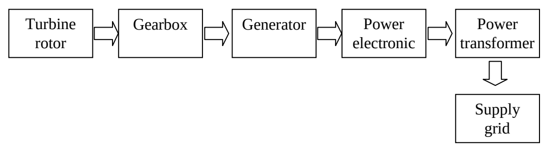

Fig. 5. The general concept of wind power plant system

Many types of WPP, especially with variable speed, use power electronics interface. This converter depends on the topology and application, may allow both direction of power flow and can interface between the generator and grid. Two main system concepts of converter system are used. The grid commutated converters are mainly thyristor converters (6 or 12 or more pulse). The second one is self commuted converter system with PWM and IGBT which can control both active and reactive power [6].

Induction generators are used in a fixed-speed system or a variable-speed system, while synchronous generators are normally used in optimum variable-speed systems. Three types of induction generators arrangements are used in wind power conversion: squirrel-cage rotor, wound rotor and doubly fed induction generator. The squirrel-cage rotor induction machine can be directly connected via a transformer into an ac system and operates at fixed-speed. The speed is kept by the grid. This concept was the most common for mechanical-electrical energy conversion in the wind turbines installed in the past. Such concept of wind turbine system can be seen in Fig. 6. The frequency of the grid determines the rotation speed of the generator. The generator speed depends on the number of pole pairs and frequency of the grid. The advantage of wind turbines with squirrel-cage rotor induction machine is the simple and cheap construction. There are some drawbacks: difficult control of active power, WPP operate at a fixed-speed with intensive mechanical stress and high starting currents. They need a reactive power compensator to reduce the reactive power from generator to the grid. The current peaks can exceed up to 10 times the rated current. The modification of this concept can use the controller (soft-starter) to current limitation and to improve the impact on the grid [6].

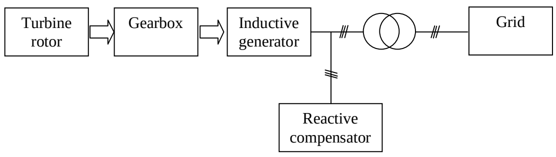

Fig. 6. Wind turbine system with squirrel-cage rotor induction machine

Fig. 7 illustrates a typical wind speed distribution curve, which depends on the site selected for the turbine [8]. Depending on the site selected, average wind will vary from 6 to 20 m/s. As a consequence, the wind turbines operate in no-optimal conditions for most of the time.

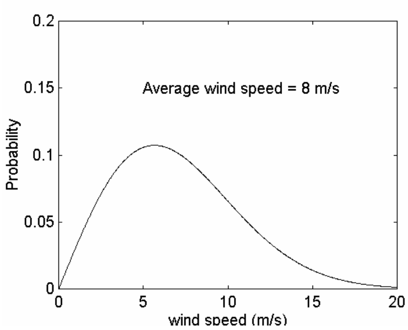

Fig. 7. Typical wind speed probability curve [8]

Developments in power electronics over the last years bring a modern WPP concept system with variable-speed of generators. Power converters are used to adjust the generator frequency and voltage to the grid. Wind turbines connected through converters have significant advantages namely: higher efficiency of energy conversion, high dynamic response, low maintenance requirements and low volume and weight.

In variable-speed systems the generator (synchronous or induction generator without rotor winding) is normally connected to the grid through a power electronics between stator of the generator and grid. The total power is determined by the electronics. For induction generators with the armature winding on the rotor, the stator of the generator is connected to the grid directly and rotor of the generator is connected through a power electronics system. This gives the advantage that only a part of the power flows through a power electronics system with lower losses. The inductive double-fed generator of WPP system can be seen in Fig. 8. The induction double-fed generator does not need a soft-starter or a reactive power compensator. Such concept is a little bit more expensive when compared to the classical system shown in Fig. 6. If the generator is running sub-synchronously, electrical power is derived into the rotor from grid. For the wind turbines in the megawatts range there is a trend towards the application of variable speed system to limit the mechanical stresses [8]. A fixed-speed wind turbine is relatively simple in comparison with variable-speed concept and that is why the price is slightly lower. The variable speed concept can generate more energy at the low speed. The active and reactive power can be easily controlled and there is lower mechanical stress.

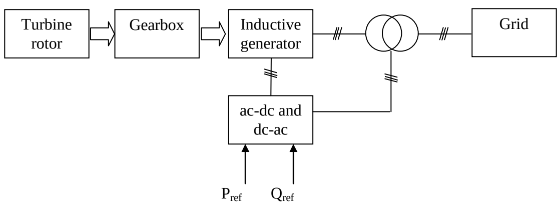

Fig. 8. Wind turbine system with doubly-fed induction machine

The WPP with a full-scale power converter between the generator and the grid are shown in Fig. 9. The wind turbine with squirrel-cage induction generator and full-rated power electronics is shown in Fig. 9a. The power electronics of this concept is able to control the active and reactive power. In system where the induction machines are connected to the grid via a full inverter coupling are higher losses in comparison with doubly-fed induction machine (Fig. 8) because the full power has to pass through the inverter. The concept of wind turbine system with synchronous generator can be seen in Fig. 9b and c. Wind turbine system with a synchronous generator connected directly to the grid (Fig. 10), is rarely applied because of the very stiff characteristics of generator [8]. The concept of Fig. 9b is more expensive and less efficient than concept from Fig. 8. and practically not applied in larger turbines [8]. The concept with synchronous generator with permanent magnets started to be very popular for variable-speed concept, which is becoming cheaper [6]. To eliminate the problems with gearboxes, the new trend is the direct drive of the generator. Direct drive turbines need a large diameter because of the high torque and then the major drawback of direct-driven machines is the large and relatively heavy generator because the generator must be designed for full-rated power. In gearless drives induction machines cannot be used because of the excessive excitation losses in these large machines due to the large air gap. For that reason synchronous machines are applied. As mentioned above, synchronous machines are too stiff for a direct grid connection, so that coupling via an inverter is necessary [8]. The concept with electric excitation of synchronous generator (Fig. 9b) is cheaper in comparison with system (9c) with permanent magnets excitation, but it operates with lower efficiency. In contrast to induction machine, the synchronous generator with permanent magnets is more expensive. However large generators in the higher MW range are usually synchronous machines with extremely high efficiency.

The WPP integrated into wind power farm (WPF) are shown in Fig. 11. Nowadays, for long distance power transmission, HVDC technology is applied because each WPP in the farm can operate at its individual optimal speed [6].

WPP share-out in market incorporate approximately 50% of doubly-fed generator systems with variable-speed, 20 % of systems with fixed speed, 20% of WPP with direct-driven synchronous generator and 10% of another art [6, 7, 8, 14, 15 and 16].

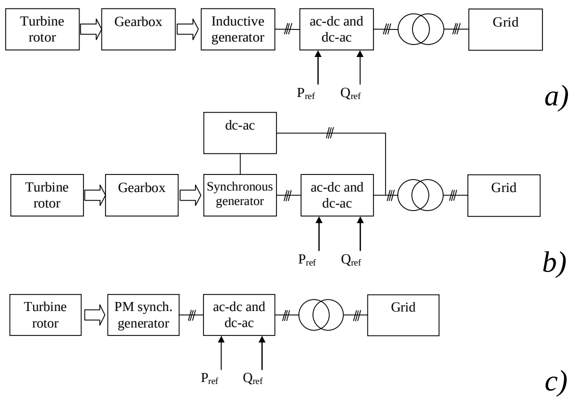

Fig. 9. WPP systems with full-scale power converter a) squirrel-cage induction machine b) synchronous generator c) synchronous generator with permanent magnets

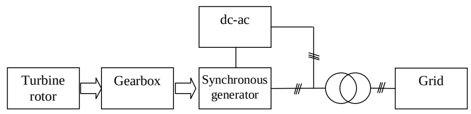

Fig. 10. WPP system with synchronous generator

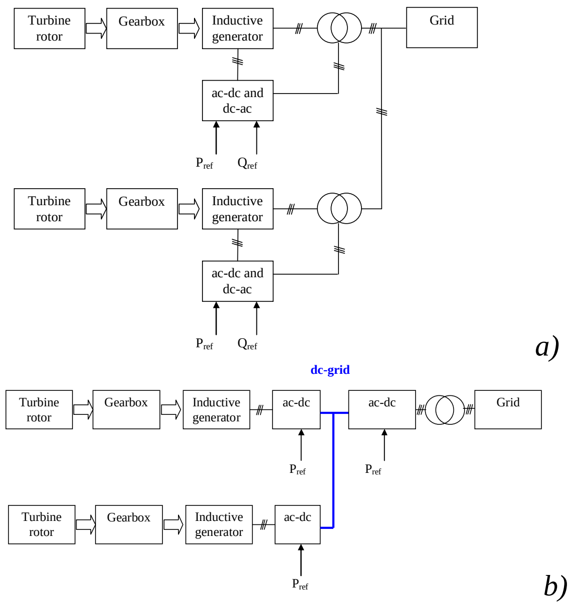

Fig. 11. Wind power farm structures a) ac-grid, b) dc-grid

4. Selected examples of WPP in CR

Wind power plants built-up and connected to the grid in CR are of different types produced mainly by foreign suppliers. The survey of types (producers) with the total installed power output can be seen in TAB II.

Tab. II. Types of installed WPP in CR and their total power output

Vestas	62,95 MW
Enercon	61,86 MW
REpower	18 MW
DeWind	16,95 MW
Nordex	12,85 MW
Tacke	6,6 MW
WinWind	6 MW
Wikov	4 MW
Fuhrlander	1,35 MW

For illustration three types of WPP (330 kW, 2 MW, 3 MW) installed in different sites of CR are shown in following tables. TAB III illustrates one WPP of the group installed on the edge of Krusne Hory in the hight 1150 m (the most high site of WPP in CR) [9]. The pictures of two of these units see Fig. 12a.

Tab. III. WPP 330 kW (Krusne hory) [10]

Rated power	330 kW
Rotor diameter:	33,4 m
Turbine concept::	Gearless, variable speed, variable pitch control
Rotor	
Number of blades:	3
Swept area:	876 m^2
Rotational speed::	31 - 79 m/s
Generátor:	ENERCON direct-drive synchronous annular
Cut-in wind speed:	2,5 m/s
Rated wind speed:	12 m/s
Cut-out wind speed::	28 - 34 m/s

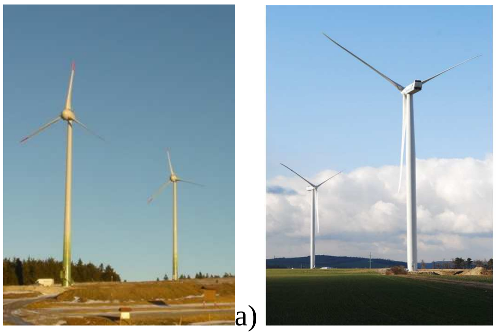

Fig. 12. a) 330 kW units in Krusne hory [9]
b) 3 MW units in Pchery [11]

Two WPP of the type WinWinD installed in central plateau of CR (Pchery near Kladno) are with their power output 3 MW each hitherto greatest units built-up in CR. Basic parameters of one of this WPP are given in TAB IV [11]. Picture of two 3 MW units see Fig. 12b.

The next WPP farm composed of 9 units of the VESTAS V90/2.0 MW type has been built on the low highs of Jeseniky Mountains. Details can be seen in TAB.V. The arrangement of WPP VESTAS V90/2.0 MW is for illustration depicted in Fig. 13, where individual components can be seen. [14]

Tab IV. WPP 3MW (Pchery) [12]

Rated power	3 MW
Rotor diameter:	100 m
Turbine concept::	high speed gear system,variable pitch control
Rotor	
Number of blades:	3
Rotor speed:	5-15 rpm
Generator:	Synchronous generator with permanent magnets
Cut-in wind speed:	4 m/s
Rated wind speed:	12.5 m/s
Cut-out wind speed::	20 m/s

Tab. V. WPP 2 MW installed (Jeseniky) [14]

Rated power	2 MW
Rotor diameter:	90 m
Turbine concept::	Gear, variable speed, pitch control
Rotor	
Number of blades:	3
Swept area:	6 362 m^2
Rotor speed:	9-14.9 rpm
Generator:	Asynchronous with OptiSpeed®
Cut-in wind speed:	2.5 m/s
Rated wind speed:	13 m/s
Cut-out wind speed::	25 m/s

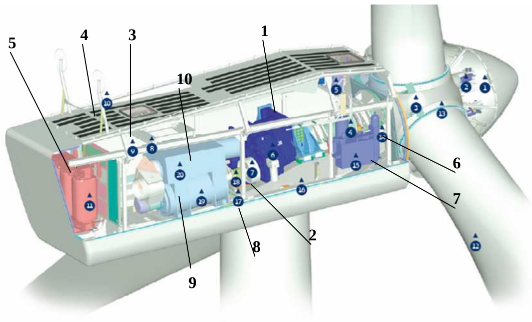

Fig. 13. Wind power plant VESTAS V90/2.0 MW [14] (1-gearbox, 2-mechanical disc brake, 3-controller with converter, 4-sensors, 5-high voltage transformer, 6-rotor lock system, 7-hydraulic unit, 8-yaw gears, 9-asynchronous generator, 10-air cooler generator.)

5. Conclusions

The aim of this paper was to inform the SME scientific community about the state-of-the-art of wind power plants (wind turbines) in Czech Republic and to show how the well known types of electrical machines, namely induction (asynchronous) generators, synchronous generators with exciters and with permanent magnets, low speed multipole synchronous generators, double fed induction generators and other machines are used in hard conditions of WPP.

The paper itself doesn´t bring something quite new, but it gives the useful survey of individual concepts of wind energy conversion by means of wind turbines as sources of mechanical energy, generators as sources of electrical energy, power electronics acting as intermediator between the generator and the grid. It is shown, that concepts of WPP arrangement have many variants with their drawbacks and advantages. The doubly fed induction generator concept using reactive power generated by the grid side converter, where the electrical power is delivered to the grid through both the rotor and stator of the generator and power electronics converters can be designed for lower power is one of interesting concepts. Consequently such concept does not need a soft-start or a reactive power compensator.

The next popular WPP concepts with full-scale power converter operate with permanent magnets synchronous generators without gearbox. The concepts are a bit more expensive but eliminate the problems with gearboxes and the efficiency is better than in concepts with doubly fed induction generator.

Nowadays, the HVDC technology using synchronous generator with permanent magnets are applied as wind power farms structures, because such concepts enable optimal speed controll of individual WPP. This solution is more efficient then recent concept with doubly fed induction generator and ac-grid connections.

As was shown in this paper, the wind power plants in the Czech Republic live through the relatively good years, but they are now a little bit in shadow of immense growth of solar photovoltaic systems.

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Reviewer

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