Wind Farms and Their Connection to a Power Line

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Abstract – **The paper shows, that with the rapid use of wind energy, significant power resources can be obtained by the connection of a set of wind generators in the so called wind farms. The paper discusses the technical features of these farms and the conditions for their operation. Their connection to the power line is of considerable importance for their correct functioning, which requires the solution of different specific problems – the random natute of wind, the selection of the farm site, the compensation of the short-time changes of wind power, the prognosis of wind intensity etc.**

Keywords – **wind generators, wind farms, electroenergy**

I. Introduction

The wind is a very convenient energy source. It is found everywhere and free of charge. However, its use is connected with large investments due to its small energy density. The achievements in the area of material knowledge, aerodynamics, processing industry technologies and the increased requirements of ecology made the cost of wind energy generationreasonable. The last two decades show considerable achievements in wind energetics. This refers mainly to the improved aerodynamics of the propellers, thus increasing the extraction $C_p$up to 37% (at a limit value of 47.3%) and especiallytheir productionby new strong and light materials, enabling constructions with large dimensions. The typical propeller for a wind generator (WTG) with power of 1.5 MW has a diameter of77 mand it extracts the energy from a wind flow with a section of 4650 m^2. Thus, power of 20 MW is obtained from a surface of 1 km^2 [1].

The connection of a separate generator to the power line is an isolated case, connected with big expenses for its joining. That is why in practice the connection of a set ofWTGis realized in the so called wind farms.

The paper presented discusses some basic features of the WTGfarms.

II. WTG Farms and their Exploitation

When combining a set of WTG, located in farms, considerable energy power is obtained. This presumes the construction of a common infrastructure, building fund, service, devices intended for connection to the network, a data acquisition system, continuous monitoring control, a system for remote measurement and control done by the operating control of the network, which includes the farm, a system for distribution of the active and reactive power among the separate WTG, lightnings protection, overvoltage protection in the general network, prognosis of the wind speed.

The singular power of a WTG, compared to the conventional thermal or nuclear generators is small—within the limits of 1-5 MW. No considerable increase of this power can be expected. It is connected with increase of the surface, covered by the propeller and increases linearly with the second degree of its diameter, that leads to many constraints of another nature – weight, dimensions, possibility for transporting, mounting, available strong materials, lightning resistance, etc. For example, a WTG with power of 2.2 MW,has a propeller with a diameter of112 m, weight of 20 tonsand it obtains the energy from a section of 9800 m^2. [2].

The connection of a separate generator to the power line is an isolated case, connected with big expenses for the joining itself. Its influence on the network can be regarded as an equivalent consumer.

For the main network, to which the farm is attached, it is regarded as a singular equivalent generator. Its dynamics is very different from conventional synchronous generators, supplying the network. This is particularly well expressed for a WTG with complete conversion. For big farms, above 150 MW, the WTG may form several separate groups, each one with a separate collecting feeder. The farm with power of 640kW, presented in [3]is comprised by four separate groups, included intwo different networks.

The farms are situated on large sites and the joining cables have big length, connecting dozens of generators. Every connection and disconnection of a generator is a pulse disturbance introduced in a homogeneous line with many reflection points. The set of the falling and reflected waves causes overvoltages that load both the cable and the devices connected to it. The sources of overvoltages in the collecting cable are the generators switchings, and in the high voltage air lines, to which the farm is connected – the lightnings occurrence.

The matching transformer farm/network is subjected to overvoltages in the two windings. The overvoltage front of raising is multiple, at least 10 times steeper on the primary winding, due to the low wave resistance of the cable (below 40 Ω),in comparison with the one of the secondary winding, connected to the air line, for which the wave resistance is 300-400 Ω.

The correct exploitation requires qualified and constant support. This is particularly important for the speed boxes. It is recommended the wind energy supplies to be located near to the energy users. Anyway, this is satisfied only in some rare cases, having in mind that these power sources are situated outside inhabited areas. The connection is usually to a network of middle or high voltage. The wind energy generation is organized in farms, with a total power of dozens orhundreds MW, included in the industrial network and its operative control.

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In [4] some data are presented for two WTGfarms, the first one being onshore, built inNässudden – Sweden, and the other one – offshore, inKentishFlats, Northern sea - England, property of Elsam (Denmark).

The farm inNässunddenincludes 100 WTG of different power, different owners and made by different manufacturers, a significant part of them belonging to VestasandOlsvennez. Thirty of the WTG are property of Vattenfall, and the data, presented below, are relevant for them.

The WTG inKentishFlatsare of one type, 30 in number, each one with nominal power of 3 MW. The whole farm is put into operation in September, 2005.

The lifecycle of the generators in the two farms is 20 years. Theavailability is about 97.5%, determined as a relation between the expected time for operation readiness and the calendar time

$$D = \frac{T_{M_P}}{T_{M_P} + T_P},$$

where T_{M_P} is the average interval between repairs, and T_P – the time for planned or extra repair (service) activities.

The investments according to the data attached are 3M€/ВГ forNässundenand 10M€/ВГ -forKentishFlats. These sums cover all the expenses for the equipment purchase, mounting, the construction of a farmnetwork, and the common connection to the industrial network, the guaranteed support by the suppliers, which is two years for Nässundenand 5 years forKentishFlats.

In order to achieve the high level of operational readiness, constant support is provided, that is of two types–prophylactic and in failure cases. The prophylactic can also be planned or extra, caused by the alterations of some parameters registered during WTG monitoring. The planned support includes screws tightening, oil and filters replacement, check of the security system.

Vattenfallprovides the support in accordance with annual contracts with companies, manufacturers of WTG– Vestas, SiemensandEnercum.

ForKentishFlats,Vestasensures complete support for 5 years, its cost being included in the investment expenses.

The two farms rely mainly on the planned support. ForVattenfallthe planned service is realized twice a year, basic and auxiliary. The basic support is accomplished by two specialists for 7 hours, and the auxiliary one – also by two persons, but for 4 hours, and the hour payment for every specialist is54 €.

In Elsamthe planned service is realized every 3-6 monthsfor the smaller and older WTG, and every 6-12 months - for the big WTG. There is a team of 10-15 workers, which supports the old WTG. For more radical repairs, some external specialized services are employed. InKentishFlatsthe planned support is realized by two workers for two days for the WTG, with daily payment for each worker of 750 €. When a more thorough support is needed, the payment is raised to 850 Euro. These expenses include all the expenses for the working staff, like training, equipment for safe work, pensions, transport, offices holding.

The replacement of some large dimension units in WTG takes a considerable part in farms life cycle. The prices of the units, without the disassembly and assembly works for the sites discussed, are as follows:speed box –300 к€, generator - 150 к€, transformer -100 к€, vanes -200 к€

For the farm inNässudden, the speed box is replaced twice, the generators - once and for 1/10 of the WTG the vanes and transformers are replaced. Some expenses for demounting and recycling are foreseen for the last year.

For KentishFlatsfarmthe expenses for large dimension units include: 11 speed boxes, 20 generators, 3 transformers and 3 vanes. Besides this, some additional checks and repairs are intended in the years 4, 6, 9, 13 and 14. One day is needed for the replacement of a large dimension unit.

III.Connection to the Power Line

The connection of WTGfarms toa power line is related with the solution of many problems. The generated power has random nature with a large range of alteration –from zero up to the nominal value and limited predictability. The null power is often with a probability above 70%. The power control is possible only in direction of random maximum decrease. With this feature the network gets one more stochastic process together with the loads. The two processes are not correlated, compensation is possible in certain periods, in others–depositing, but in general, the dispersion increases. Due to the high probability for farm inactiveness, the nominal power of every farm must be reserved by conventional sources power. This reservation is especially heavy at relatively big share of the wind energy in the network. The reservation could be decreased with the help of the construction of several farms, located in sites with non-correlated wind energy. This requires good knowledge of the wind picture of the network region and appropriate planning of wind energetic development. Meteorological services data can be used for initial evaluation of a more continuous period of one up to three years.

The selection of farms sites is a complex optimization task. Besides the wind power, “statistic” independence, the location of the consumers, the distance to the electric network, the allocation of the conventional generators, their dynamics for compensating the changes of the wind energy must also be taken into consideration. The connection to the farm end (the generators remote points) may lead to decrease in network losses.

The compensating of short time alterations of the wind power is a separate task. It is done by rotating reserve powers and connected with additional dynamic losses. According to UCTE requirements (15),each change of the power consumed (for the wind power –positive or negative) must be compensated in an interval up to 15 min. The WTG with a cage rotor and especially those with complete conversion, have high dynamics and can participate in the compensation process, caused by load changes.

The predicting of the generated power has great significance in restricting the reserve and particularly the reserve rotating powers for every farm. It is usually assumed that the wind farms introduce strong disturbances in the energy network operation. The use of short-time (15 min) and daily (up to 38 h) prediction enables considerable decrease of the necessary rotating reserve powers. There are some well known methods, which, using the prognostic information, allow the short-time planning of the power, supplied by the conventional and wind generators for optimizing the value of the generated energy and the network reliability [2,5,6].

The stochastic feature, introduced in the network by the wind farmsin case of relatively large participation in the general power, is a potential source for instability. The operative staff must often distribute the generators loading, as well as the rotating reserve powers, including the wind, for minimizing the cost of the energy produced, accounting the constraints for:

- consumed electric energy,
- consumed thermal power by thermal and nuclear stations,
- possibilities of the generators for impulse (short-time) alteration of the generated power,
- actual prognosis for possible wind energy,
- special operation mode at small consumption–night hours, off days, holidays,
- water consumption in hydro electrical stations,
- electrical energy accumulation at PAWEC.

The rules for electric network operation, as well as the including of new energy sources is regulated by gridcodes, specific for different countries and regions, but not differing much. Due to the principal difference of the wind energy generation in comparison with the conventional sources, there are introduced specific requirements in the countries with advanced wind energetics.

In USA several organizations encode the wind energy share in the network - FERG, AWEA, WECC, NERC [29]. The including of wind powers above 20 MW is treated by Order No 2003 from July 2003 and Appendix G, Order No 661 from 5 July 2005.

Some more specific requirements of AWEA grid code for the wind farmsare:

- supervisor control, data acquisition, equipment for exchange of telemetric data and remote control, with the main purpose -exchange of forecast, setting of the power generated by the farm, when the network operative control implies restriction on the maximal power;
- exchange of information about the actual status of farm equipments. Used to renovate the network model in optimizing the operation mode;
- it is recommended that the WP would work with a power factor of +/- 0,95;

The WP participates in network voltage maintenance, as the farm remains connected, at time-voltage dependence in the connection point above the curve, shown on Fig. 1.

This is connected with the possibility to cover short-time deep voltage drops [7]. The WTGfarm (or a separate WTG) must remain connected to the network in case of voltage drop up to 15 % from the nominal one for 625 ms (75 network semi periods at 60 Hz) and constantly - in case of decreased voltage up to 90 %. It must also support other degrees of falling with a duration according to the figure. The relation accepted is important for network restoring after short-time overloading, including short circuits. The accepted norm is a strict requirement towards the generators under stress loading.

The Swedish code of operation at dropped voltage permits also work after short circuit at the WTGfarm output, but only for 240 ms and lower feasible durations of operation with decreased voltage, as shown on Fig. 2 [8]

The energetic system must be stable with respect to the damages, including the short circuits, which are a natural and quite frequent event in its sections. A damage in one section must not lead to cascade falling off of other sections. This refers both to the whole system, and also to the WTGfarm, composed of several independent units. The short circuits are connected with the consumption of big reactive power, the supply of which is not a problem for the WTG.

The influence of the changeability of the wind energy on the whole network decreases considerably for wind farms, which are not closely located. Measurements of the power network in Western Denmark and North Germany show that even at mighty windy fronts the gradient of the wind power does not exceed 10 MW/min (installed power of 2.4 GW) and 16 MW/min (installed power of7.05 GW), respectively for the first and the second network [9]. The smoothing of the power, supplied by WTGfarms, is investigated in [10]. It is demonstrated, that at considerable share of the wind energy, it is impossible all the WTG to operate in a mode of maximal energy extraction.

The influence of the wind speed dynamics on the non-harmonic spectral components (flicker) is studied in [10]. The optimization in the network is realized by optimization of smoothing. Some approaches are proposed for different number of farms, different degree of correlation of the wind energy in them, different averaging interval.

Modern WTG enable the efficient and sufficiently quick control of the generated power, allowing significant participation in the complete power of the network. In Schleswig-Holstein the wind energy covers 33% of the annual consumption, and the maximal share of its power is 44% [9]. In Western Denmark the complete consumption in the network could be covered for hours by the wind farms.

IV. Conclusions

The connection of WTG farms to the network causes losses distribution. The total losses diminish, but in separate sections of the complex network they might increase and surpass the feasible limits. This implies network re-sizing.

At small share of the wind energy in the network total power, no particular control is necessary, it can be regarded as commutation of more powerful consumers and the WTG may work in a maximal power mode. At significant participation - 10% and more, the wind farm is included in the operative control of the industrial network.

When the wind is absent (below the lower bound for WTG), the conventional generators must take up the whole power of the network.When the wind is strong, both the network and the farm must enable quick control.

It is probable that at certain time moments of severe winds,

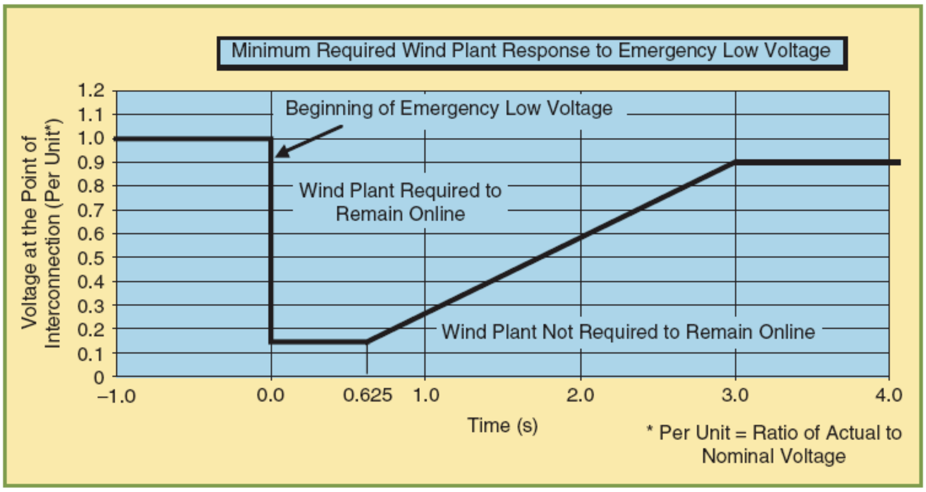

Fig. 1

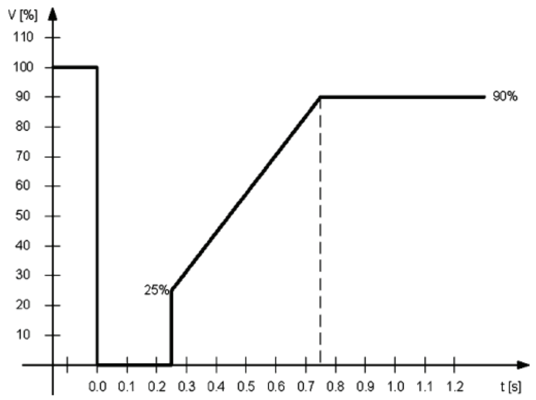

Fig.2

the relative share of the wind farmsis increased multiple –in days off the total consumption decreases twice and more. The other generators must be able to ensure quick reaction to the alterations in the supplied wind energy. This requires a constant reserve of sufficient rotating power in the system. The farms may be given the task to provide the necessary reactive energy in the system for constant voltage support. The WTG with full conversion may provide reactive energy, equal to their nominal power.

The wind farms are a new branch with their advantages and shortcomings. Their implementation must be realized after thorough analysis and evaluation of the perspectives for decreasing their cost and the development of other energy sources, especially nuclear stations.

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