БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ • BULGARIAN ACADEMY OF SCIENCES

ПРОБЛЕМИ НА ТЕХНИЧЕСКАТА КИБЕРНЕТИКА И РОБОТИКАТА, **63**
PROBLEMS OF ENGINEERING CYBERNETICS AND ROBOTICS, **63**

София • 2011 • Sofia

Reliability of Wind Turbine Generators and Exploitation of Wind Farms

Zdravko Nikolov , Chavdar Korsemov, Hristo Toshev

Institute of Information and Communication Technologies, 1113 Sofia
Emails: chkorsemov@iinf.bas.bg toshev@iinf.bas.bg

Abstract: *The paper discusses the reliability of Wind Turbine Generators (WTGs) in the production of wind electric energy and the correct functioning of the power line they are connected to. Some data of the actual reliability, obtained through monitoring of 1500 WTGs working in Germany for 15 years, are indicated. The investment and exploitation expenses for the construction of wind farms are presented. In order to achieve high operation fitness, constant maintenance is provided, including two types of services – prophylactic and emergent.*

Keywords: *Wind turbine generators, reliability, farms exploitation.*

I. Introduction

The energy potential of wind is remarkable. About 1-2% of sun energy, falling on earth, is transformed into wind energy. As comparison it could be noted that the energy absorbed by the plants in photosynthesis and transformed into bio mass is only 0.02-0.03%, i.e., almost a hundredfold smaller. Modern civilization, often defined as lavish, consumes about 0.005-0.006% of this energy [1]. According to the evaluation in [2], the actual energy consumption could be satisfied, utilizing the wind energy at height of 80 m on 20% of the sites with annual average wind energy above 6.9 m/s.

The world resources of easily acquired wind power are considered about 1500 GW, with annual production of 3×10^{12} kWh, which makes about 500 kWh per every inhabitant of the 6-milliard world population [3].

A specific feature of the wind generators, caused by the random character of the wind speed and the big dispersion, is the multiple difference between the average power generated and the installed nominal power. The relation between them, defined as utilization, is often determined as number of operation hours at nominal power, during which the same quantity of energy is produced, as the really generated for all 8760 hours of the year. Utilization of 23.5% is accepted as very good utilization, which corresponds to 2000 hours work at nominal power.

The achievements in generators construction, computer technologies and power electronics enabled the creation of new generations of generators with full conversion and variable speed, which allow maximal deriving of energy at any wind speed. They comprise mainly the synchronous generators with constant magnets made from rare metals, as well as the asynchronous doubly fed generators. The generators with full conversion enable operation into a three-quarter mode – active power, reactive inductive and reactive capacitive with arbitrary ratios in-between. Their great advantage is that even under conditions of weak winds they can generate reactive power equal to the nominal fictitious power.

The single power of the Wind Turbine Generators (WTGs), compared to the conventional thermal or nuclear generators, is small – within the limits of 1-5 MW. No considerable increase of this power could be expected.

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

Power quantity, sizable for energy industry, can be obtained when combining a set of WTG, located in farms. This implies the construction of common roads, a cable network, buildings, service, coordinating devices for connection to the network, a data acquisition system, continuous supervisor control, a remote measuring system and operative control of the network, towards which the park is attached, a system for distribution of the active and reactive power among the separate WTGs, lightning conductors, over-voltage protection in the common network, prediction of the wind speed.

A WTGs' farm is regarded as a single equivalent generator by the main network, towards which it is connected. Its dynamics is rather different than the one of conventional synchronous generators, which feed the network. This is particularly expressed in WTGs with full conversion. For large farms, above 150 MW, the WTGs may form several independent groups, each one with a separate summing feeder. The farm, presented in [4], with total power of 640 kW, is composed of four separate groups, connected to two different networks.

II. Reliability of the wind turbine generators

The most often used generator in WTGs is the Doubly-Fed Induction Generator (DFIG), shown on Fig. 1. The rotating speed of the propeller is controlled, regulating the energy, obtained by the rotor windings.

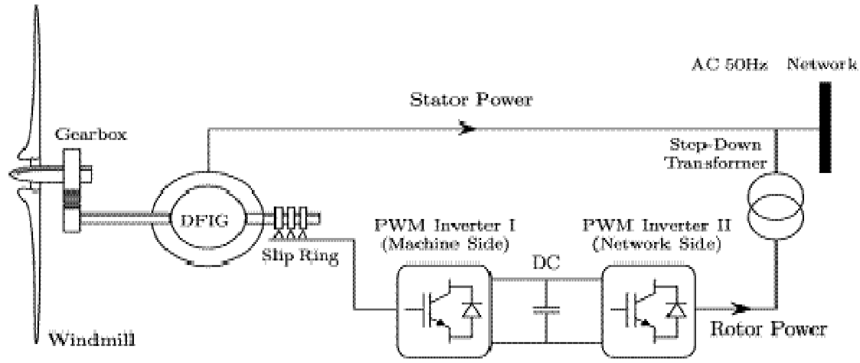

Fig. 1

The double inversion enables efficient control of the slipping power (which reaches about 30% of the nominal power), as well as its transmission together with the one of the stator, to the network. The contemporary valves of the type of IGBT allow inversion with high yield.

In order to produce the generators in acceptable volumes and hence – reasonable weights, their revolutions are most often selected within the bounds of 1000-2000 revolutions per 1 min and poles number of 4 or 6. In order to reach these revolutions, three-degree gear boxes are used. It is considered, that the losses in each gear degree is about 1% of the power transmitted.

The gear box is an important element of a WTG. It is considerably affected by wind stress loading. The nacelle, or the WTG itself, containing a propeller, a gear box, a generator, attaching and protecting units, is a large construction with big weight. Due to the restrictions for few gear degrees, the generator itself is with big weight too. One of the known types of WTGs, that of Vestas, with power of 3 GW, weights about 70 t [5]. Enercon produce WTGs with direct transmission without a gear box and power of 4.5 MW, but the nacelle weight rises up to 450 t.

Both synchronous and asynchronous generators are used with variable rotation speed and double conversion of the whole power – the basic one and that from slipping. The complete unbinding between the rotation speed of the propeller and the network frequency enables operation into the four quadrants – modes of the generator, the motor and the consumer or generator of reactive power (capacitive, inductive).

This is an important feature, the use of which can raise the network reliability, towards which connected. At small active power due to the low wind speed, such a generator could provide the network with reactive power up to its nominal fictitious power.

The synchronous generators can be designed with electric excitation and constant magnets as well. The last variant leads to weight decrease. However, the price of the magnets made from rare metals, remains still quite high, which limits their use. Some realizations of synchronous generators with constant magnets and direct transmission without a gear box and direct generation of high voltage are known, which avoid the necessity of a step-up transformer for connection to the network. This approach potentially assumes high efficient use of the wind energy.

But there are not any data available about their including in a real power line and that is why they are not discussed in detail.

WTGs function without any operating staff. This requires high reliability of the main and auxiliary equipment. Some interesting data concerning the reliability reached in WTGs is given in [6]. The data presented are obtained after monitoring about 1500 WTGs in duration of 15 years. The generators number and the time duration give considerable reasons for high statistic validity, regardless of the fact that the generators are currently connected and they are different in concept, power, mounted on different locations and hence, different conditions. The indicators are averaged for an interval of 10 years. The technical availability obtained is 98%. This means that the average time of unuse is 1 week per year, when prophylactic or repair activities are accomplished.

A significant reliability indicator is the annual failure rate of WTGs. This indicator is shown on Fig. 2 for three classes of WTGs˜ below 500 kW, 500-1000 kW, and above 1 MW. It decreases for all the classes with increase of the years, which could be connected with the typical “infantile diseases” of complex products. Another interesting fact noticed is that the failures frequency increases with power. This can be explained with their more intensive loading and the not entirely developed technology of production – they are a new generation of generators.

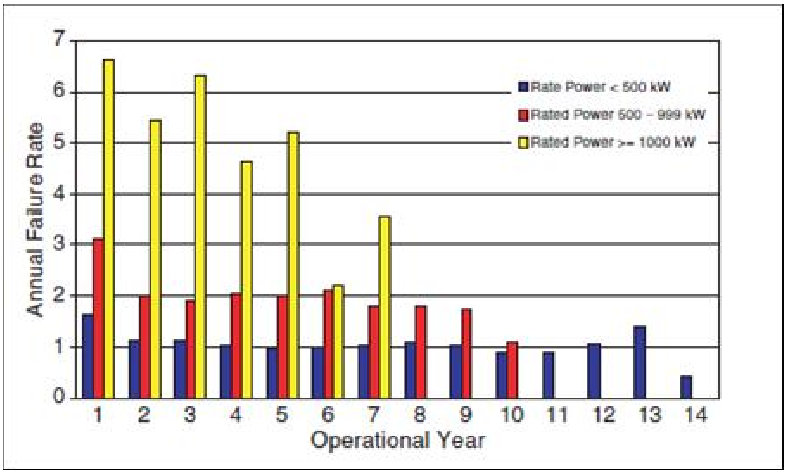

Fig. 2

The idle times are due to prophylactic inspections and planned repairs and probable failures – unexpected faults. Fig. 3 shows the relative share of the separate components of a WTG in the outages caused by unexpected faults. The duration of these idle times depends on the availability of spare parts and the service team qualification. At the beginning the repairs of the large elements – electric generator, nave, gear box, vanes, have lasted for weeks. It is interesting to note that one half of the outages are connected with the electric components, while the other one – with the mechanic ones.

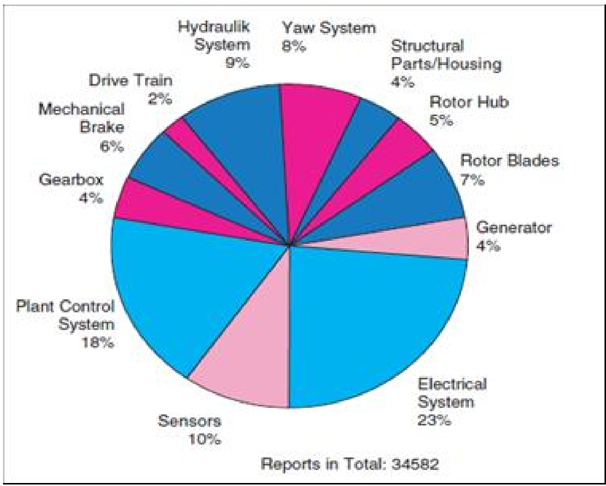

Fig. 3

Fig. 4 shows the annual average number of unexpected failures and the down time durations for the different components. It is clearly noticed that the elements, which are subjected to rarer damages, require longer repair activity and vice versa.

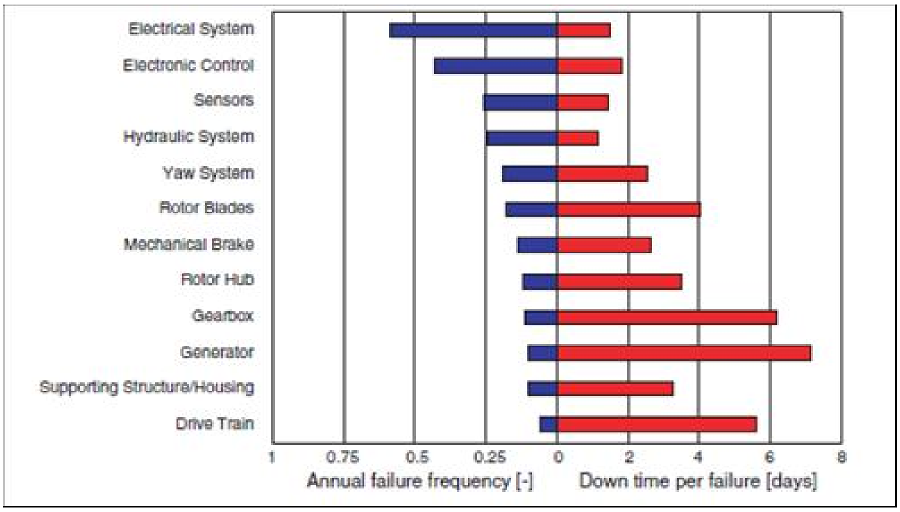

Fig. 4

III. Wind farms exploitation

In compliance with the obligations, accepted by our country after its entry to EC, wind energy of the order of 700 MW will be mounted and put into operation up to the end of 2010. As far as there is not any experience in the exploitation of such WTGs, connected to the national Electric Network (EN), it is good to introduce some data about the investment and exploitation expenses for some already realized WTG farms.

Such data are published in [6] for two WTG parks, the first one being onshore, built in Nässudden – Sweden, the other one – offshore, in Kentish Flats, Northern sea, England, property of Elsam (Denmark).

The park in Nässundden has 100 wind generators of different power, different owners and produced by different manufacturers, a large part of them being of Vestas and Olsvennez. Thirty WTG are property of Vattenfall, and the data further exposed, refer to them.

The WTG in Kentish Flats are of one and the same type, 30 in number, each one with nominal power of 3 MW. The whole farm is put in exploitation in September 2005.

The life cycle of the generators in the two farms is 20 years. Their computed availability is 97.5%, determined as the ratio between the expected time of operation fitness and the calendar time:

$$D = \frac{T_{M_{\mathrm{p}}}}{T_{M_{\mathrm{p}}} + T_{\mathrm{p}}},$$

where $T_{M_{\mathrm{p}}}$ is the average interval between repairs and T_{p} – the time for planned or extra planned repair (restoring) activities.

According to the data applied, the investments add up to 3 M€/WG for Nässunden and 10 M€/WG for Kentish Flats. These sums cover all the expenses for purchase of the equipment, mounting, construction of the park network and connection to the industrial power line, guarantee support by the providers, which is two years for Nässunden and five years for Kentish Flats.

In order to reach the designed high level of readiness, constant maintenance is realized that is divided in two types – preventive and emergent. The preventive support is also defined as planned and extra planned, caused by the alteration of some parameters, noticed during WTG's monitoring. The planned maintenance includes screw tightening, change of the oil and filters, check of the safety system.

Vattenfall ensures support with the help of annual contracts with companies - producers of wind generators – Vestas, Siemens and Enercum.

For Kentish Flats, Vestas provides full 5-years maintenance, the cost of which is included in the investment expenses.

Both farms rely mainly on the planned service. For Vattenfall the planned service is realized twice a year, and it is divided into main and auxiliary. The main service is accomplished by two specialists within 7 hours work by each one, and the auxiliary one – also by two workers, but within 4 hours and an hour payment for every specialist of 54 €.

Elsam performs planned service every 3-6 months for the smaller and older WTGs, and every 6-12 months for the bigger WTGs. A team of 10-15 professionals is organized, that supports the older WGTs. For more serious repairs external specialized services are employed. For Kentish Flats the planned maintenance for WTGs is done by two workers for two days at daily payment of 750 € per a specialist. If more thorough service is needed, the payment is raised to

850 €. These expenses cover all the expenses for the staff, such as training, equipment for safety conditions of work, pensions, transport, offices backing.

A significant share in the expenses during the life cycle of the parks is the replacement of some large size units in a WTG. The costs of the elements, without the assembly and disassembly expenses for the objects considered, are as follows:

a gear box –	300 K€,
a generator –	150 K€,
a transformer –	100 K€,
vanes –	200 K€.

For the park in Nässudden, a twofold change of the gear box is intended for the life cycle, and one – for the generators, and replacement of the vanes and transformers in 10% of the wind generators. Some expenses for the disassembly and recycling are predicted for the last year.

Fig. 5 shows the annual costs for Nässudden farm, calculated with reference to the date of putting into operation, at discount of 7 %.

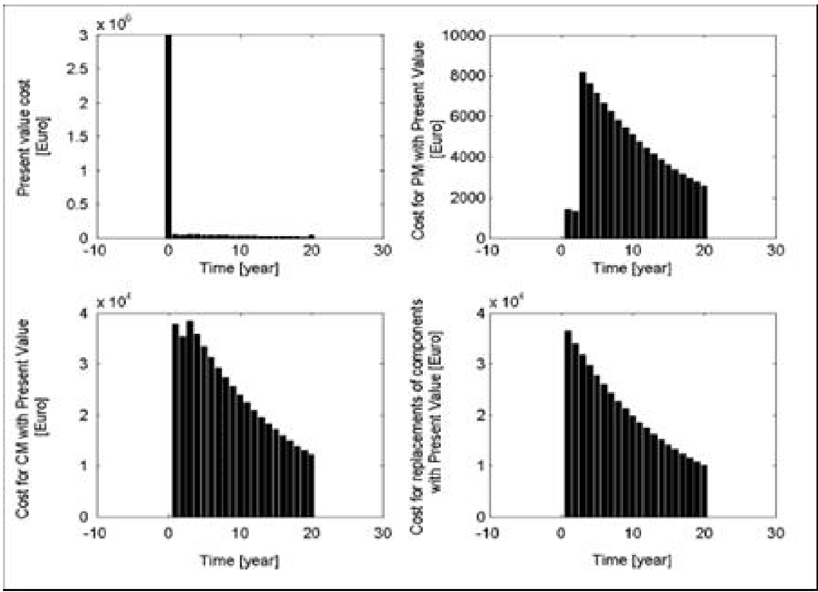

Fig. 5

For Kentish Flats, some park expenses are foreseen for the replacement of large size units, as follows: 11 gear boxes, 20 generators, 3 transformers and 3 vanes. In addition, some thorough tests and repairs are planned for this site in the years 4, 6, 9, 13 and 14. One day is given for the replacement of a large size element. Fig. 6 shows the expenses foreseen for this site, calculated in the way, used for Fig. 5.

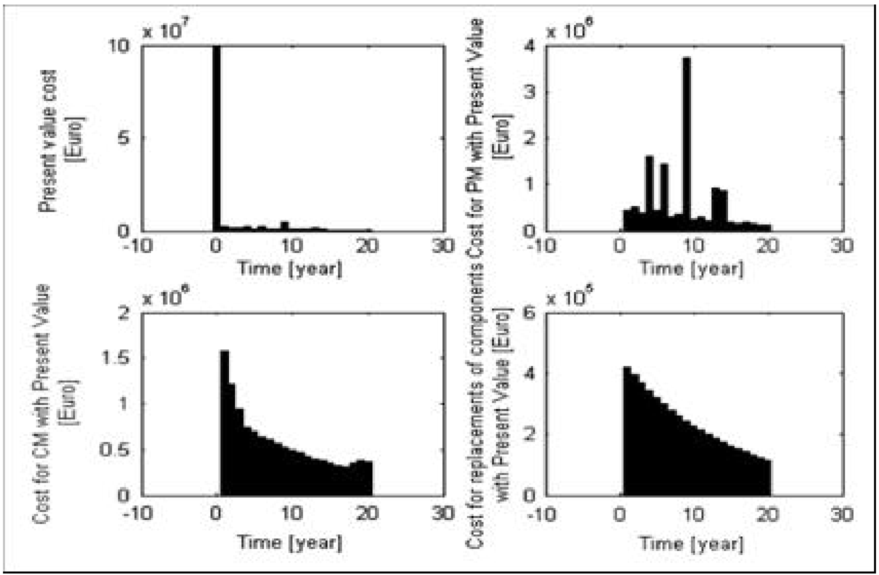

Fig. 6

A system of constant monitoring is provided for every one of the parks, storing of the basic parameters and statistical data acquisition on the operation of every generator.

The cost of the improved park Kentish Flats for a separate wind generator is 20 K€ and for the whole park – 600 K€.

IV. Conclusions

The discussions about WTG reliability and wind farms exploitation above given are the basis for the following conclusions:

– a specific feature of the WTG, caused by the random character of the wind speed and its large dispersion, is the multiple difference between the average generated power and the installed nominal power, which defines the particularly important role of reliability in WTG operation;

– the data, presented in the paper demonstrate, that the average idle time, when accomplishing prophylactic activities or repair work, is one week per year;

– the reliability indicator, connected with faults number, decreases with the number of years and the failures frequency increases with power increment;

– the average annual number of the unexpected failures and outages durations, shown on Fig. 4 indicate, that the components, which are more seldom damaged, require longer repair and vice versa;

– constant maintenance is provided in order to achieve the planned high level of readiness, which is done at two levels – preventive (being planned and extra planned) and emergent, when unexpected faults appear;

– for the purpose of correct operation of the wind farm, different systems for constant monitoring are constructed, and archiving of the main parameters and statistical data acquisition on the functioning of every generator is accomplished.

R e f e r e n c e s

1. Danish Wind Energy Association. **http://www.windpower.org/en/core.htm)/fr/tour/wres/index**
2. A r c h e r, C. L., M. Z. J a c o b s o n. Evaluation of global wind power. – Journal Geophis. Res., Vol. **110**, 2005, p. D 12110.
3. Wind Force 12, 2005. **http://ewea.org/fileadmin/ewea_documents/documents/publications/WF12/wf12-2005.pdf**
4. M u s t a k e r o v, I., D. B o r i s s o v a. Wind Park Layout Design Using Combinatorial Optimization. – In: Wind Turbines. Ibrahim Al-Bahadly, Ed. ISBN 978-953-307-221-0 (Hard cover, 652 p.). InTech, April 2011, 403-424.
5. M u s t a k e r o v, I., D. B o r i s s o v a. Wind Turbines Type and Number Choice Using Combinatorial Optimization. – Renewable Energy, Vol. **35**, 2010, Issue 9, 1887-1894.
6. B o r i s s o v a, D., I. M u s t a k e r o v. A Generalized Combinatorial Optimization Approach to Wind Power Plant Design. – Cybernetics and Information Technologies, Vol. **10**, 2010, No 4, 62-74.
7. A n d e r s o n, D., A. P e t e r s s o n, E. A g n e h o l m, D. K a l s s o n. Kriegers Flak 640 MW off-Shore Wind Power Grid Connection. A Real Project Case Study. – IEEE Trans. Energy Convers., Vol. **22**, March 2007, No 1, 79-85.
8. G e r t m a r, L., L. L i l j e s t r a n d, H. L e n d e n m a n n. Wind Energy Powers-That-Be Successor Generation in Globalization. – IEEE Trans. Energy Convers., Vol. **22**, March 2007, No 1, 13-28.
9. H a h n, B., M. D r u s t e w i t z, K. R o h r i d. Reliability of Wind Turbines. – In: Wind Energy Proceeding of the Euromech Colloquim, 4-7 October 2005, Oldenburg, Germany. Berlin-Heidelberg, Springer-Verlag, 2007.

Надежность ветровых турбинных генераторов и эксплуатация ветровых парков

Здравко Николов, Чавдар Корсемов, Христо Тошев

Институт информационных и коммуникационных технологий, 1113 София
Emails: chkorsemov@iinf.bas.bg toshev@iinf.bas.bg

(Р е з ю м е)

В работе обсуждается роль надежности ветровых турбинных генераторов (ВТГ) при производстве ветровой электрической энергии и корректное функционирование электрической сети, к которой они включены. Показаны данные действительной надежности, получены при наблюдении 1500 ВТГ, которые работают в Германии в течении 15 лет. Представлены также данные инвестиционных и эксплуатационных расходов при конструировании ветровых парков. Для достижения высокого уровня готовности обеспечена непрерывная поддержка, которая включает два типа – профилактику и аварийную поддержку.