RELIABILITY AND MAINTENANCE OF WIND POWER SYSTEMS

FIABILITATEA ŞI MENTENANŢA SISTEMELOR EOLIENE DE PRODUCERE A ENERGIEI ELECTRICE

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Abstract: *The paper presents the basics on the reliability and maintenance of wind power generation systems. The positive and negative practical aspects of the operation of a monitored wind system shall be analyzed and the strategies applied to perform maintenance of this system shall be presented in the most commonly known variants: Corrective maintenance, preventive maintenance and predictive maintenance. Defect analysis of the main components of the wind system is carried out in order to improve its reliability.*

Keywords: Wind turbine, maintenance, reliability, electrical equipment

Rezumat: *Lucrarea prezintă elementele de bază privind fiabilitatea şi mentenanţa sistemelor eoliene de producere a energiei electrice. Se analizează aspectele practice pozitive şi negative ale funcţionării unui sistem eolian supus monitorizării şi se prezintă strategiile aplicate pentru realizarea mentenanţei acestui sistem în cele mai cunoscute variante ale acesteia: mentenanţa corectivă, mentenanţa preventivă şi mentenanţa predictivă. Se realizează analiza defectelor elementelor pricipale ale sistemului eolian în scopul îmbunătăţirii fiabilităţii acestuia.*

Cuvinte cheie: Sistem eolian, mentenanţă, fiabilitate, echipament electric

1. Introduction

Promoting the production of electricity from renewable sources is an imperative in the current period, driven by environmental protection and the need to diversify the sources and methods of electricity generation.

The solution of power generation from wind sources has become more competitive with the development of power electronics, the improvement of aerodynamic models in the design of wind turbines, the optimization of the turbine geometry and the optimal location of these turbines on a given terrain, so that the mutual influence between different turbines is minimized. Special optimization software has been designed for this purpose, which should be applied directly related to the characteristics of the terrain on which these turbines will be located. Direct or

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indirect financing of these wind systems can be done through green certified support schemes by state and European institutions.

With the implementation of the provisions of Directive 2009/28/EC [1] the target set for Romania for the share of energy produced from renewable energy sources in gross final consumption was set at 24% for 2020. According to Eurostat[2] data this target was already achieved in 2017.

When installing wind turbines in a wind farm, should be taken account of fundamental elements such as the reliability and maintenance of the main components of the farm so that the technical-economic parameters achieved are as good as possible and the lifetime of individual components is as long as possible. This paper will present some theoretical and practical aspects of increasing the reliability of wind systems, but also the strategies that should be followed to increase the maintenance of these systems.

2. Reliability of wind systems

From a qualitative point of view, the reliability of a product or system is the ability to operate without damage under specified service conditions over a given period of time. In quantitative terms, reliability is the probability that the system will operate without faults and with acceptable performance under normal operating conditions and within a given time frame.

Reliability is an essential attribute of equipment, which must be taken into account by both the designers and manufacturers of this equipment. Reliability characteristics are the parameters defining any design activity of industrial equipment. The performance of the individual functions of the system is dependent on the way in which the components perform their own functions, which leads to the conclusion that the reliability of the system components is dependent on the reliability of the system components.

The relatively low production price and reliability of wind turbines has been an important disadvantage for the implementation of this type of electricity production solution. In recent years, the production price per unit of electricity has decreased significantly and the reliability of the systems has been improved.

Reliability aims at:

- study of defects (causes, processes of occurrence and development, methods of control);
- quantitative appreciation of the product behavior over time, as a function of internal and external influences;
- the establishment of methods and models for calculation and forecasting reliability, on the basis of specific tests and tracking of the in-service behavior of products;
- establishing the construction and operational methods for maintaining and increasing the reliability of systems, devices and components;

- establishing methods for selecting and processing data on product reliability;
- determining optimal values for reliability indicators.[3]

3. Component failure modes of a wind system

The concept of failure refers to the alteration or interruption of the ability of a system to perform the function for which it was constructed, under normal operating conditions.

Damage to a system can have one of the following two consequences:

- loss of performance of one or all of the functions provided by the assembly. If they fall below the stop level defined by the functional specifications of the assembly, the damage becomes a failure;
- a damaged sub-assembly with no functional consequences on the assembly and which does not cause the assembly to stop;

Failure mode is the effect by which a malfunction occurs (e.g. a short circuit). Failure modes are defined for a functioning state of the equipment in all or only one part of the equipment. If another equipment state is considered, the modes of failure of that component may change.

The same equipment may have several failure modes, caused by internal (non-functioning of equipment components) or external failures (simultaneous failure of other equipment that is related to the assembly being analyzed).

As an example, consider a wind turbine that drives an electric generator.

The most important elements in a wind turbine where defects occur are as follows:

- nacelle, tower, blades;
- mechanical components (bearings, axles, couplings, gears, gearbox, etc.)
- the electric generator;

3.1. Wind turbine faults

a. Turbine blade faults

Defects in the blades of a wind turbine occur due to a change in the roughness of the blades' surface, due either to structural defects in construction or to ice deposition or pollution. The change in the roughness of the blades causes an imbalance in the rotating masses resulting in the emergence of centrifugal forces that are transmitted to the nacelle and to the tower.

b. Drive system

Faults in the wind turbine drive system are faults that occur at the shaft (e.g. cracks). The causes of the drive system failures can be torque overload, bending effect due to asymmetrical rotational forces, improper materials used in the manufacture, and improper transportation or assembly of the turbine. [4], [5], [6].

Faults in the drive system can be detected by means of an inductive sensor that measures the shaft movement during rotation.

c. Defects in the rolling bearings

A classification of these defects may be according to the category to which they belong, each category containing several types of possible defects and the causes and consequences given below in Tab. 1.

Table 1. **Classification of defects in rolling bearings**

Category	Defect	Causes	Consequences
Destruction by friction	Wear	Destruction of surfaces under load and increased wear due to faulty lubrication	Increase the distance between the balls and bearing tracks
	Fatigue	High loads	Cracks and damage to the running gear
Overload	Deformation	Extreme loads, continuous wear	Deformation of the track
	Cracks	Continuous wear	Cracking of the components
Overheating	Cracks	Overheating and cooling frequently	Cracking of the components
	High temperature operation	Increased speed, shape deformations, lubrication problems	
Corrosion	Surface corrosion	Increased humidity, environmental influences (salty air, for example)	Wear, pollution of lube oil
Conduction currents	Destruction of the running surfaces	High currents due to natural electrical discharges or electrical problems	Problems with the running surfaces

a. Gearbox faults

The classification of the categories to which the defects in the wind turbine gearbox occur and their causes and consequences are listed in Tab. 2.

Table 2. **Classification of faults occurring on the gearbox of the wind turbine**

Category	Defect	Causes	Consequences
Cracks	Cracks in the base of the teeth	Extreme loads, jams	Tooth destruction, modified surface
	Cracks in the teeth face		Cracks and damage to the running gear
The tooth face	Cracks, holes, marks, wear, erosion	Wrong geometry, overload, vibration	Surface deformation or pinching
Overheating	Cracks	Overheating and cooling frequently	Cracks and excessive wear
	High temperature operation	Increased speed, shape deformations, lubrication problems	
Corrosion	Corrosion of surfaces	Increased humidity, environmental influences (e.g. salty air)	Excessive wear
Induction currents	Destruction of the surfaces	High currents due to natural electrical discharges or electrical problems	Surface problems

d. Electrical generator faults

The failure of a rotating machine is related to electrical, mechanical, thermal and ambient characteristics that cause wear and degradation of stator insulation. Overheating is one of the main causes of stator insulation and stator winding damage. To increase the reliability of the electric generator, many manufacturers have equipped it with sensors and transducers capable of measuring the magnetic flux in the regions at the ends of the coil, the currents through its windings, the voltages applied to these windings and the temperatures of the most demanded parts of it. Monitoring of the generator operating parameters is difficult and this does not always allow detection of local imperfections of the generator.

The power generation is one of the most important elements of a wind turbine, so its reliability is of major importance to maintain the integrity of a wind power plant. Continuous monitoring or frequent inspection is required to prevent and remedy defects before the generator is taken out of service. The failure of the stator insulation of the generator is a gradual process and usually occurs after a long period of operation, of years or even of decades This is critical because it causes both electrical losses to increase in the generator and therefore the generator efficiency to decrease, and that the resulting heating can damage the insulation of the conductors and in major cases it can melt even the magnetic core of the stator. [7] [8].

For the detection of defects in an electrical generator, sensors and transducers can be installed on the shields at the front and rear of the generator and periodically checked the insulation quality of the stator magnetic core by testing it at nominal voltages or at higher voltages.

4. Wind power plant maintenance strategies

The definition of maintenance according to European Standard EN 13306:2001 [4] is all the technical, management and administrative actions designed to restore or maintain a system or equipment in a condition in which it can perform its required function during the life cycle of that system.

Maintainability is the ability of a system as a whole and its components to maintain its technical condition or to return, under given operating conditions, to the state in which it can meet a functional requirement. Maintainability is closely related to the probability that the system will be brought back into operation within a certain time frame. [5]

The main objectives of maintenance in electricity generation, transmission and distribution systems are:

- preventing damages and maintaining the assembly in normal operation for a long time;
- increase the availability of the energy system and its subsystems, including their component equipment, by carrying out only the necessary work;
- extending the system life by increasing the quality of the work;
- increase economic efficiency by improving the reliability of installations and reducing the number and duration of interruptions (unplanned repairs);

Maintenance actions can be simulated in the laboratory on the prototype of the equipment in order to guarantee its serviceability. Among the issues to be taken into account in prototype studies are:

- ensure accessibility, which refers to the ability to mount or remove any component and to measure physical parameters directly on the equipment under minimum time and effort;
- determination of typical failures that may occur, the mode and means of their rapid remediation by providing a minimum repair operation time;

The reliability of the systems is currently influenced by the type of maintenance strategy applied.

Maintenance strategies can be divided into three main categories:

- corrective maintenance, intended for the restoration of the equipment after the damage occured;

- preventive maintenance;
- predictive maintenance

4.1. *Corrective maintenance*

Corrective maintenance is based on operation of the equipment after a malfunction has occurred (e.g. partial or total repair or replacement of defective equipment). The effectiveness of the maintenance program is judged by the cost of the life cycle of the equipment or systems and not by how quickly it is restored.

Thus, the main objectives of corrective maintenance are to eliminate interruptions in operation, deviations from optimal operating conditions and unnecessary interventions. This requires early troubleshooting, with repairs checked before putting the equipment or system back into service. All deviations from optimal operating parameters, such as yield, production capacity or product quality, shall be corrected as soon as they are identified.

Advantages of corrective maintenance:

- reduced value of spare parts stock;
- no monitoring of the machine is required;
- the intervention does not require programming;
- the use of the changed component parts is at maximum;
- maintenance is relatively cheap. Disadvantages of corrective maintenance:
- there is no scheduling of the working time of maintenance personnel, which may involve an emergency intervention that can generate additional costs
- no resources allocated; (money for components, time, etc.)
- the waiting time before delivery of the spare parts may be high;
- the operation of the installation is often interrupted

Focusing only on production costs is a changing concept. Most companies are looking for ways to reduce maintenance costs, but going only on the idea of intervening on the equipment when it has failed, no control can be given to the occurrence of defects or no ways to reduce maintenance costs were found.

4.2. *Preventive maintenance*

Preventive maintenance is a concept that is based on a preventive action taken at pre-defined intervals recommended by the equipment manufacturer or results from operating experience and is designed to prevent system components from failing or to reduce the probability of failure over time.

The concept of preventive maintenance has several meanings, an interpretation of it can be the program that aims to eliminate or prevent corrective maintenance. A preventive maintenance program involves periodic evaluation of equipment or systems to detect potential problems and after finding them to program the necessary interventions that will prevent any degradation of operating conditions. [9]

Preventive maintenance is known in the specialized technical documents and as time-based, scheduled or systematic maintenance. Figure 1 shows the possibility of a fault occurring depending on the operating time.

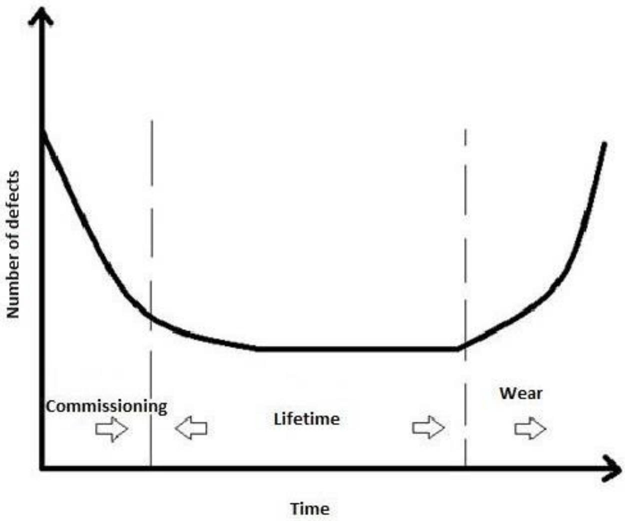

Figure 1. Statistical representation of the occurrence of defects for a machine or system.

This means that new equipment is more likely to fail in the first week after commissioning due to problems with installation, design or manufacture. After this period the probability of a defect occurring is relatively low for a longer period of time, which is generally specified by the manufacturer as the service life (duty cycle) without maintenance. After this period, the probability of failure increases rapidly with elapsed time. Preventive maintenance management takes this statistic into account for the purpose of implementing preventive maintenance management and planning repair and maintenance work.

<u>The benefits of preventive maintenance are:</u>

- it is a repetitive task;
- it is easy to schedule and execute;
- requires little control of the work team and equipment;
- maintenance efficiency is high
- the theoretical training for the maintenance team is easy to organize;
- budget planning is clear, simple to do. <u>Disadvantages of preventive maintenance:</u>

- repetitive work can become tiring, boring;
- there is a tendency to skip certain checks;
- some of the components which are still in operation (e.g. circuit breaker extinguishing rooms) and some which are damaged (bearings, seals) are replaced too late;
- the budget allocated to spare parts is important;
- parts stock is high;

Preventive maintenance predefines time intervals based on data from experience in equipment operation, where components are changed after a specified period of use and are practiced as a usual maintenance strategy, with satisfactory results. However, it is not the best option in terms of actual cost in all cases, because a number of equipment will not remain in operation until the end of its possible life.

The next step in the evolution of the maintenance strategies was to move from maintenance based solely on programming the time to predictive maintenance.

4.3. Predictive maintenance

It is a concept based on the use of meters capable of monitoring the condition of the equipment, which can be determined directly in the operation within a certain time frame. In literature this is also called status-based maintenance.

Predictive maintenance actions perform equipment monitoring and diagnosis to detect conditions that may become malfunctions over time, reduce their probability of evolution over time, and avoid equipment damage.

The application of the predictive maintenance strategy requires proper equipment with devices capable of transmitting information continuously or information obtained at certain intervals from modern recording and diagnostic equipment (thermal imaging, chromatography, sensors, transducers, etc.).

In most cases, predictive maintenance involves monitoring vibration of rotating machines, thermal imaging of electrical contacts, motors, or other equipment to identify potential problems that may result in equipment failure.

Unlike preventive maintenance, which is based on the timing of the commissioning or last repair to organize maintenance activities, predictive maintenance is based on programming based on parameters or actual operational indicators of the equipment or system [9]. Using predictive maintenance provides real-time data on the current state of each system and the performance of each process. This will help avoid unscheduled interruptions in the production process by identifying problems before they degenerate. This may bring considerable financial advantages depending on the type of activity, but at the same time predictive maintenance requires an investment in monitoring equipment.

The advantages of predictive maintenance:

- increases the life of the components;

- it increases the reliability of the equipment and thus the availability indicators of the installation;
- monitors the actual condition of the equipment;
- ensure that the spare parts budget and working time are well organized.

Disadvantages of predictive maintenance:

- it is necessary to pay close attention to both machines and people;
- meters shall be of high accuracy class;
- large investment in suitable measuring equipment;
- big investment in the schooling of people who will take measurements.

Globally, predictive maintenance tends to replace preventive maintenance, thus achieving substantial labor and material savings.

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5. Conclusions

The paper presents the basic elements for the reliability and maintenance of wind power generation systems. The objectives pursued in the paper relate mainly to the characteristics to be met by a maintenance system capable of leading to the prevention of damage, to extend the service life by increasing the quality of the work in order to increase economic efficiency and reduce the number and duration of interruptions in operation of the system.

The positive and negative aspects of the operation of a wind system are analyzed for its main construction elements: The wind turbine, the electric generator and the gearbox.

R E F E R E N C E S

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