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Review Paper

NO-CONTACT DIAGNOSTICS IN THE FUNCTION OF RISK-BASED MAINTENANCE ON A WIND GENERATOR MODEL

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Abstract. *When it comes to risk-based maintenance of technical systems, selecting a diagnostic procedure is the weakest link in the chain of steps that guarantee the system's availability, sustainability, and safe operation while utilizing its working characteristics.*
The model of a wind generator, which by virtue of its technological structure represents an increasingly widespread system in the geographical and topographical sense, was used to examine diagnostics based on non-contact, remote collection of pertinent information, which is essential for assessing the state of the technical system. In addition, the fact that the system is not physically accessible to the maintenance teams emphasizes the necessity of taking prompt action to rectify work in order to preserve production capacity and the security of the exploitation process.
When applied to the wind generator model, proactive maintenance based on risk allows for enhanced interconnected machine efficiency, optimal maintenance process planning, and real-time production process control. These factors contribute to the advancement and refinement of the contemporary 4K industry philosophy.
The concept of remote diagnostics in complex technological structures is of interest to the authors. The goal is to process information about the condition through the lens of risk, paying particular attention to the diagnostic method's reliability and improving prediction accuracy in the maintenance of industrial plant machinery.

Key words: *wind generator, diagnostics, maintenance.*

1. INTRODUCTION

Because wind energy is dependable, sustainable, and efficient, it is the renewable energy source with the fastest rate of growth in the world. In order to turn wind energy into electricity, both onshore and offshore wind generators are frequently utilized. Not only is wind energy a renewable energy source, but it also emits no CO_2 or SO_2 into the atmosphere.

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Fossil fuel prices have always had an impact on interest in wind energy. Fuel became less expensive after World War II. Interest in wind energy starts to wane at that point. The Organization of the Petroleum Exporting Countries imposed an embargo and fuel costs increased in the 1970s, which piqued interest. The need to increase wind generator productivity and optimize wind farm ROI grew along with this expansion.

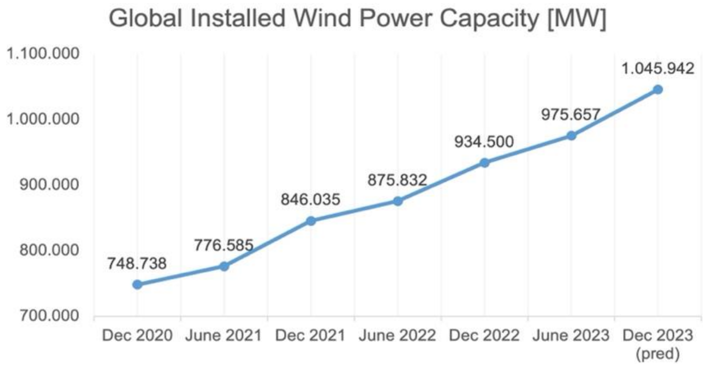

Fig. 1 Global installed capacities of wind generators [1]

Since "the net income from a wind farm is the income generated from the sale of electricity less operation and maintenance [2]," appropriate (technically feasible and economically profitable) maintenance strategies will be needed for successful future development.

According to data from the World Wind Energy Association, 1.045.942 MW of electricity could be produced using wind power by the end of 2023. In 2020, an additional 93 GW of energy was added. The generation of wind power has increased by 58% during the past five years. [1]

Wind generators require frequent monitoring and maintenance because they typically operate in harsh environments, but accessing them can be challenging due to their remote locations. Thus, one of the primary obstacles impeding the growth of wind energy is the expense of maintenance.

2. Wind Generator Components

The tower, rotor, and casing are the three main components of a wind generator. The housing that holds the brake, control device, generator, and transmission system is attached to the rotor.

The case's function is to safeguard the internal components as well. The generator and transmission system are the two main components of the wind generator.

Hub, main shaft (relatively), bearings, couplings, and gear transmission make up the transmission system Fig 2 [3]. Gray cast iron is used to make the head because of its unique shape. Forging steel is the most common method of creating the main shaft. The main shaft rotates at 40–60 revolutions per minute. Typically, bearings are made of spherical rollers. In order to minimize wear and tear and the ingress of water and dirt into the bearing, the sealing is labyrinthine. The torque is transmitted from the main shaft to the gear transmission through a friction coupling.

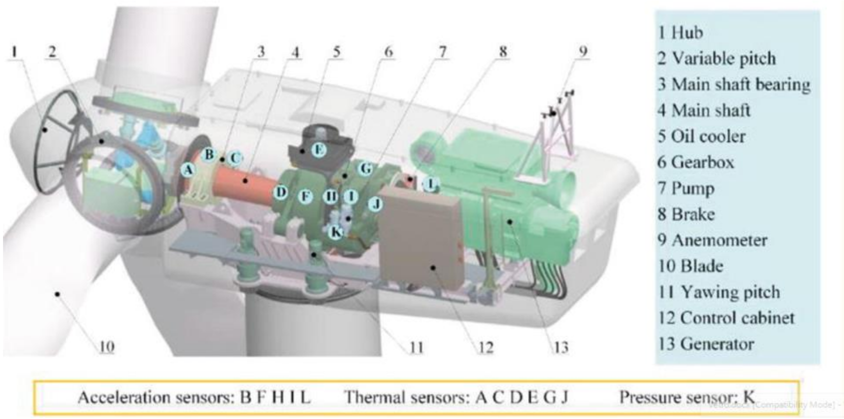

Fig. 2 The main components of wind generators [4]

Large, heavy gears are needed for the gear transmission's function of raising the main shaft's rotational speed from 40–60 rpm to 1500–1800 rpm. Transmission can be two-stage (150 MW), three-stage (300 MW), or planetary (above 450 MW) depending on the output power. A rigid coupling connects the transmission's output shaft to the generator.

3. Reliability and Maintenance of the System

The use of contemporary maintenance techniques is necessary to meet the system's current needs for high dependability in wind generators. Larger, heavier constructions are the tendency in modern wind generator development, which raises the failure rate. In actuality, offshore and onshore wind turbine systems of the same type have very different failure rates. The failure rates of wind generating systems and parts are depicted in the Fig 3 [5].

Damage to the wind generator, or to a structural component, is what we mean when we say that the production situation is unacceptable. Put differently, damage denotes a notable departure from the initial functioning state and, as such, is unacceptable to the owner. Two categories of harm stand out in this regard:

1. Functional damage to the wind generator is defined as its inability to meet all of the performance requirements listed in the relevant technical file. As such, it is typically detected by the machine operator, who is the process owner.
2. The physical state of the equipment suggests that functional damage is highly likely to occur, which presents potential damage to the wind generator. The maintenance department is usually the one to identify this problem.

Because they carry extremely high loads during the exploitation process, the bearings in wind generator subassemblies are the most vulnerable parts of the assembly. The bearings may have to support big loads at low speeds or modest loads at high speeds, depending on the subassembly's location and the operating load. Low wind speeds can result in high stresses at low speeds, which can rupture the oil film and reduce the bearing's lifespan. Typically, an automatic lubrication system is used to grease the bearings in the gear transmission. High oil purity is guaranteed by the oil filter, which is independent of the oil cooling system.

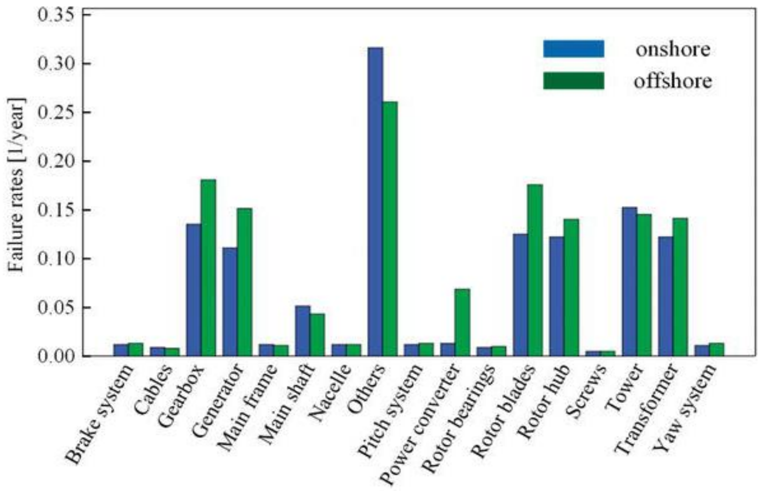

Fig. 3 Failure rates for onshore and offshore wind turbine subassemblies [5]

This is a critical solution for arid climates, where airborne dust particles can abrasively wear down toothed gears. Salt and moisture are constant risk considerations for wind turbines situated on offshore platforms. The toothed transmission can become contaminated during installation, through wear and tear, leaks through vents and seals, and negligent maintenance diagnosis. For these reasons, it's crucial to ensure that the oil is clean.

Assembling under unsuitable settings results in the introduction of contaminants during installation. These contaminants are the most hazardous to start since the oil filter cannot get rid of them right away. The main sources of impurities that develop inside the transmission are bearings, gears, and other component wear. Wear can show up as fretting, adhesion, abrasion, micro pitting, and macro pitting. Seals and vents allow dirt to enter the transmission. It is important to do maintenance, such as relubrication, to stop contaminants from penetrating. Preventive maintenance, which involves monitoring for water presence, viscosity, acidity, and oil pollution, can help lower the frequency of failures.

The rotor blades are the second most susceptible structural component of the wind generator to damage. Wind energy powers the rotor blades of wind turbines, converting it into mechanical energy. Blades have high failure rates due to their frequent alternating stress; fatigue, fracture, cracking, wear, inadequate resistance to low temperatures, and sensor failure are the main causes of failure. The rotor blades' location within the structure makes maintenance and repair challenging, and any malfunction raises the cost of extraction. Therefore, in order to create highly reliable blades, it is crucial to thoroughly and meaningfully investigate the elements that contribute to damage.

4. Maintenance Strategies

A contractual guarantee of two to five years is typically included with wind turbines, and it covers both preventive and corrective (time-based) maintenance methods. These tactics are typically used for the wind generator's ongoing maintenance after the contract time expires [6, 7]. Operating the wind turbine or any of its components until they break is known as fault-based maintenance. This tactic is typically used in situations where failing won't have an adverse effect on customer happiness, revenue, or health and safety. Critical component failures in wind turbines, however, can have detrimental effects on operations as well as public health, safety, and the environment.

The maintenance plan for wind generators is often implemented following the predetermined warranty period [7, 8], giving the owner the opportunity to make an informed decision and put their faith in the most dependable idea.

4.1. Maintenance concepts

Vibrations develop under operating conditions as a result of inertial disturbance forces produced by the machine system's complicated structure and the dynamic activity of its unbalanced elements during technological engagement. It has been demonstrated by contemporary practice that undesired vibrations can be an effective diagnostic tool for preventive engineering and machine system maintenance. All actions taken by the process owner to plan and carry out work aimed at keeping the machine in operable condition are collectively referred to as maintenance. Four well-known models serve as the foundation for the idea of guaranteeing production conditions and operational circumstances from the perspective of machine maintenance:

1. Corrective maintenance is maintenance performed after a failure;
2. Preventive or scheduled maintenance is maintenance carried out on schedule;
3. Preventive maintenance based on equipment condition monitoring is maintenance carried out on schedule;
4. Proactive maintenance.

The pros and cons of each of the aforementioned principles are considered while selecting the best model for sustaining the current equipment.

Operating the wind turbine or any of its parts until failure occurs is known as failure-based maintenance. This tactic is typically used in situations where failing won't have an adverse effect on customer happiness, revenue, or health and safety. Critical component failures in wind turbines, however, have the potential to be disastrous and have negative effects on operations, safety, and the environment.

Planned maintenance, or scheduled maintenance, is carrying out maintenance duties on a prearranged, regular basis. When the failure pattern is well-known, this tactic is frequently used to install original components without nullifying the manufacturer's warranty. The challenge lies in selecting the appropriate period because an interval that is too frequent raises operating expenses, wastes production time, and necessitates the replacement of components that are still in good condition, while unexpected failures frequently happen in the intervals that are too long [9]. As a result, money and resources are typically allocated to maintenance without much awareness of the equipment's actual condition.

The other two models, numbered 3 and 4, illustrate a contemporary idea of equipment maintenance. Preventive maintenance, also known as maintenance according to condition, suggests that machines be stopped for overhauls based on the values of characteristic parameters, or indicators (temperature, pressure, voltage state, vibrations), whose changes are regularly (sometimes) observed off lines or continuously (on line).

It is possible to identify and comprehend the underlying causes of typical machine failure modes through proactive maintenance. Preventive maintenance and root cause analysis, or RCFA, or root cause failure analysis, are combined in proactive maintenance. This makes preventative maintenance different from traditional preventive maintenance, which typically identifies the problem's effect rather than its cause, which is then further eradicated. In order to eliminate issues that have arisen in the past, a proactive strategy frequently calls for fundamental changes to the machine.

The risk-based maintenance paradigm of RBI, or Risk-Based Inspection, and proactive maintenance are extremely similar. The primary objective of the maintenance management process is to prioritize maintaining the necessary availability and dependability, or the proper probability of failure, before addressing the unfavorable effects of these occurrences. In actuality, it is far more convenient to keep an eye on both of these variables at the same time-that is, the likelihood that undesirable occurrences will occur and their effects. Combining these two elements will enable more logical and sensible judgments to be made, as risk is defined as the product of the likelihood of an undesirable event and its effects.

The requirement to evaluate the risks resulting from the Machinery Safety Directive and its associated standards just serves to validate the notion that a machine's operational life officially commences with commissioning following installation in a production facility. Products that are put on the market must adhere to the fundamental standards for health and safety protection in order to be allowed to remain in the single market (Europe). The life cycle of the machine is depicted in Fig 04 in stages. The manufacturing of components and the assembling of assemblies come first, followed by testing to ensure that labeling and the new, worldwide approach are followed. The machine is assembled upon delivery, and following functional testing, it is turned on. From that point on, the machine is the focus of the maintenance service's process owner. All phases of the life-work cycle involve interaction with the machine in the maintenance role.

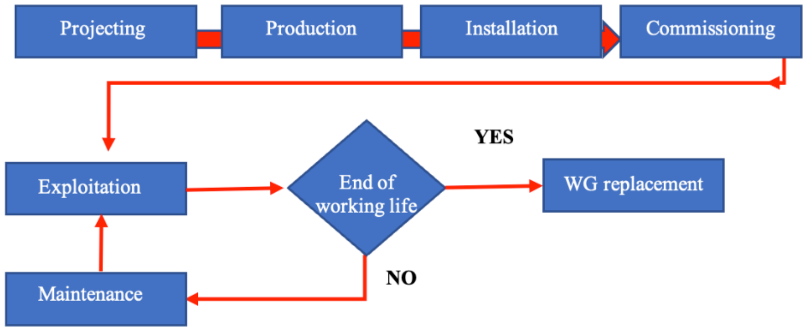

Fig. 4. Stages of the life-work cycle of a working machine-wind-generator

A machine's availability will be decreased by a failure at any point during its life cycle. All machine damage is related to commonplace, basic physical processes such as wear and tear, friction, erosion, corrosion, and shock loads. The way the operator or members of the maintenance department interact with the machine largely determines whether and how much these causal factors manifest on the machine.

It has been determined that condition-based maintenance, which comes from a proactive manner, is the most economical for maintaining important equipment [10-11]. When equipment or component performance declines as indicated by the condition monitoring process, a condition-based maintenance plan is implemented to fulfill the needs of the maintenance process [12]. Condition-based maintenance is a huge field of study that also includes wind turbines and related power facilities, but it has received little attention. While thermal imaging and acoustic emission are used to monitor the structural integrity of turbine blades [13–14], performance monitoring [15], temperature monitoring systems, and online analysis [16–17] are also used.

Table 1 Condition monitoring techniques in WT,

	Blades	Rotor	Gearbox	Generator	Bearing	Tower
Vibration	a, f	a,c	a, b, c, d, e, f, bef, eb, fg		a, c, d, f, g	d
Acoustic emission	a, f,	f	a, f,		a, b, de	
Ultrasonic techniques	a, f,					
Oil analysis			b		a	
Strain	a, c					
Shock Pulse methods					de, a, f	
Performance monitoring	a		c	a, b,	cd	

a: Statistical methods; b: Time domain analysis; c: Cepstrum analysis; d: Fast Fourier transformation (FFT); e: Amplitude demodulation; f: Wavelet transformation; g: Hidden Markov models; h: Novel techniques. [18]

One of the sophisticated diagnostic techniques that aligns with the idea of proactive maintenance of technological systems is contactless signal transmission Table 1, which provides information on physical phenomena that represent the condition of equipment in permanent exploitation mode. With good data acquisition and appropriate signal processing, faults can thus be detected while components are operational and appropriate actions can be planned in time to prevent damage or failure of components. FALCON's module for automatic non-contact diagnostics was mandated in order to put the concept of proactive maintenance for wind generators into practice. This module offers pertinent and trustworthy data on the value of diagnostic parameters required to describe the functional state of particular wind generator elements under operating conditions.

A wide range of flaws, including unbalance, misalignment, inappropriate assembly, friction, structural resonance, lubrication defects, bearing defects, gear defects, pump cavitation, and more, are identified by the module as prevalent in the industry. There is a high degree of dependability and confidence in the identification of errors, which are expressed precisely and clearly.

The synchronous acquisition shortens the time needed for data collection and equipment condition decision-making, and the outstanding measuring capabilities of the three-axis wireless sensor FALCON significantly boost production. The wireless sensors are swiftly mounted, and then automated sensor positioning is used to make measurements remotely. The reproducibility of the data is guaranteed by the monitoring of the controlled parameters, and errors resulting from the wiring and measurement point placement are totally eliminated. The module is the quickest gadget in the technical diagnostics industry since it allows real-time signal processing. By doing this, it is possible to arrange maintenance procedures and identify flaws in rotating machinery several months ahead of time, preventing unscheduled shutdowns and lost output.

5. CONCLUSION

Costs or lost benefits from production loss, component failure-related damage escalation, and repaired damaged components are incurred for corrective maintenance. Proactive maintenance in accordance with the risk-based condition will incur more costs for the process owner, but it will also lessen missed production and progressive damage.

In the context of the wind generator model, proactive maintenance based on risk refers to maximizing the productivity of networked and self-governing machinery as well as optimally scheduling maintenance procedures and controlling production in real-time, all of which facilitate the adoption of the 4K industry philosophy.

Non-contact diagnostics, or remote equipment condition monitoring, has an advantage over all other diagnostic techniques because it provides access to information about the state of a complex technical-technological system under actual operating conditions. This is made possible by advancements in sensor technology. The idea of technical advancement enables process automation, which gives the process owner remote control over all connected devices and visibility into the process, ultimately leading to a higher level of process management.

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BEZKONTAKTNA DIJAGNOSTIKA U FUNKCIJI ODRŽAVANJA ZASNOVANOG NA RIZIKU NA MODELU VETROGENERATORA

Izbor dijagnostičke procedure u funkciji održavanja tehničkih sistema zasnovanog na riziku, predstavlja najslabiju kariku u lancu procedura koje obezbeđuju bezbednu funkcionalnost, raspoloživost i održivost sistema u eksploataciji raspoloživih radnih karakteristika.

Dijagnostika zasnovana na bezkontaktnom, daljinskom prikupljanju relevantnih informacija, bitnih za ocenu stanja tehničkog sistema, razmatrana je na modelu vetro-generatora, koji po svojoj tehnološkoj strukturi predstavlja sve rasprostranjeniji sistem u geografskom i topografskom smislu. Istovremeno se radi o sistemu koji nije fizički dostupan timovima za održavanje, što dodatno ističe potrebu za blagovremeno preduzimanje mera korekcije rada u cilju održavanja proizvodnih kapaciteta i bezbednosti procesa eksploatacije.

Proaktivno održavanje zasnovano na riziku, aplicirano na modelu vetro-generatora, omogućuje povećanje efikasnosti međusobno povezanih mašina i optimalno planiranje procesa održavanja i kontrolu procesa proizvodnje u realnom vremenu, što omogućuje razvoj i unapređenje savremene filozofije industrije 4K.

Interesovanje autora je razvoj koncepta dijagnostike na distanci u složenim tehnološkim strukturama, sa ciljem da se informacije o stanju procesuiraju kroz aspekt rizika posebnim osvrtom na pouzdanost dijagnostičke metode i povećanja tačnosti predikcije u funkciji održavanja mašina industrijskih pogona.

Ključne reči: *vetrogeneratori, dijagnostika, održavanje*.