DIJAGNOSTIKA VJETROELEKTRANE

DIAGNOSTIC OF WIND POWERS

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REZIME
Svaki sistem zahtijeva redovno održavanje pa tako i vjetroelektrane. Savremeno održavanje vjetroelektrana se temlji na dijagnostici stanja vjetroelektrane koji se realizira kroz mjerenje parametara stanja sistema vjetroelektrane te obradi rezultata etabliranim metodama. U ovome radu je dat prikaz savremenih metoda koje se primjenjuju u nadzoru stanja vjetroelektrane.

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SUMMARY
Each system requires regular maintenance including wind power. Modern maintenance of wind powers is based in the diagnosis of the state of the wind power, which is realized through measuring parameters of wind power system and data processing by the established methods. This paper presents the modern methods used to control the state of the wind farm.

1. UVOD

Pojam dijagnostika vuče korijen iz starogrčkih riječi *dia* (kroz) i *gnosis* (znanje) čijim spajanjem je nastala riječ diagnosis (grčki: *διαγνοσισ*) koja u doslovnom prijevodu znači "kroz upotrebu znanja". Medicinska dijagnostika je široko poznata za razliku od tehničke dijagnostike čiji pojam i značaj su poznati samo u užem krugu tehničkih stručnjaka. Međutim, jednako kao što medicinska dijagnostika podrazumijeva sve postupke koji se provode da bi se spoznala bolest pacijenta preko zapažanja i tumačenja uočenih simptoma koji upućuju na nju tehnička dijagnostika podrazumijeva postupke otkrivanja oštećenja mašina, postrojenja i uređaja na temelju izvršenih mjerenja i pregleda nad istima [1].
Savremeno održavanje vjetroelektrana se temelji na dijagnostici stanja vjetroelektrane koja se realizira kroz mjerenje parametara stanja sistema te obradi rezultata etabliranim metodama.
Ranije strategije održavanja koje su bile zasnovane na čisto subjektivnoj dijagnostici

1. INTRODUCTION

The term diagnosis dates back to the ancient Greek words *dia* (through) and *gnosis* (knowledge) whose merger formed the word diagnosis (Greek: *διαγνοσισ*) which literally means "through the use of knowledge." Medical diagnostics is widely known as opposed to technical diagnostics, whose concept and importance are known only to a narrow circle of technical experts. However, just as medical diagnostics includes all procedures performed to meet the patient's disease through observation and interpretation of the observed symptoms that indicate her technical diagnostics includes methods for detecting damage to machinery, plant and equipment on the basis of measurements and monitoring over to them [1].
Modern maintenance of wind powers is based on a diagnosis of the state of the wind power, which is realized through measuring the parameters of the system and the processing of results to established methods.
Earlier maintenance strategies that were based on

stanja opreme imale su za posljedicu održavanje nakon momenta kvara sa svim negativnim implikacijama koje ova strategija nosi [2]. Pažljivo odabran i implementiran sistem dijagnostike može pomoći operateru da izbjegne situacije koje dovode do trajnog oštećenja sistema vjetroelektrane. Pored toga, sistem omogućuje vrlo rano otkrivanje oštećenja u njihovom ranom stadiju što omogućava provođenje aktivnosti održavanja prije pojave kvara.

2. OŠTEĆENJA I KVAROVI VJETROELEKTRANE

Najbitniji dijelovi vjetroelektrane su: elisa, reduktor, generator i transformator te se dijagnostici ovih dijelova mora posvetiti najveća pažnja [3, 4, 5]. Dosadašnja iskustva u eksploataciji vjetroelektrana govore da je najveći prioritet rizika kvara upravo na navedenim dijelovima. Dosadašnja iskustva, također govore, da su najčešći uzroci oštećenja i kvarova elise greške u proizvodnji istih, a značajno utiču i greške operatora te grmljavine i taloženje leda na lopaticama elise. Uslijed ovih uzroka dolazi do pukotina na lopaticama koje se najčešće javljaju na spojevima. Elisa je postavljena na glavnom ležaju na kome se javljaju oštećenja i kvarovi karakteristični za kotrljajuće ležaje i koji se otkrivaju etabliranim metodama ispitivanja kotrljajućih ležaja. Reduktor je dio vjetroelektrane kod koga najčešće dolazi do kvara [5], a na reduktoru se kvare kotrljajući ležaji i nešto manje zupčanici na kojima dolazi do pukotina. Reduktori su generatori buke te se njihovoj dijagnostici i održavanju mora posvećivati posebna pažnja. Na generatorima i transformatorima se javljaju oštećanja i kvarovi karakteristični za ove mašine.

3. METODE DIJAGNOSTIKE VJETROELEKTRANE

3.1. Vibrodijagnostika i ispitivanje stanja ležaja

U jeftinijoj varijanti, koja se primjenjuje kod vjetroelektrana manje snage, se instaliraju ukupno četiri vibrosenzora i to na: glavni ležaj, reduktor i dva ležaja na generatoru. Vibrosenzor instaliran na glavni ležaj detektira oštećenja glavnog ležaja i djelimično oštećenja elise dok ležaj instaliran na reduktoru detektira oštećenja ležaja reduktora i zupčanika. Dva ležaja instalirana na generatoru detektiraju oštećenja ležaja generatora, a također i električne probleme na generatoru kao što su međuzavojni spojevi te oštećenja rotora.

purely subjective diagnosis of the condition of equipment have resulted in the maintenance after the moment of failure with all the negative implications that this strategy carries [2]. Carefully selected and implemented system diagnostics can help the operator to avoid situations that lead to permanent damage to the wind power system. In addition, the system allows early detection of damage in their early stages of providing a maintenance activities before the onset of failure.

2. DEFECTS AND FAILURES OF WIND POWER

The most important parts of the wind power are: propeller, gearbox, generator and transformer and diagnosis of these parts must be given the greatest attention [3, 4, 5]. Previous experience in the exploitation of wind power say that the highest priority risk of failure is in these parts. Previous experience also say that the most common causes of damage and failures of propeller are manufacturing defects of the same, a significant impact and operator errors and thunder and deposition of ice on the blades propeller. Due to these reasons, there are cracks in the blades, which usually occur at joints.
Propeller is set on the main bearing on which occur defects and failures typical for roller bearings and which reveal the established testing methods of rolling bearings. Gearbox is part of the wind farms in which most often leads to failure [5], and the gearbox break down rolling bearings and gears slightly less that are subject to cracks. The gearbox is noise generators and their diagnostics and maintenance should devote special attention. For generators and transformers occur defects and failures typical of these machines.

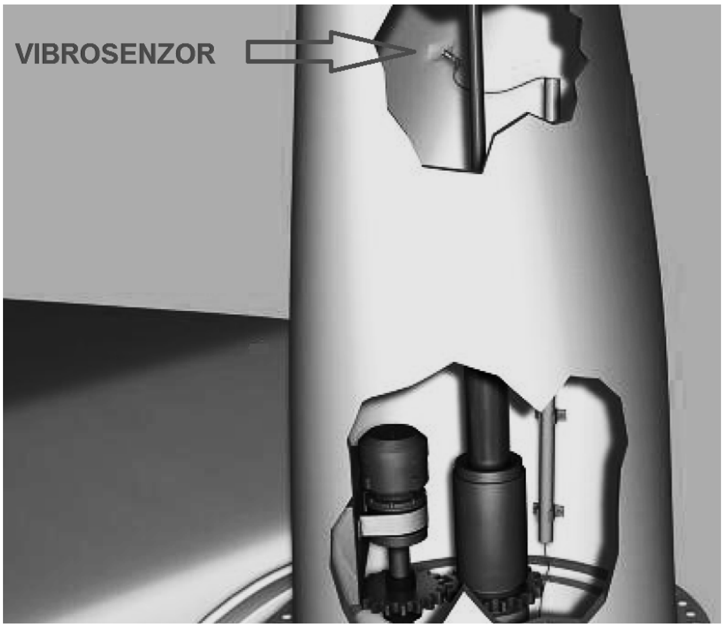
3. METHODS OF WIND POWER DIAGNOSIS

3.1. Vibration diagnosis and testing bearing condition

In the cheaper variant, applied to wind power with less power, are installed four vibration sensors on: main bearing, gearbox and two bearings of the generator. Vibration sensor installed on the main bearing detects defects to the main bearings and partially defects of blades while the vibration senzor is installed on the gearbox detects bearing defects and gear defects. Two vibration sensors are installed in a generator are detected bearing defetct of generator, and also a defetcs of electrical problems such as inter-turn joints and damage to the rotor.

U skupljoj varijanti se instalira ukupno deset vibrosenzora koji su raspoređeni na elisi, glavnom ležaju, reduktoru i generatoru. Na svaku lopaticu elise se postavi po jedan vibrosenzor. Zadatak ovih vibrosenzora je da detektiraju oštećenja lopatica i taloženje leda na lopaticama koje dovodi da neravnoteže elise. Na slici 1. je ilustrirano instaliranje vibrosenzora na lopatici ležaja. Signal sa vibrosenzora se prenosi bežičnim putem ili preko kliznih kontakta. Na glavni ležaj se instalira jedan vibrosenzor i eventualno specijalni senzor za detektiranje oštećenja ležaja. Na reduktor se instaliraju vibrosenzori na kućištima ležaja koji detektiraju oštećenja ležaja i zupčanika reduktora.

In the more expensive version are installed ten vibration sensors which are arranged on the propeller, main bearing, gearbox and generator. On each blade propeller is placed vibration sensor. The task of these vibration sensors is to detect damages on the blades and deposition of ice on the blades, which leads to an imbalance blades. In Figure 1. is illustrated installation of vibration sensor at blade. Signal from vibration sensor is transmitted wirelessly or via sliding contacts. On the main bearing is installed one vibration sensor and possibly a special sensor to detect bearing damage. On gearbox are installed vibration sensors on the bearing housing to detect bearing defects and gear defects.



Slika 1. *Instaliranje vibrosenzora na lopatici elise [5]*
Figure 1. *Installing the vibration sensors on the propeller blades [5]*

Zbog poteškoća u instaliranju vibrosenzora na lopaticama elise često se primjenjuje i dijagnostika sa sedam vibrosenzora gdje su četiri vibrosenzora postavljena na reduktoru, dva na generatoru i jedan na glavnom ležaju. Ovdje se pretpostavlja da je ugrađen jednostepeni reduktor sa ukupno dva vratila, što je najčešća izvedba, ali ako je ugrađen reduktor drugačije izvedbe tada je potrebno prilagoditi rješenje dijagnostike. U pojedinim izvedbama, rotor elise je postavljen na dva glavna ležaja i tada na oba ležaja treba postaviti vibrosenzor, a preporučljivo je i da se ugradi specijalni senzor za nadzor stanja ležaja ili univerzalni senzor koji mjeri vibracije i istovremeno omogućava nadzor stanja ležaja specijalnim metodama.

Caused by the difficulty in installing of vibration sensor on blades, often is applied diagnostics with seven vibration sensors where four vibration sensors are mounted on the gearbox, two on the generator and one on the main bearing. This is supposed to be built single-stage gearbox with a total of two shafts, which is the most common version, but if installed gearbox other versions, it is necessary to adjust the solution diagnostics. In some versions, the rotor blades is set to two main bearings and then on both bearings should be placed vibration sensor. It is recommended to incorporate special sensors to monitor the condition of the bearings or universal sensor that measures the vibration and at the same time to monitor the condition of the bearing by special methods.

Viborsenzor postavljen na glavni ležaj mjeri i vibracije tornja tako da se najčešće ne ugrađuje poseban vibrosenzor za mjerenje vibracija tornja, ali u posebnim slučajevima se može ugraditi i vibrosenzor na toranj.

Veoma značajni dijelovi vjetroelektrane su kotrljajući ležaji te se ispitivanju njihovog stanja poklanja posebna pažnja. U tome smislu je razvijeno više specijalnih metoda se ispitivanja, a također razvijene su i specijalne izvedbe vibrosenzora. Metode ispitivanja stanja kotrljajućih ležaja se dijele u dvije grupe: statičke metode i dinamičke metode. Statičke metode su metode ispitivanja koje se primjenjuju nad ležajima dok ležaj miruje, a dinamičke metode su metode koje se primjenjuju nad ležajem koji je u radu. Prednost statičkih metoda je njihova visoka pouzdanost, a nedostatak statičkih metoda je što zahtijevaju zaustavljanje i rastavljanje mašine kako bi se obavilo dijagnosticiranje. Tehnički indikatori (ne)ispravnosti ležaja su: zazor ležaja, količina metalnih čestica u mazivu ležaja, temperatura ležaja u normalnim radnim uslovima, jačina ultrazvuka, nivo vibracija ležaja i indikacija neke od specijalnih metoda. Otpor električne izolacije je tehnički indikator ispravnosti kod izolovanih ležaja koji se koriste u pojedinim elektromotorima.

U stručnoj literaturi se može naći opis devet stadija otkaza kotrljajućeg ležaja, međutim prema opšte prihvaćenom stanovištu postoje četiri stadija otkaza ležaja. U prvom stadiju otkaza samo specijalnim dijagnostičkim metodama se mogu uočiti simptomi defekta. U četvrtom (završnom) stadiju otkaza svim dijagnostičkim metodama je moguće dijagnosticirati kvar. Temperatura ležaja je uvećana tek u završnom stadiju, odnosno mjerenjem temperature nije moguće vršiti ranu detekciju otkaza ležaja. Vibracije i buka se mogu detektovati u trećem stadiju otkaza. Može se zapaziti da je ispitivanje ultrazvukom i specijalnim metodama primjenjivo za potrebe predikcije otkaza ležaja te u izvjesnoj mjeri mjerenje vibracija, dok je mjerenje temperature primjenjivo isključivo za potrebe zaštite tj. kako bi se imao pouzdan podatak o otkazu na temelju koga se donosi zaključak da mašinu treba zaustaviti kako ne bi došlo do oštećenja drugih elemenata.

Vibration sensor placed on the main bearing also measure the vibrations of the tower so it is usually not incorporated special vibration sensor to measure the vibration of the tower, but in special cases can be installed vibration sensor at the tower.

Very important parts of a wind power plant are rolling bearings and study their condition is paid special attention. In this regard have been developed special methods to test, but also developed special constructions of vibration sensors. Methods for testing the condition of rolling bearings are divided into two groups: static methods and dynamic methods. Static methods are test methods that are applied over bearings while bearing is stationary and dynamic methods are methods that are applied over the bearing in operation. The advantage of static methods is their high reliability, a lack of static methods is that require stopping and dismantling of machines in order to accomplish the diagnosis. Technical indicators of (in)correctness bearings are bearing clearance, the amount of metal particles in the lubricant of the bearing, the bearing temperature under normal operating conditions, the intensity of ultrasound, vibration level and bearing an indication of some of the special method. Electrical insulation resistance is technical indicator correctness in isolated beds that are used in some electric motors.

In the literature one can find a description of nine stages of roller bearing degradation, however, according to the generally accepted viewpoint there are four stages of bearing degradation. In the first stage of the degradation only special diagnostic methods are observable symptoms of the defect. In the fourth (final) stage of the degradation of all diagnostic methods is possible to diagnose the problem. Bearing temperature is increased only in the final stage, and temperature measurements can not be performed early failure detection beds. Vibration and noise can be detected in the third stage of the cancellation. It can be noted that the ultrasonic testing and special methods appropriate for the purposes of predicting failure of the bearings and, to some extent, vibration measurement, while measuring the temperature applicable solely for the purpose of protection, ie. In order to have reliable information about the cancellation on the basis of which yields the conclusion that the machine should be stopped so as not to damage the other elements.

3.2. Mjerenje temperature

Senzori za mjerenje temperature se instaliraju na glavni ležaj, reduktor, generator i transformator. Na temelju mjerenja temperature oštećenja se mogu relativno lako otkriti, jer svaki element ima ograničenja temperature, odnosno temperaturno područje u kojem je dozvoljen rad, međutim okolina može uticati na temperaturu ispitivanog elementa što umanjuje pouzdanost ove dijagnostičke metode, te se mjerenje temperature ne koristi kao primarni izvor informacija za detektiranje defekata već prvenstveno u svrhe zaštite [1, 3]. Ukoliko dođe do pregrijavanja glavnog ležaja, najvjerojatnije da je podmazivanje ležaja neadekvatno, a mogući uzrok je i deformacija elise. Pregrijavanje reduktora je najčešće posljedica lošeg podmazivanja.

3.3. Nadzor stanja ulja

Nadzor stanja ulja reduktora se obavlja ugradnjom kapacitivnog senzora za mjerenje sadržaja vode u ulju i ugradnjom optičkog senzora za detektiranje prisustva čestica u ulju te ugradnjom kapacitivnog senzora za kontrolu nivoa ulja. Prisustvo vode u ulju je veoma štetno, jer dovodi do ubrzanog trošenja dijelova te je detektiranje prisustva iste veoma bitno. Prisustvo čestica u ulju je najčešći pokazatelj ubrzanog trošenja dijelova [1].

3.4. Dijagnostika generatora i transformatora

Dijagnostika generatora i transformatora se provodi metodama koje su uobičajene za ove mašine. Na vjetroelektranama se primjenjuju suhi transformatori čiji nadzor se provodi kroz mjerenje struje, napona i temperature namotaja [6]. Dijagnostika generatora se provodi kroz mjerenje struje, napona i temperature namotaja te mjerenje vibracija. Magnetni monitoring je također jedna od metoda kojom se nadzire stanje generatora. Najčešće primjenjivani senzori magnetnog monitoringa su mjerne zavojnice koji mjere promjenu magnetnog toka kroz površinu koju obuhvataju te Hallovi senzori koji mjere magnetnu indukciju.

3.5. Kontinuirano i periodično dijagnosticiranje stanja vjetroelektrane

Kontinuirano dijagnosticiranje stanja se provodi kroz mjerenje vibracija, temperatura, nadzor ulja, struja, napona i broja obrtaja elise. Sve ove dijagnostičke podatke prikuplja nadzorno-dijagnostički sistem vjetrolektrane i dostavlja ga do centralnog nadzorno-dijagnostičkog sistema vjetroparka.

3.2. Temperature measurement

Sensors for temperature measurement are installed on the main bearing, gearbox, generator and transformer. Based on measurements of temperature defect can be relatively easy to detect, because every element has a limit temperature or temperature range in which it is allowed to operate, however, the environment can influence the temperature of the test element which reduces the reliability of this diagnostic method, and the temperature measurement is not used as a primary source of information for detecting defects but primarily for the purpose of protection [1, 3]. In case of overheating of main bearing, most likely to be inadequate lubrication of the bearing, a possible cause of the deformity and propeller. Overheating of the gear unit is usually a result of poor lubrication.

3.3. Oil monitoring

Oil monitoring at gearbox is done by installing capacitive sensors for measuring water content in oil, installing an optical sensor for detecting the presence of particles in the oil and installation of capacitive sensors to control the oil level. The presence of water in oil is very harmful because it leads to accelerated wear of parts and detecting the presence of the same very important. The presence of particles in oil is the most common indicator of accelerated wear of parts [1].

3.4. Diagnostics generators and transformers

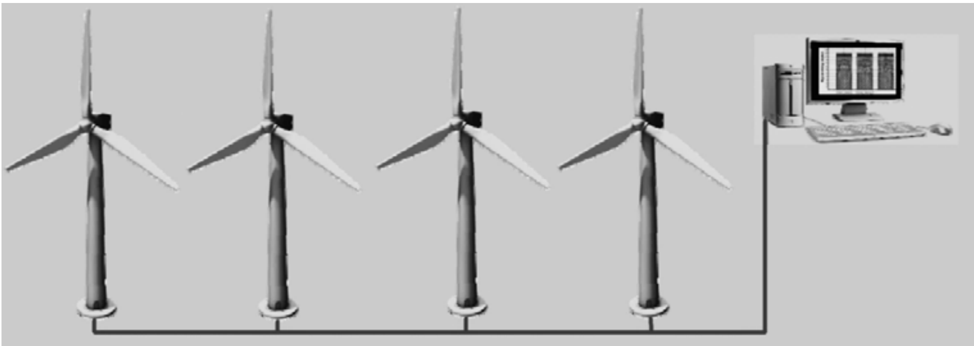
Diagnosis of generator and transformer is carried out by methods that are common to these machines. For wind power plants apply dry-type transformers which monitoring is carried out through the measurement of current, voltage and winding temperature [6]. Diagnosis of generator is carried out through the measurement of current, voltage and winding temperature and vibration measurement. Magnetic monitoring is also one of the method that monitors the state of the generator. The most commonly applied magnetic monitoring sensors are measuring coil which measures the change in the magnetic flux through and Hall sensors which measure magnetic induction.

3.5. Continuous and periodic diagnosis of wind power conditions

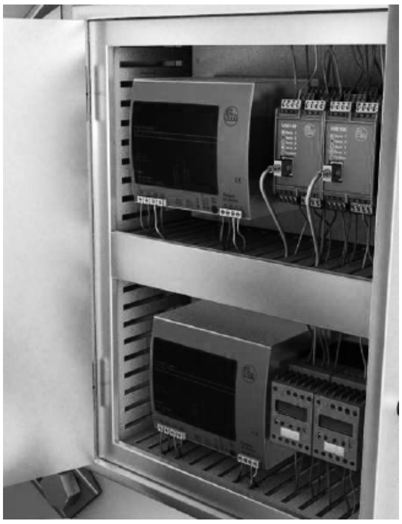
Continuous diagnosis of the condition is carried out through the measurement of vibration, temperature, control oil, electricity, voltage and propeller speed. All the diagnostic data are collected by monitoring system of wind power and delivers it to the central monitoring and diagnostic systems of a wind farm.

Analiza ovih podataka se vrši etabliranim metodama. Na slici 2. je ilustrirana struktura nadzorno-dijagnostičkogsistema vjetroparka. Prema standardu EN 50160 se vrši ispitivanje kvaliteta električne energije generisane u vjetroelektrani i za te potrebe se ugrađuje namjenski proizvdene uređaj. Ovaj uređaj ima ugrađen akumulator - UPS (uređaj mjeri i 5 sati po nestanku napajanja električnom energijom). Elektroormar nadzorno-dijagnostičkog sistema vjetroelektrane je prikazan na slici 3.

Analysis of these data is carried out by established methods. In Figure 2. is illustrated structure of the monitoring system of wind farm. According to standard EN 50160 is done testing the quality of the electricity generated in wind power and for this purpose is incorporated dedicated manufactured device. This device has a built in battery - UPS (device measures and 5 hours after the disappearance of the power supply). Electrobox of monitoring system at wind power is shown in Figure 3.



Slika 2. *Struktura nadzorno-dijagnostičkog sistema vjetroparka [5]*
Figure 2. *Structure of the monitoring system of wind farm [5]*



Slika 3. *Elektroormar nadzorno-dijagnostičkog sistema vjetroelektrane [5]*
Figure 3. *Electrobox of monitoring system at wind power [5]*

Osim kontinuirane dijagnostike stanja neophodno je redovno vršiti periodične preglede vjetroelektrane tokom kojih se vrši: vizuelni pregled, preslušavanje šumova kako u audibilnom tako i u ultrazvučnom području i termografski pregled kamerom. Također se vrši mjerenje vibracija na sekundarnoj opremi vjetroelektrane.

Except continuous diagnostics it is necessary periodic inspections during which is made: visual examination, listening to the audibly noises and in the ultrasonic range and thermographic camera review. Also vibration measurements on the secondary equipment of wind power is done.

Zbog činjenice da najčešće dolazi do kvarova na reduktoru upravo dijagnostici reduktora treba posvetiti posebnu pažnju. Najčešće dolazi do oštećenja na ležajima reduktora, ali nisu rijetkost ni oštećenja na zupčanicima [7]. Na slici 3.4. je prikazano podizanje rezervnih dijelova neophodnih za popravak reduktora.

Due to the fact that most often leads to failure of the gearbox exactly to gearbox diagnostics should be given special attention. The most common defects in the gerabox are bearing defects, but not a rarity damage the gears [7]. Picture 3.4. is shown lifting spare parts necessary for the repair of the gear unit.

Slika 4. Podizanje rezervnih dijelova [4]
Figure 4. Lifting spare parts [4]

Detaljan opis oštećenje zuba zupčanika je dat standardom ISO 10825 Zupčanici - Habanje i oštećenje zuba zupčanika, te standardom AGMA 110-04 - Nomenklatura načina kvarova zubaca zupčanika, ali tehnička praksa je pokazala da se najčešće susreću slijedeći defekti na zupčanicima: habanje (trošenje), korozija, pregrijavanje, erozija, električna varničenja, površinski zamor materijala, lomljenje zuba, plastična deformacija, naboranost površine i pukotine [7]. Električna varničenja nastaju uslijed lutajućih električnih struja koje teku kroz zupčanike, te uslijed stranih elektromagnetnih polja koja dovode do indukovanja električne struje [8, 9, 10]. Varničenja se javljaju tokom dodira površina dva zupčanika koje uslijed spomenutih struja nemaju isti električni potencijal. Ovo je veoma česta pojava kod reduktora koji se nalaze u blizini električnih generatora i elektromotora velike snage. Pojava se sprječava ugradnjom ležaja sa električnom izolacijom ili uzemljivanjem vratila zupčanika preko grafitnih četkica [7, 11].

A detailed description of damage to the tooth is given by standard ISO 10825 Gears - Wear and damage to the tooth, and standards AGMA 110-04 - Nomenclature mode of failure of gear teeth, but technical practice has shown that the most frequently encountered the following defects in the gear: wear (wear) corrosion, overheating, erosion, electrical sparks, surface fatigue, breaking teeth, plastic deformation, surface wrinkles and cracks [7]. Electrical arcing resulting from stray electrical currents flowing through the gears, and as a result of foreign electromagnetic fields that lead to the induction of electric current [8, 9, 10]. Sparks occur during the contact surface two gears that due to the above mentioned currents have the same electrical potential. This is very common in gear, which are located near the electric generator and the electric motor of great power. The appearance is prevented by installing bearing with electrical insulation or grounding shaft gear via carbon brushes [7, 11].

4. ZAKLJUČAK

Primjenom savremenih metoda tehničke dijagnostike i nadzora stanja se mogu otkriti oštećenja sistema vjetroelektrane prije nego što dođe do kvara i na taj način se aktivnosti održavanja mogu provesti prije pojave kvara. Na ovaj način se značajno snižavaju troškovi održavanja i eksploatacije vjetroelektrane kroz izbjegavanje nastanka oštećenja i kvarova velikih razmjera i provođenje aktivnosti održavanja u onom momentu kada je najprikladnije. U ovome smislu, instaliranje nadzorno-dijagnostičkog sistema postaje uobičajeno rješenje pri gradnji vjetroelektrane.

4. CONCLUSION

Applying modern methods of technical diagnostics and condition monitoring it is possible to detect damage of the wind power system before failure occurs and thus the maintenance activities can be carried out before the onset of failure. In this way, are significantly lower maintenance costs and the exploitation of wind power through the avoidance of defects and failures of large-scale implementation and maintenance activities at the moment when it is most appropriate. In this sense, the installation of the monitoring system becomes a common solution in the construction of wind farms.

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