ENERGETIKA. 2022. T. 68. Nr. 1. P. 91–96

Vibration analysis for the detection of combined mechanical defects of a wind turbine

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Wind energy is a source of renewable energy derived from the kinetic force of the wind. It has experienced the greatest expansion due, above all, to its low impact on the environment and the gradual reduction of costs, which produce clean, competitive and economically viable energy. In order to ensure the stability of the energy produced, many studies are working to develop a reliable maintenance process based on new online diagnostic techniques, fast and accurate, optimised for wind turbine systems. For this, an experimental study was carried out on a wind system based on electric generators with the aim of contributing to the diagnosis and predictive detection of combined mechanical faults, where the configuration is complex because one fault can hide another. For this, it is imperative to associate each symptom with the appropriate method or methods in order to highlight it unambiguously to detect each defect at the appropriate time. Hence the interest in using more elaborate techniques in order to improve the procedures for detecting and analysing combined faults.

Keywords: wind turbine generator, vibration analysis, detection of combined defects, signal processing, discrete wavelet transforms (DWT)

THE THEORETICAL CONTEXT

Thanks to advances in technology, wind energy is produced by the force exerted by the wind on the blades of a propeller. It is clean energy, which does not emit any greenhouse gases, and its raw material, the wind, is available everywhere in the world and completely free [1].

Maintenance of a wind turbine is necessary for good energy production and extended life. Among the most reliable failure detection techniques for generators is the analysis of the measured vibration signals, a very powerful tool for establishing an in-depth diagnosis since we will seek to trace the origin of the defect, and note the effects, without necessarily having a history [2].

The main advantage of vibration analysis on wind turbines is the ability to detect failures before they lead to an unplanned shutdown of the wind system from the vibrations regularly collected on generators. In this work, piezoelectric accelerometers are fixed on well-defined parts of the generator which generates a voltage signal proportional to the acceleration, thus the analysis of the vibration signal presents the real information transmitted by the machine used to detect possible malfunctions and follows their evolution in order to plan maintenance actions [3–5].

Frequent signatures of mechanical failures

Regardless of the care taken in the construction and assembly of the various parts of the wind turbine system, it is not possible to make the axis of rotation coincide with the centre of gravity of each elementary section of the rotor, which characterises the unbalance fault.

As a result, the rotating shaft is subjected to centrifugal forces, which deform it. These forces result in vibrations linked to the rotation frequency f_r. The unbalances generally come from defects in the machining, and the assembly of the rotor with the wind turbine system. In operation, the rotors of the generators can then also deform under the effect of asymmetrical heating or following the rupture and departure of a piece of the rotor or a fin. In the case of degraded generator, an instantaneous evolution of the vibrations is observed [6]. For better exploitation of the signal obtained, the fast Fourier transform (FFT) is a reliable, precise and widely used technique for fault detection in the area of rotating machinery; then the evolution of the signature vibration is seen when monitoring the amplitude and phase of the vibration frequency $f_{\text{unbalance}}$ determined by the following equation:

$$f_{\text{unbalance}} = 1 \times f_r. \tag{1}$$

We also observe various vibratory phenomena following a poor tightening of the structure of the wind farm caused by poor fixing of the machines and the components of the system on their supports or massifs. If the assembly is defective or if there is play due to an unbalance or another defect, the sinusoidal vibratory movement will be transformed into a periodic movement all the richer in harmonics as the signal will be distorted. In this case, the analysis of the spectrum of the vibration signal reveals harmonics and sub-harmonics of the order of half of the rotation frequency and its multiples [7]:

$$f_{\text{loosening}} = ½ \times f_r. \tag{2}$$

Discrete wavelet transform approach (DWT)

Discrete Wavelet Transform (DWT) makes it possible to apply a multi-resolution analysis on a vibratory signal. It can be considered as a process of decomposition of an original signal through two complementary filters, high pass (H) and low pass (L): one represents the approximation, which corresponds to the low frequencies, and the other represents the detail which corresponds to the high frequencies of the signal S (s_1, s_2... s_n) thus the Daubechies wavelet is taken for calculating the approximation and detail coefficients in each level using the expression below:

$$s(t) = \sum_i \alpha_i^n \psi_i^n(t) +^{\to} \sum_{j=1}^{n} \sum_i \beta_i^j \vec{\varphi}_i^j(t) = a_n + d_n + \ldots +^{\to} d_1, \tag{3}$$

where:

- α, β are the scales and coefficients of the wavelet,
- ψ_n, ψ_j are respectively the decomposed function at level n and the wavelet function at level j,
- n is the level of decomposition, a_n is the approximation signal at level n, d_n is the signal detail at level n.

Several research works have demonstrated that DWT provides a powerful tool for fault diagnosis and monitoring as it provides time-frequency information about the signal [8–10].

MATERIALS AND METHODS

Figure 1 presents the experimental setup used to carry out our study on the detection of combined faults affecting the wind system based on a generator coupled to a variable speed direct current

Fig. 1. Experimental setup for combined fault detection

motor. Its kinetic energy is transmitted to the alternator and converted into electrical energy. The name plate details of the motor and generator taken are given in Table.

Table. **Machine details**

Machinery type	DC motor	AC generator
Manufacturer	Leroy-Somer	Leroy-Somer
Country	France	France
Power	3 kW	3 KVA
Voltage	220 V	220 V
Current	10 A	7.5 A
Speed	2400 rpm	2400 rpm

The analysis of the signature vibrations for the monitoring and the diagnosis of the generators consists of several main stages, namely, the acquisition of data, which consists of obtaining the samples of vibration at the time of the healthy and defective conditions implemented by the creation deliberate of a combined defect consisting of unbalance in the shaft, and a loosening defect in the alternator

Then the vibration signal is processed by MATLAB to test the algorithm, where it is necessary to transform the signals from the time domain into frequency or time-frequency. For this, several signal processing techniques have been used, such as fast Fourier transform (FFT) and DWT, so the last step is recognition of the fault affecting the wind systems.

RESULTS AND DISCUSSION

FFT approaches

Figure 2 presents the vibration signal in the frequency domain of the different conditions of the generator. We only observe that in the presence of

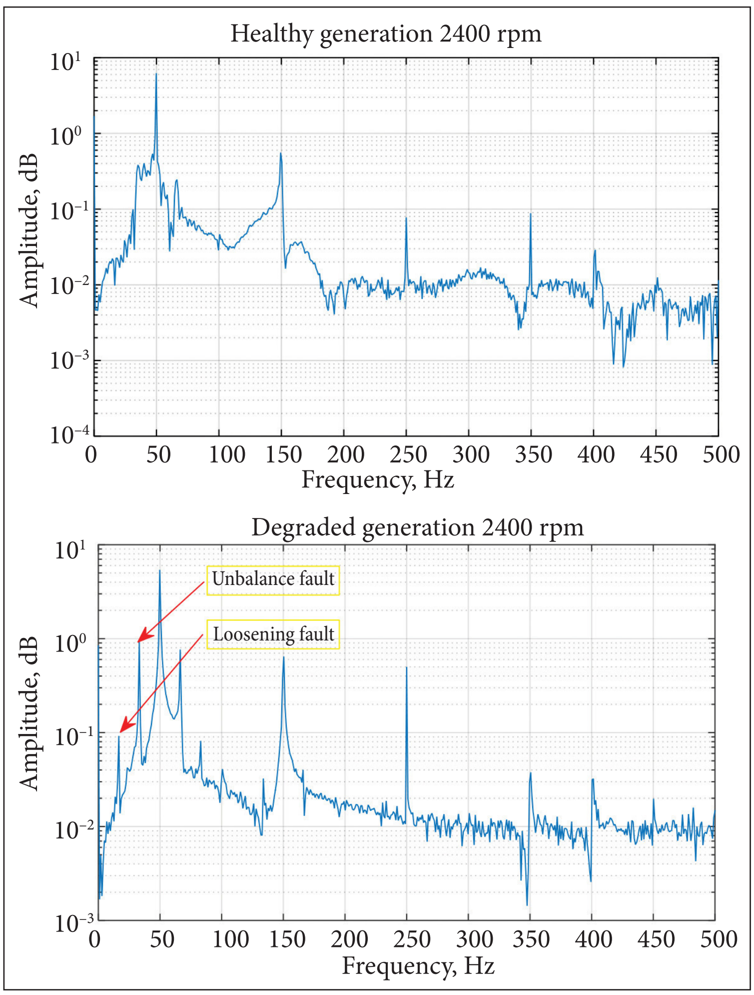

Fig. 2. Frequency domain signals of different generator conditions

combined defects, the FFT amplitudes are higher than in healthy condition. It can also be seen that there are two major peaks at the frequencies of 20 Hz and 40 Hz.

Discrete wavelet transform approaches

In this work, DWT was applied to process the vibration signals collected on the generator in the time-frequency domain. For this, six levels of signal decomposition were used. Figure 3 illustrates the decomposition of the vibration signal; we noticed a smoothing in the case of healthy generation.

Figure 4 presents the result of processing vibration signal by discrete wavelet transform (DWT) under the fault of rotor unbalance and loosening with a speed of 2400 rpm.

Contrary to the case of the healthy generator, we noticed clearly very different behaviours of the signals indicating the effects of the combined

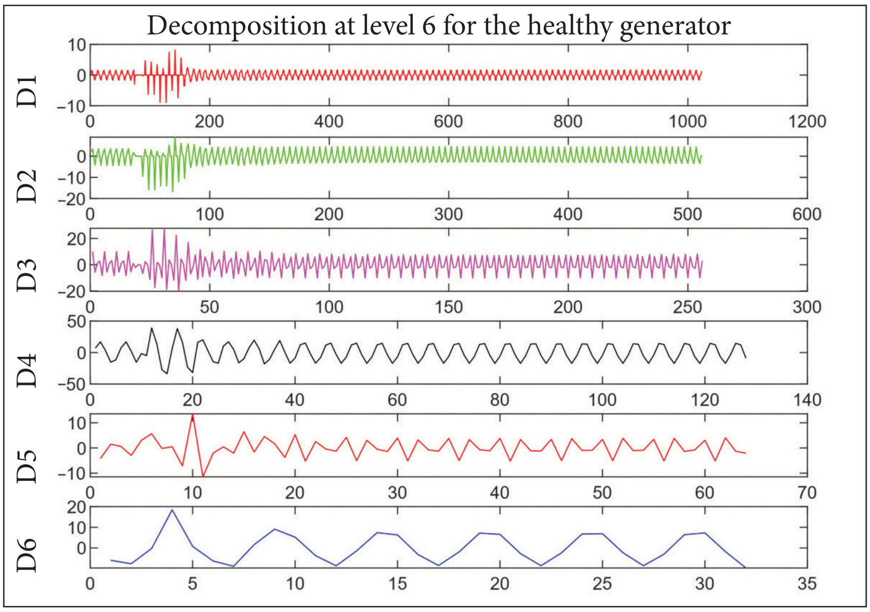

Fig. 3. Decomposition of the vibration signal of the healthy generator at speed of 2400 rpm

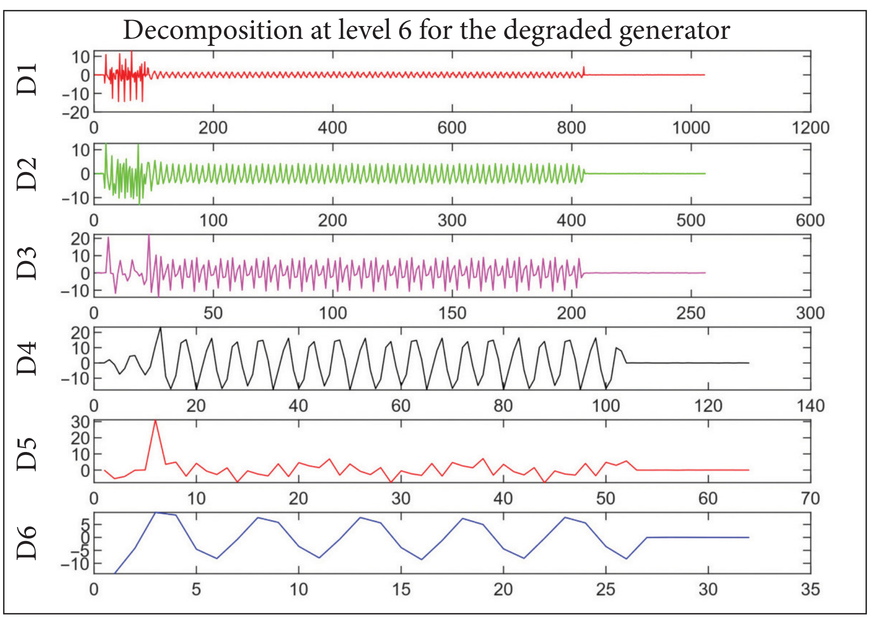

Fig. 4. Decomposition of the vibration signal of rotor unbalance and a loosening fault at speed of 2400 rpm

mechanical defects on the vibratory behaviour of the generator, translated by the appearance of oscillations in, d3 and d4 confirms the defective state.

CONCLUSIONS

This article presents the application of vibration analysis, FFT and DWT, to detect the combined mechanical fault affecting the wind turbine system.

During the presence of the combined defects, we can observe an overlap between the characteristic frequencies of the defect and other frequencies that poses a problem of ambiguity. The experimental results for the different conditions are presented. The detection of the combined defects was possible using the Fast Fourier Transform algorithms (FFT) analysis, and we found more information about the defect in the detail coefficients.

The specificity of this experimental research in real climatic conditions is the precision, the speed, and reliability of the diagnosis of the breakdowns via the vibratory technique. This will yield good results whatever the type or the operating conditions of the wind turbine system, which will allow us to plan preventive maintenance actions and reduce the operating costs of wind farms.

Received 30 May 2022
Accepted 14 November 2022

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VIBRACIJŲ ANALIZĖ, SKIRTA KOMBINUOTIEMS MECHANINIAMS DEFEKTAMS VĖJO TURBINOSE APTIKTI

Santrauka

Vėjo energija yra atsinaujinančios energijos, gaunamos iš vėjo kinetinės jėgos, šaltinis. Ji buvo labiausiai plėtojama dėl mažo poveikio aplinkai ir laipsniško sąnaudų mažinimo, todėl gaminama švari, konkurencinga ir ekonomiškai perspektyvi energija. Siekiant užtikrinti gaminamos energijos stabilumą, atliekama daugybė tyrimų kuriant patikimą techninės priežiūros procesą, pagrįstą naujais greitais ir tiksliais internetiniais diagnostikos metodais, optimizuotais vėjo turbinų sistemoms. Tam buvo atliktas eksperimentinis vėjo sistemos su elektros generatoriais tyrimas, kurio tikslas – padėti diagnozuoti ir aptikti kombinuotus mechaninius gedimus, kai konfigūracija yra sudėtinga, nes vienas gedimas gali paslėpti kitą. Todėl būtina kiekvienam požymiui pritaikyti atitinkamą metodą ar metodus, kad jis būtų aiškiai išskirtas ir kiekvienas defektas būtų aptiktas tinkamu laiku. Taigi, norint pagerinti kombinuotų gedimų aptikimo ir analizės procedūras, reikia naudoti sudėtingesnius metodus.

Raktažodžiai: vėjo turbinos generatorius, vibracijų analizė, kombinuotų defektų aptikimas, signalų apdorojimas, diskrečiųjų bangelių transformacijos (DWT)