Monitoring of the Wind Turbine Induction Generator with the Rotor Electrical Unbalance Fault

Bouhafs Lina and Salah Tamalouzt

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Lina Bouhafs[1]
[1]Laboratoire de Technologie Industrielle et de l'Information (LTII), Faculté de Technologie, Université de Bejaia, 06000 Bejaia, Algérie
lina.bouhafs@univ-bejaia.dz

Salah Tamalouzt[1]
[1]Laboratoire de Technologie Industrielle et de l'Information (LTII), Faculté de Technologie, Université de Bejaia, 06000 Bejaia, Algérie
salah.tamalouzt@univ-bejaia.dz

Abstract— **The field of the electricity production from renewable energy sources is in continuous progress, and wind systems on their part are following this trend. Similar to all industrial systems, wind turbines are frequently exposed to failures caused a damage affecting their proper functioning. In this context, this paper proposes an approach based on predictive maintenance using spectral analysis allow to detect the Rotor Electrical Unbalance (REU) fault in wind turbine induction generator. The proposed methodology has been validated on DFIG driving b WT for experimentally test rig with rotor fault levels under variable speed driving conditions. A comparative study is carried out for both healthy and faulty conditions generator operation. The results show that this approach is robust, efficient and useful.**

Keywords— Wind Turbine, WRIG, Rotor Electrical Unbalance, Fault indicator.

I. INTRODUCTION

The consumption of electricity keeps increasing; currently a large part of the energy consumed is fossil origin. However, these energies are exhaustible, polluting and their costs are instable. For this, the scientific researchers thought of using renewable energies in order to compensate for the increase in demand. to safeguard and protect the environment. Among the existing renewable energies, wind energy represents a fairly significant potential [1]. Its principal is based on the conversion of kinetic energy into mechanical energy then into electrical using a generator [2]. The DFIG remains widely used, because of the possibility of achieving high efficiencies in energy production.

However, the development of renewable energies has highlighted the problem of optimizing of the maintenance process [3]. The appearance of failures in wind turbine equipment causes the unavailability of this faulty equipment and an increase in intervention costs. currently, the forecast of failures in wind turbine system has become essential for improving reliability, this forecast is based on preventive maintenance which relies mainly on the study of the evolution of the level of degradation of the system using the analysis of frequency components [4].

WRIG is presently one the most commonly used in the in the onshore wind industry for variable speed applications [5]. WRIG have received a high level of research interest. So, it is essential to detect failures of this machine.

Recently, in [6], authors have used current and power frequency domain analysis to provide reliable indications of rotor unbalance for a wound rotor induction generator. Another method has used in [7] named continuous wavelet transform (CWT) for broken bar diagnosis in squirrel cage induction motors. Whilst, in [8] authors investigated automated approach of detection fault for wind turbine induction generators with rotor electrical asymmetries.

This work investigates the effect of Rotor Electrical Unbalance (REU) fault on the electricals and mechanical quantities of WRIG under steady state and variable speed conditions. The spectral and envelope analysis of the magnitudes measured signals described is based on experimental data. They are obtained from an experimental test rig based on an wound rotor induction machine, at Durham university in the aim to detect the influence of the level of the fault from monitoring the harmonic frequency components amplitudes of fault.

II. Proposed Approach

The proposed approach is based on spectral and envelope analysis, those are signals processing techniques often used for fault detection in electric machines. Both techniques use spectral analysis of electrical and mechanical signals [7] to evaluate the failure level in the induction machine according to the order of harmonic components and the amplitude of the spectrum [9].

The defect studied, which is Rotor Electrical Unbalance (REU), will generate an asymmetry that is in the case of a power supply by a symmetrical voltage system, will be at the origin of an inverse rotating magnetic field of frequency $-2sf_s$ in the rotor circuit. This will generate currents circulating in the stator circuit at frequencies:

$f = (1 \pm 2ns) f_s$. A demodulation by envelope analysis provides the exact frequency related to the fault $2nsf_s$.

In the aim of obtaining the spectrum $X(f)$ of $X(t)$, the Fast Fourier Transform (FFT) is applied [10]:

$$X(f) = \int_{-\infty}^{+\infty} e^{-2\pi ft} dt \qquad (1)$$

Where, the n, s and f_s are respectively the harmonic rank, the generator slip and the stator frequency.
The envelope analysis acts on the signal modulation $X(t)$ using the Hilbert Transform (HT), it is expressed as follows [10]:

$$Z(t) = A(t)e^{i\varphi(t)} \qquad (2)$$

Where, $A(t)$, $\varphi(t)$ are the instantaneous amplitude and phase respectively.

III. Generator Test Rig

In order to carry out an experimental study on the case of a REU fault than can occur on a WRIG, the University of Durham (England) accomplished experimental research on a test bench. This bench consists of an industrial doubly fed induction generator with: 4 poles, three-phases, 240V, 50Hz, 30kW, with a nominal rotor phase resistance of 0.066 Ω. It is driven by 40kW DC motor. A REU is simulated on this generator by introducing an external resistance R_d in a rotor phase winding of the WRIG as shown in the following figure 1 [11].

The measured time signals of the electrical and mechanical quantities are processed in the frequency domain using spectral analysis in order to extract the amplitudes of the harmonics of the modulated frequency created by the fault $(1 \pm 2ns) f_s$, then apply demodulation by envelope analysis to extract the frequency exact related to the default which is $2nsf_s$. Different unbalance fault levels: 0%, 150%, 225% and 300% of the rotor phase resistance have been chosen for the three training speeds (1530 rpm, 1560 rpm and 1590 rpm) in order to determine the severity of the fault, as given in Table 1.

Table 1. REU progressively introduced into one rotor phase circuit.

Additional Phase Resistance [Ω]	REU Level [%]
0.099	150
0.1485	225
0.198	300

IV. Exploitation of Experimental Results

The spectrum of current signals are analyzed to pursue the amplitude evolution of the harmonics related to the fault frequency $(1 \pm 2ns) f_s$ in the case of stator current modulation

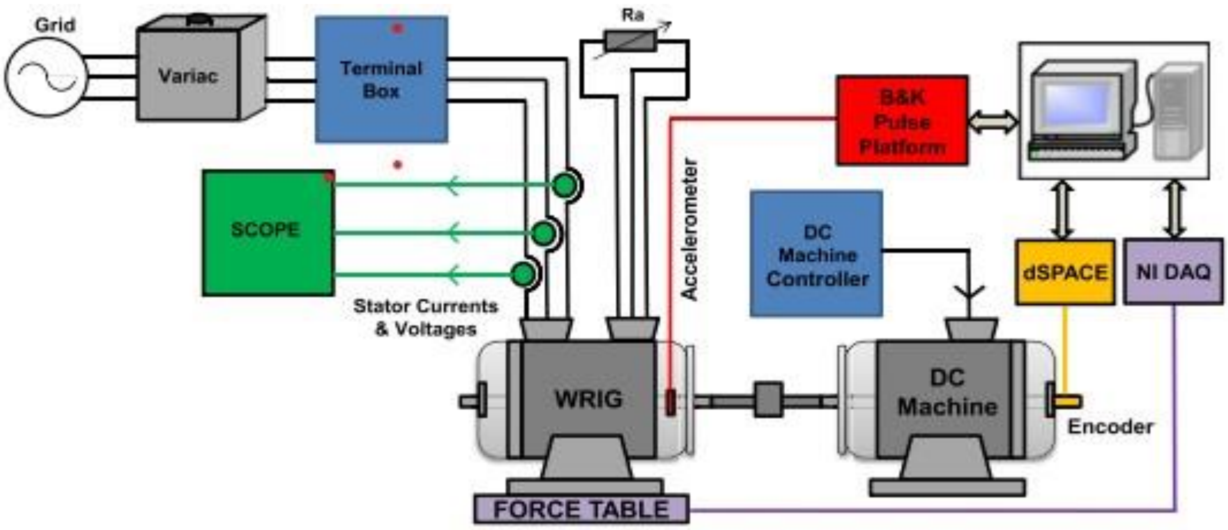

Figure 1. Experimental test rig and its instrumentation [11].

and *2ns* f_s in the case of demodulation.

Figure 2 show the evolution of the envelope spectrum amplitude at the fault frequency *2ns* f_s after the demodulation of the stator current signal in both events healthly and defect using the envelope analysis. where, more than the drive speed increase more than the envelope amplitude of stator current corresponding to the fault frequency increase.

Note that, the envelope amplitude of the stator current linked to the fault frequency is proportional to the percentage REU fault.

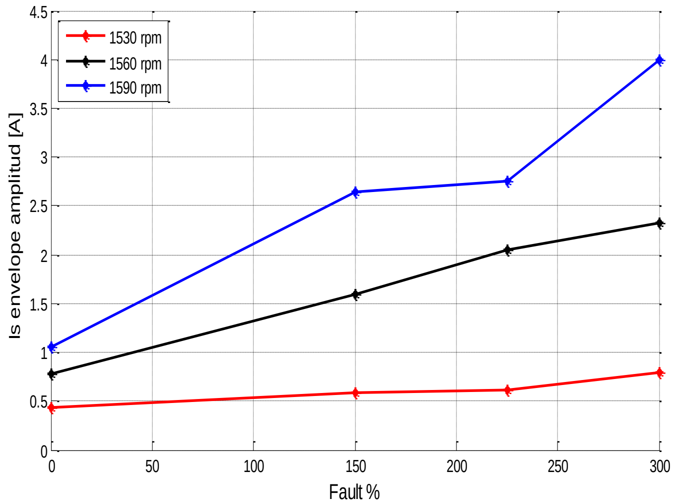

Figure 2. Amplitude evolution at the frequency characteristic of defect on the stator current envelope spectra for different severity and input speeds.

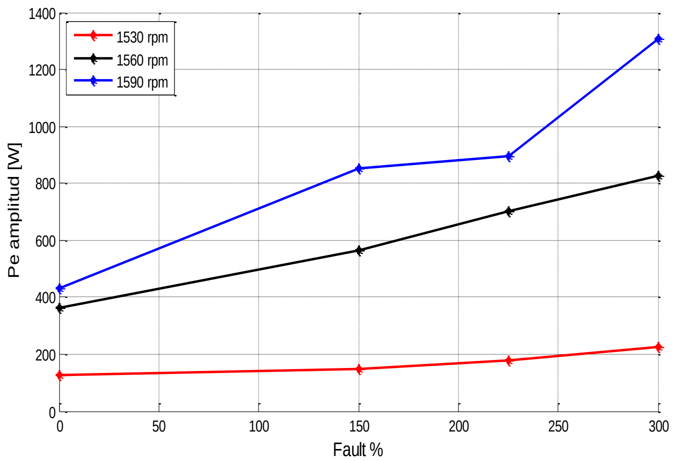

Figure 3. Amplitude evolution at the frequency characteristic of defect on the electrical power spectra for different severity and input speeds.

The spectrum of electrical power, rotational speed and electromagnetic torque signals are analyzed to stalk the amplitude evolution of the harmonics related to the fault frequency *2ns* f_s. Figures 3, 4 and 5 expose the evolution of the amplitudes at the fault frequency *2ns* f_s of electrical power, rotational speed and electromagnetic torque respectively using spectral analysis. Where, more than the drive speed increase more than the amplitudes of electrical and mechanical quantities corresponding to the fault frequency increase. Note that, the amplitudes of the electrical power, rotational speed and electromagnetic torque linked to the fault frequency is proportional to the percentage REU fault.

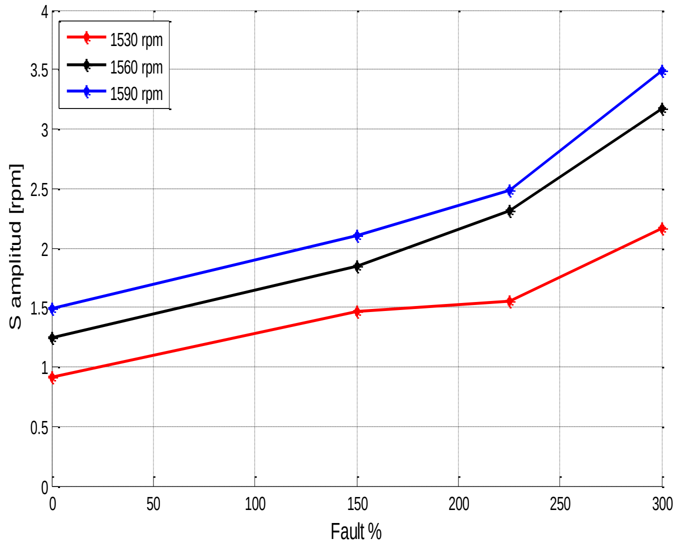

Figure 4. Amplitude evolution at the frequency characteristic of defect on the rotational speed spectra for different severity and input speeds

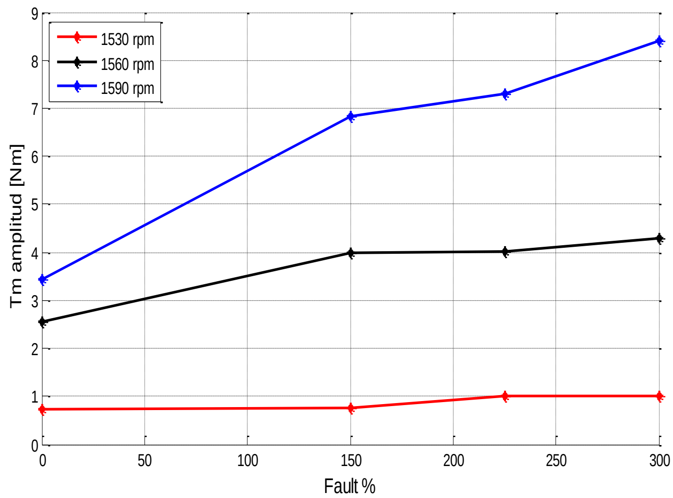

Figure 5. Amplitude evolution at the frequency characteristic of defect on the mechanical torque spectra for different severity and input speeds

V. CONCLUSION

This paper presents a study of electrical and mechanical signatures for WRIG Rotor Electrical Unbalance (REU) fault, a spectral and envelope analysis method is applied in order to track, extract information on the state of the system and study influence of defects for different fault severity and speed rotation on the frequency content from the measured signals. The results show the different amplitude at the frequency characteristic of defect on the current envelope spectra signatures and spectra of rotational speed, electrical power and electromagnetic torque signatures.

It is important to conclude that the results obtained showed the usefulness and efficiency of the proposed approach, where it is easy and quick to track and detect WRIG rotor failures.

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