World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:13, No:5, 2019

Vibration Signals of Small Vertical Axis Wind Turbines

Aqoul H. H. Alanezy, Ali M. Abdelsalam, Nouby M. Ghazaly

Abstract**—**In recent years, progress has been made in increasing the renewable energy share in the power sector particularly in the wind. The experimental study conducted in this paper aims to investigate the effects of number of blades and inflow wind speed on vibration signals of a vertical axis Savonius type wind turbine. The operation of the model of Savonius type wind turbine is conducted to compare two, three and four blades wind turbines to show vibration amplitudes related with wind speed. It is found that the increase of the number of blades leads to decrease of the vibration magnitude. Furthermore, inflow wind speed has reduced effect on the vibration level for higher number of blades.

Keywords**—**Savonius wind turbine, number of blades, vibration amplitude, renewable energy.

I. Introduction

In last few decades, the energy crisis strongly appears due to the huge increase in human needs. The renewable energy is a new source for world energy demand nowadays, especially the wind energy. The global energy consumption is expected to increase, with fast growth in population, by 56% through 2010 to 2040 [1]. In 2016, power generation from renewable energy accounted for approximately 62% of net additions to global power generation capacity [2]. Worldwide, the share of renewable energy will increase to address global climate change by 2030. Four popular markets are using renewable energy sources in increasing rate, which include; on-grid power generation, transport fuels, heating and cooling, and rural/off-grid power generation services [3]. Among renewables, wind power has emerged as the biggest renewable energy source in the world, whose potential when employed properly serves to provide the best power output.

The materials used for rotor blades contribute to a high-level of uncertainty in predicting the wind turbine health [4], [5]. The turbine rotors are subjected to fatigue, which leads to deformation of the blades through operation. Common deformations that occur include cracks, surface damage, structural discontinuity and delamination in composite blades [6], [7]. Accumulation of ice, dirt, and moisture, and manufacturing defects which include imbalance and aerodynamic asymmetry are all factors that induce deformations causing the degradation of the wind turbine rotor blades. Monitoring the structural health and condition of wind turbine blades therefore becomes a necessity to help to improve reliability [8]-[11].

The Savonius wind turbine rotor is subjected to significant vibrations during operation. This is due to the highly unsteady inflow conditions and the unbalance in the forces acting on the rotor (unsteady blade loads) at its different rotational angles. The effect of the time-varying relative velocity sensed by the turbine rotor plays a significant role on its aerodynamic behavior [12]. Additionally, this uneven turbine loading not only leads to reduction in the turbine performance, but also contribute to actual wind turbines wearing out faster.

Woude and Narasimhan [13] proposed vibration isolators at the top of the turbine tower, a feasible solution to reduce the dynamic response of wind turbine structures. The effect of the rotational speed on the power production and bearing dynamic vibration of a vertical axis wind turbine is investigated by Mabrouk et al. [14]. A tiny change in the dynamic vibration was observed, when changing the rotor rotational speed.

In the present work, it is proposed to investigate the dynamic vibration of Savonius wind turbine rotor, which is one of the most important factors to optimize their design, operation and maintenance costs and to verify their reliability. The vibration analysis includes the effect of inflow wind conditions and number of blades, on the dynamic vibration.

II. Test RIG and Measurement Instrumentation

Small model of the wind turbine is designed and constructed for the purpose of the experimental study. Three Savonius wind rotors are fabricated and used in the measurements, with two, three and four blades as shown in Fig. 1. The rotor diameter is the same for the three wind turbines of D=40 cm (D is the rotor diameter). The turbine blades are made from steel sheet of 2 mm thickness. The two end plates and the main shaft are used as support to fix the blades and form the wind turbine model. The wind turbine is built with overlap ratio of zero, aspect ratio of 1.0 and end plate of 1.1 D. Other components of the model are bearing, wheel, belt, and dynamo. A low speed wind tunnel (open circuit) available in the aerodynamic lab, faculty of Engineering, South Valley University, is used. An anemometer (LUFFT BI-AR -826 type), with range of 0.3~ 45 m/s and resolution of 0.1 m/s, is used to measure the velocity of the wind, while a photo-type tachometer (Type S119-LT) with range of 2.5~999.9 rpm and resolution of 0.1 rpm, is used to measure the rotor rotational speed. The measurements are conducted three times for each experiment. Different inflow wind speeds are used ranging from 3.8 to 12.8 m/s. A

Aqoul H. H. Alanezy is with the Mechanical Engineering Department, Faculty of Engineering, South Valley University, Qena-83521, Egypt.

Ali M. Abdelsalam is with the Mechanical Power Engineering Department, Faculty of Engineering, Menoufia University, Egypt and Menoufia High Institute for Engineering and Technology, Egypt.

Nouby M. Ghazaly is with the Mechanical Engineering Dept., Faculty of Engineering, South Valley University, Qena-83521, Egypt (corresponding author, e-mail: nouby.ghazaly@eng.svu.edu.eg).

piezoelectric accelerometer with sensitivity of 100 mV/g, is used to acquire the vibration signals. It is directly mounted over the base of the wind blades through a magnetic base. The piezoelectric accelerometer is an electromechanical transducer that generates an electrical output when subjected to mechanical shock or vibration. The accelerometer output signal is directly fed into a dual channel vibration analyzer and is stored as vibration signatures. Time domain signals are acquired at different speeds and different applied loads. The analyzer used for this wind turbine test rig is Brüel & Kjær Vibro-Acoustics Data Acquisition System (Type 3560-B) of five input channels, which is a compact data acquisition system for battery/DC powered operation. PULSE software is used to analyze the stored data, which is retrieved from the vibration analyzer through a charge amplifier and cable connected to the computer.

(a) Two blades (b) Three blades (c) Four blades

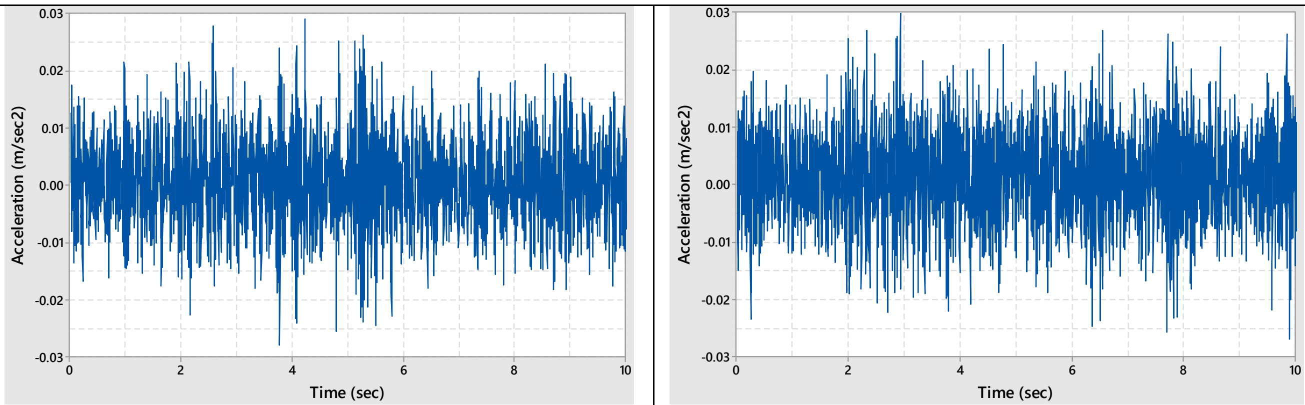
Fig. 1 Photograph of the three fabricated Savonius models

III. Results and Discussions

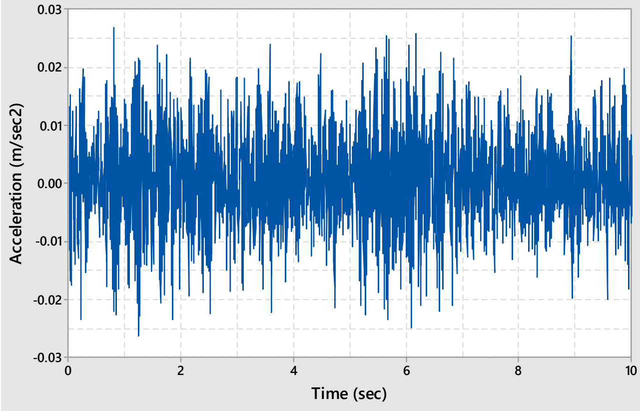
In this section, vibration signatures of wind turbine models, using the experimental facility, are presented. The experiments are conducted on three wind turbine rotors of 2, 3, and 4 blades. The wind turbine is fixed onto a fixture in front of the working section of the wind tunnel. The wind speed is manually controlled by a variable frequency motor, with a maximum measured wind speed of 12.8 m/s. Time domain signals are obtained for different wind speeds ranging from 3.8 m/s to 12.8 m/s, with tip speed ratio of 0.7~0.8. Furthermore, the root mean square values are calculated from time wavelength. Finally, comparison between all vibration magnitudes is reported.

Time domain signals of the vibration amplitude is presented in Fig. 3 for the two-bladed rotor at five wind speeds (3.8, 5.6, 8.2, 10.4, 12.8 m/s, respectively). The time domain signals display a regular waveform with peak in the amplitude less than ± 0.03 m/s^2. A slightly increase in the vibration amplitude is observed at higher wind speed. The effect of the inflow wind speed is more observable for the three-bladed rotor presented in Fig. 4. However, the increase of the blades has a significant effect in the reduction of the vibration level, as compared to two-bladed rotor. This may be due to the reduction in the cyclic torque variation accompanied by the increase of the number of wind turbine blades. Vibration signals of the four-bladed rotor are presented in Fig. 5. Similar trend to the three bladed-rotor rotor is observed at the different inflow wind speeds, however, with slightly higher amplitudes. The peak of the vibration amplitude is less than ± 0.03 m/s^2 for both the three and four bladed rotors.

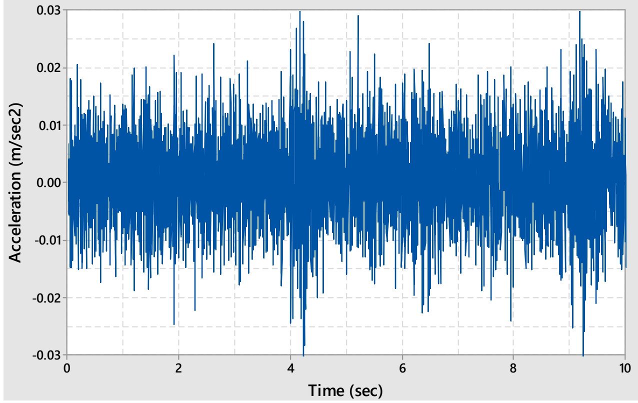
Fig. 2 Wind tunnel used for flow generation



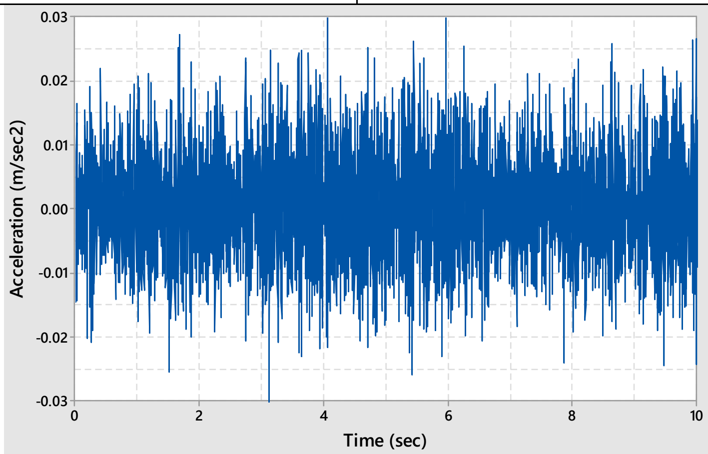
(a) Wind speed = 3.8 m/s (b) Wind speed = 5.6 m/s



(c) Wind speed = 8.2 m/s

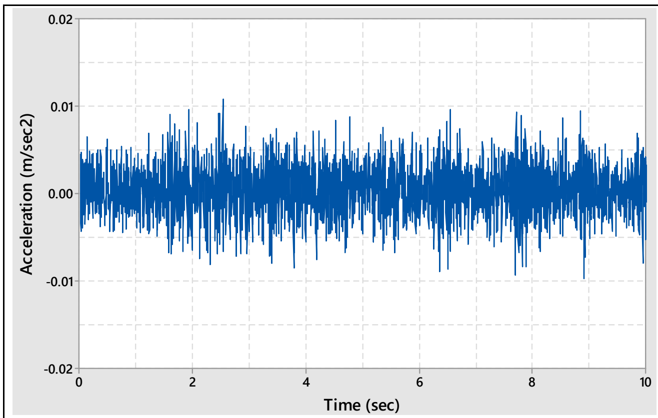


(d) Wind speed = 10.4 m/s

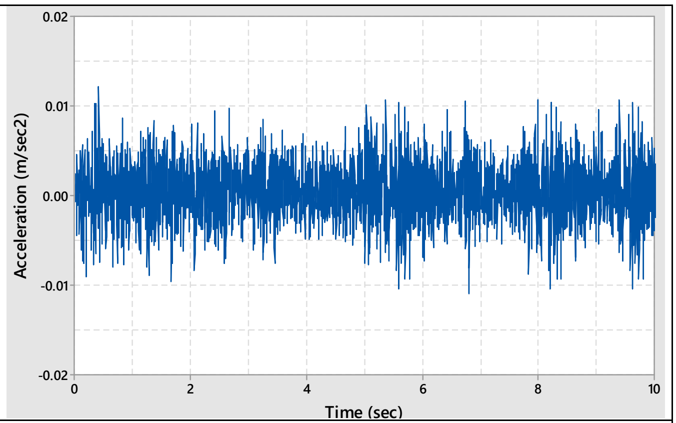


(e) Wind speed = 12.8 m/s

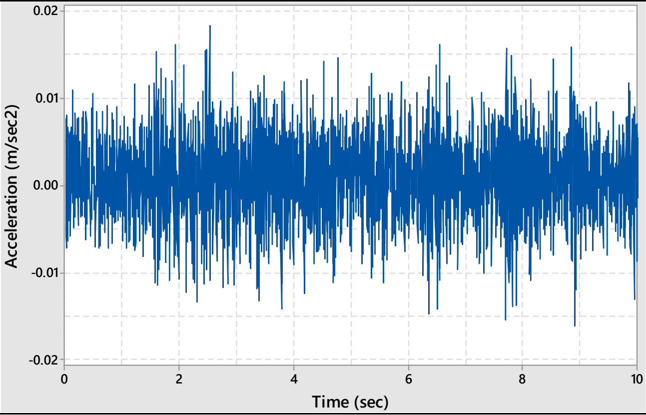
Fig. 3 Time domain of the two-bladed rotor at different wind speeds



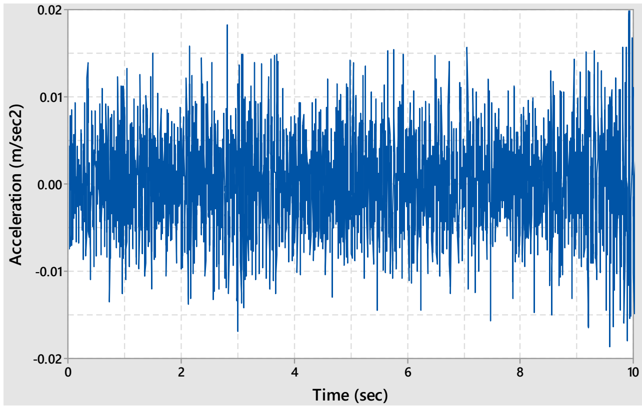
(a) Wind speed = 3.8 m/s



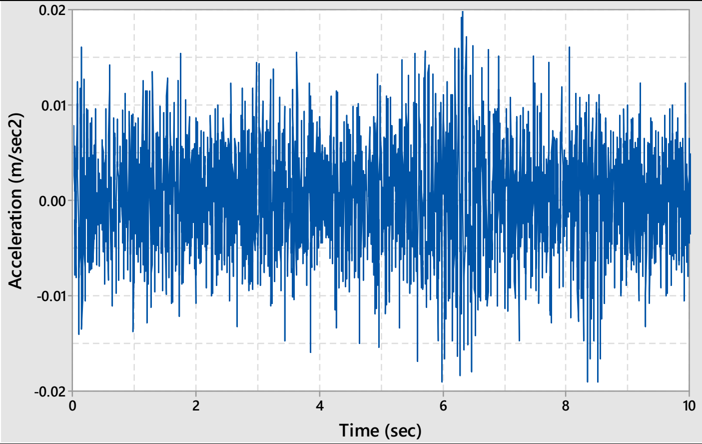
(b) Wind speed = 5.6 m/s



(c) Wind speed = 8.2 m/s

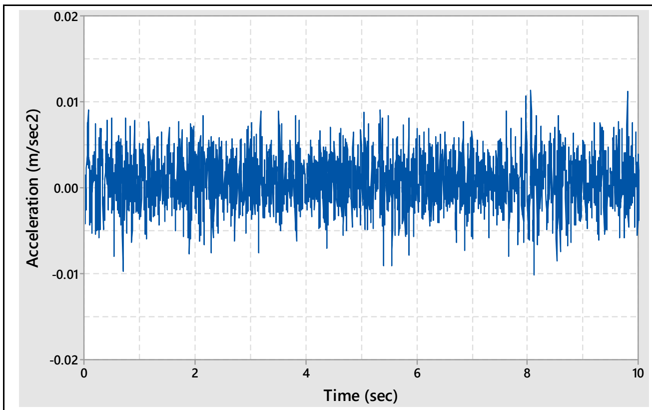


(d) Wind speed = 10.4 m/s

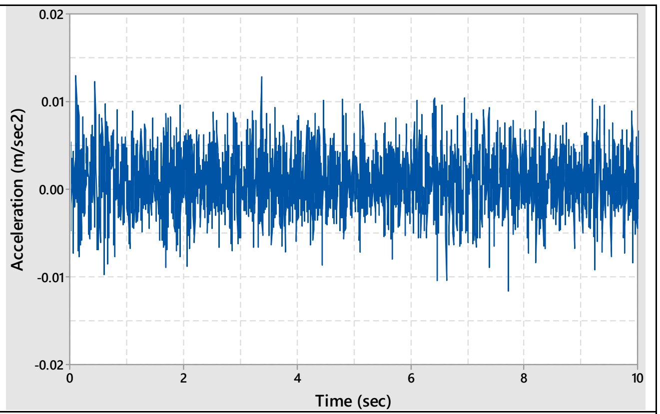


(e) Wind speed = 12.8 m/s

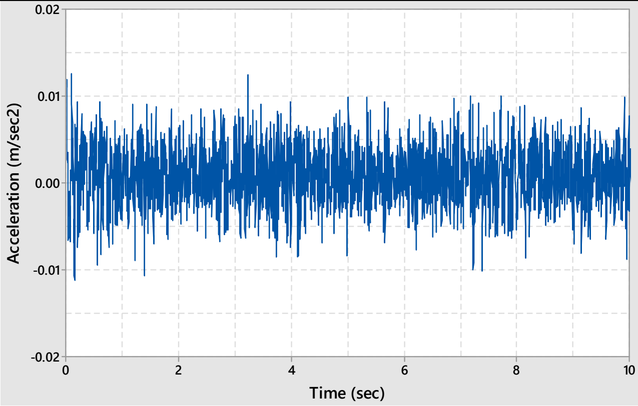
Fig. 4 Time domain of the three-bladed rotor at different wind speeds



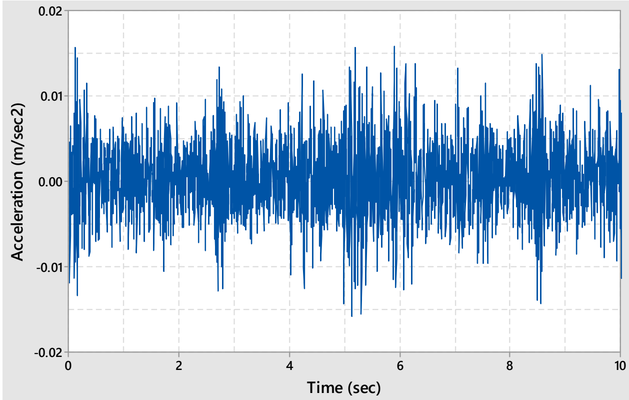
(a) Wind speed = 3.8 m/s



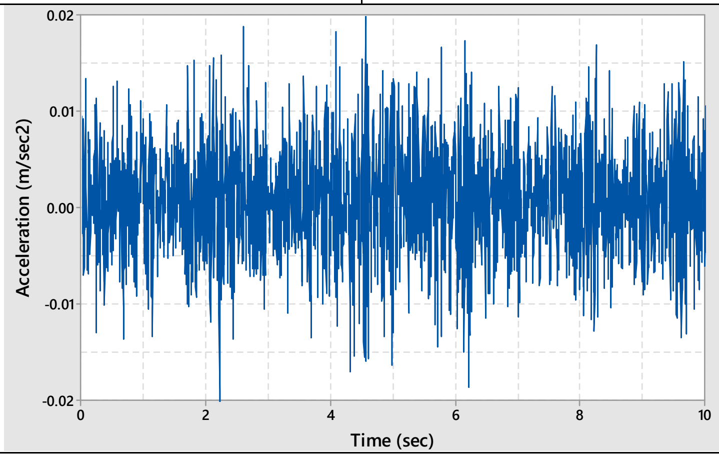
(b) Wind speed = 5.6 m/s



(c) Wind speed = 8.2 m/s



(d) Wind speed = 10.4 m/s



(e) Wind speed = 10.8 m/s

Fig. 5 Time domain of the four-bladed rotor at different wind speeds

Vibration magnitude can be represented by the root mean square (RMS) value, which is used for the comparison between the three models of two, three and four blades. It serves as an indicator for average amplitude of frequency analysis signals. RMS can also be regarded as a damage index. The RMS is defined as:

$$RMS = \sqrt{\frac{1}{N_s}\sum_{i=1}^{N_s} x_i^2} \quad (1)$$

where, N_s is the number of samples, and x_i is the sample amplitude (acceleration)

Fig. 7 presents the RMS of the vibrations for the three rotors, at different wind speeds ranging from 3.8 m/s to 12.8 m/s. It is shown that the vibration level of the wind turbine increases with the increase in the incoming wind speed for the three tested rotors. The rate of increase in the turbine vibration with wind speed is higher for the two-bladed rotor. Furthermore, significant reduction in the vibration amplitude is achieved for the three-bladed rotor, compared to the two-bladed rotor. Further increase in the number of blades to four has less effect on the vibration level reduction.

The power coefficient is a measure used to evaluate the wind turbine performance. It is the ratio of the mechanical power generated by the rotor to the incoming wind power available through the projected area of the wind turbine. The performance of the three tested rotors is presented in Fig. 7, at inflow wind speed of 10.4 m/s. It is observed that the peak of the power coefficient Cp_{max}=0.136 is achieved for the three-bladed rotor. Increasing the number of blades more than three has a negative effect on the rotor output power. Hence, three-bladed rotor achieves highest performance along with significant reduction in vibration level.

IV. Conclusions

This paper presents experimental tests which are carried out on several sets of wind turbine blades. Initially, rotor with two blades is fixed in the test rig and signals are recorded using data acquisition system to establish the base-line behavior of vibration signals. The two-bladed rotor is then replaced by three and four bladed rotors, and the vibration signals are recorded for each case separately, under the same inlet conditions. Time domain analysis and root-mean-square are employed to identify different vibration magnitudes of the Savonius wind turbine. It is concluded from the experimental results that, the vibration level decreases significantly with the increase of the number of blades, while it increases with the increase in the inflow wind speed. The three-bladed rotor has the highest power coefficient with significantly reduced ibration levels, compared to two-bladed rotor.

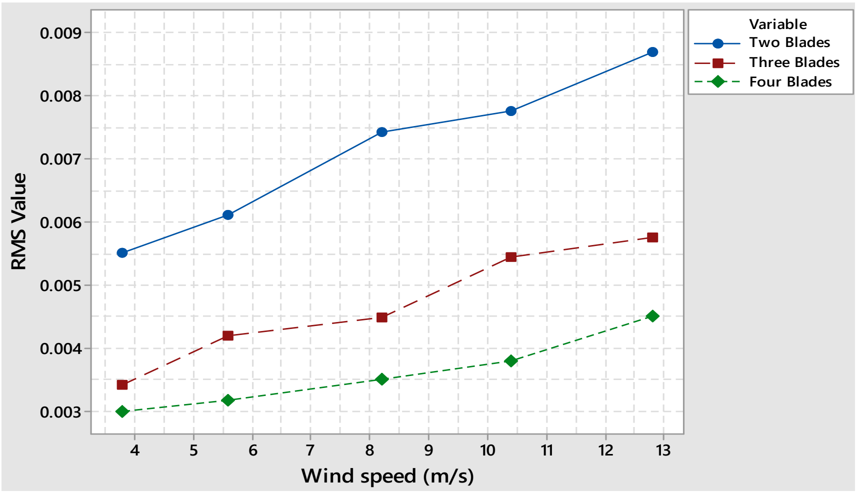


Fig. 6 Effect of number of blades on vibration RMS at different wind speeds

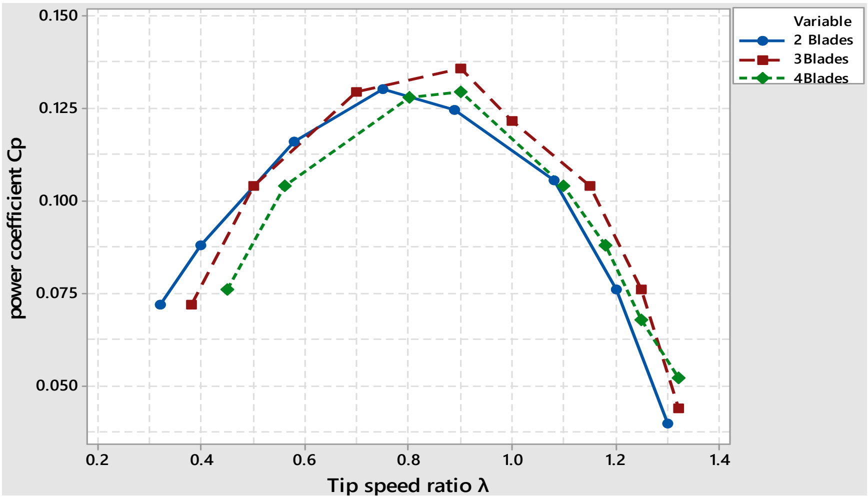


Fig. 7 Power coefficient versus tip speed ratio λ for the three tested rotors

REFERENCES

[1] A. Ghoshal, M. J. Sundaresan, M. J. Schulz, and P. F. Pai, “Structural health monitoring techniques for wind turbine blades”, J. Wind Eng. Ind. Aerodyn., vol. 85, no. 3, pp. 309–324, 2000.

[2] Renewables 2017 Global Status Report, REN21. Paris, 2017.

[3] F. B. Sørensen, E. Jørgensen, P. C. Debel, M. F. Jensen, M. H. Jensen, K. T. Jacobsen, and M. K. Halling, “Improved design of large wind turbine blade of fibre composites based on studies of scale effects (Phase 1)", Summary Report (Risø-R-1390(EN)), Denmark, 2004.

[4] M. J. Sundaresan, M. J. Schulz, and A. Ghoshal, “Structural health monitoring static test of a wind turbine blade", Subcontract Report NREL/SR-500-28719, Colorado, USA, 2002.

[5] F. B. Sørensen, L. Lading, P. Sendrup, M. McGugan, P. C. Debel, J. D. O. Kristensen, G. Larsen, A. M. Hansen, J. Rheinlander, J. Rusborg, and D. J. Vestergaard, “Fundamentals for remote structural health monitoring of wind turbine blades", a pre-project Risø-R-1336(EN), Riso-R-1336(EN) Report, Denmark, 2002.

[6] A. Staino, and B. Basu, "Dynamics and control of vibrations in wind turbines with variable rotor speed", Engineering Structures, pp. 58-67, 2013.

[7] T. Irvine, "An introduction to shock & vibration response spectra", 2002, Available: https://info.mide.com/hubfs/eBooks/ebook-tom-irvine-shock-vibration-response-spectra.pdf 2002 09/03/2019.

[8] O. T. Bulut, "Non-linear vibrations of a rotating beam", Journal of sound and vibration, pp. 314-335, 2009.

[9] J.-H. Park, "Linear vibration analysis of a rotating wind turbine blade", Current applied physics, pp. 332-334, 2009.

[10] O. O. Ajayi, "The Potential for Wind Energy in Nigeria", Wind Engineering, pp. 303-312, 2010.

[11] P. Guo, and D. Infield, "Wind turbine tower vibration modelling and monitoring by the non-linear state estimation technique", Energies, pp. 5280-5293, 2012.

[12] C. Strangfeld, H. Müller-Vahl, C. N. Nayeri, C. O. Paschereit, and D. Greenblatt, "Airfoil in a high amplitude oscillating stream", J. Fluid Mech., vol. 793, pp. 79-108, 2016.

[13] C. V. Woude, S. Narasimhan, "A study on vibration isolation for wind turbine structures", Engineering Structures, vol. 60, pp. 223–234, 2014.

[14] I. B. Mabrouk, A. ElHami, L. Walha, B. Zghal, M. Haddar, "Dynamic vibrations in wind energy systems: Application to vertical axis wind turbine", Mechanical systems and Signal Processing, vol. 85, pp. 396–414, 2017.