Comprehensive Review of the Effects of Vibrations on Wind Turbine During Energy Generation Operation, Its Structural Challenges and Way Forward

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Comprehensive Review of the Effects of Vibrations on Wind Turbine During Energy Generation Operation, Its Structural Challenges and Way Forward

I. P. Okokpujie, E. T. Akinlabi, N. E. Udoye, and K. Okokpujie

Abstract The effects of vibration cannot be overemphasized when it comes to generating energy via wind turbine. Vibration is one of the major challenges faced by the wind turbine, due to the complexity of the structure and the area of installation. This research work focuses on a compressive review of the effects of vibration occurrence on wind turbine during energy generation operations and its economical challenges'. Therefore, this research paper has reviewed various aspects of vibration effects in horizontal wind turbine such as the blades region, tower structure, nacelles compartment, and condition monitoring along with fault diagnosis models. The result from this study has shown that, there are needs to develop and implement a good reliability model, fatigue assessment process, and a well-developed monitoring model for wind turbine during operation. When these things are properly put in place, it will help to reduce unwanted vibration occurrence, eliminate unexpected failure of the wind turbine in operations, and hence sustainable energy generation from wind turbine.

Keywords Vibration · Reliability for sustainability · Wind turbine blade · Wind turbine tower

1 Introduction

Vibration will occur when a structure is dislodged from its location of stable equilibrium. The structure will generally return to its stable position under the activity of

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re-establishing powers. The towel holds the displacement of the forward and backward movement of the wind turbine over the issue of its balance [1]. A structure is combinations of element designed to act together to achieve a goal. A stationary element is one whose operation makes its yielding time depends just on the contribution at a time while a dynamic element yield depends on previous information [2]. A static and dynamic framework is two great types of the frameworks that consist on all components and one powerful component, respectively [3]. The issues of vibration in wind turbine can seriously affect the energy preservation; due to the fact that, the vibration will help to expand the system which will lead to loss of energy generated from the wind turbine during operations and after.

Wang et al. [4] recommended a damage identification and determination technique for wind blades based on the unique elements property and mode shape distinction arch data. It likewise gives a minimal effort and effective, nondestructive instrument for wind turbine blade condition examination. Notwithstanding mix with modular investigation strategies, the auxiliary strain field information likewise assumes an essential job in identifying the harm existing in the breeze turbine system, including the sharp edges and tower, on the grounds that the slight difference in basic physical properties may prompt the rearrangement of basic strain. As a rule, the strain contrast between nearby strain sensors can be considered as a list of the nearness of a split and utilized as an attainable system to accomplish remote exhaustion harm recognition for OWT towers. Nonetheless, the achievement predominantly relies upon the sensible game plan of strain sensors around the pinnacle and the expectation of extraordinary wind conditions [5, 6].

To discover the abilities of different tension sensors made with fiber Bragg grating (FBG), optical backscatter reflectometer (OBR), and typical strain checks in harm identification, an example acknowledgment system utilizing progressive nonlinear essential segment investigation (h-NLPCA) in light of the strain field estimation was depicted to recognize harm amid the affirmation trial of the blades [7, 8]. In light of the trial results, the FBGs have more points of interest over the strain measures. FBGs are reasonable for being inserted into the compound materials straightforwardly amid the operational procedure of OWTs and observing progressively inside changes in strain, which strain measures reinforced onto the surface cannot accomplish. What is more, the FBGs have a more drawn out life in administration well-being observing and harm discovery frameworks dependent on strain estimations for seaward wind ranches. From there on, Downey contemplated a crossover thick sensor arranges comprising of meager film sensors and FBGs and proposed an information-driven harm recognition and limitation technique for wind turbine sharp edges. This procedure uses the blunder between the evaluated strain maps and measures strains to characterize harm location which includes and applies a novel strategy for reviewing vast quantities of sensors without the requirement for complex model-driven methodologies by intertwining sensor information into a solitary harm discovery highlight [9]. The wind turbine also has a lot of electrical activities, which will need electrical models to establish in the remote areas [10]. The challenge faced by researchers in the field of wind turbine is very enormous, due to the fact that wind turbine development and operations are very complex. There is great need to bridge the gap between researcher, teachers, and the industry in order to provide solutions to these challenges [11–13].

However, this paper aimed at carrying out a compressive review on the effects of vibrations occurrences during operation of wind turbine. This study will further assist to eliminate and to reduce vibration occurrence on wind turbine.

2 Review of the Effects of Vibrations on Horizontal Wind Turbine During Operations

Escaler and Mebarki [14] study vibration analysis on the wind turbine. The vibrations were experimentally determined in precise positions applying the same type of sensors for the period of six-month covering the whole range of working situations. The data obtained were preliminary certified to eliminate outliers based on the hypothetical energy curves. The influential frequency points in the blade, gearbox, and generator on vibrations were discovered and identified established on averaged energy spectra. The amplitudes of the points induced by some environmental effects were compared in various positions. There were observations on the broadband vibration on the wind speed reliance during this study. Finally, the authors detected a fault case in the change of vibration enforce by a damage in the gearbox, as shown in Fig. 1.

According to Hossain et al. [15], said that wind turbine is greatly subjected to various fault on the mechanical system during operation which can be tired to the issues of vibrations occurrences. Figure 2 shows the analysis of various failure rates in wind turbine components, and Fig. 3 shows all the basic components of wind turbine fully in operations. This analysis is in line with the observation from Okokpujie et al.

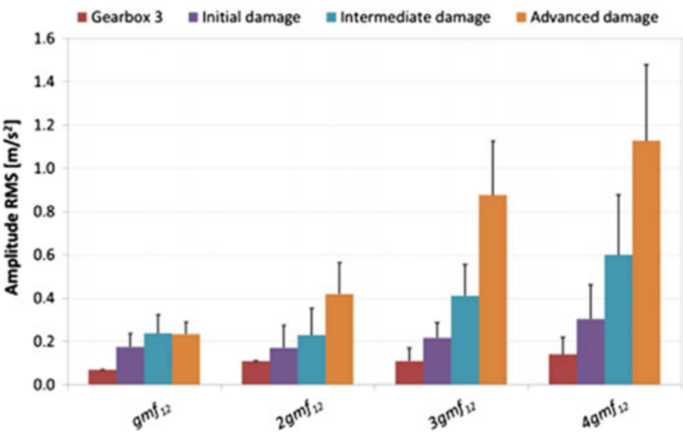

Fig. 1 Evaluation between the reference means vibration (RMS) amplitude on the gear mesh frequency (GMF) and the harmonics (gearbox 3) showing the various levels of damage [14]

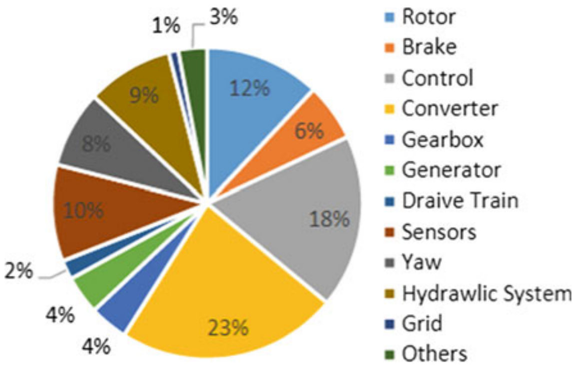

Fig. 2 Rate of failure of the various component of the wind turbine [17]

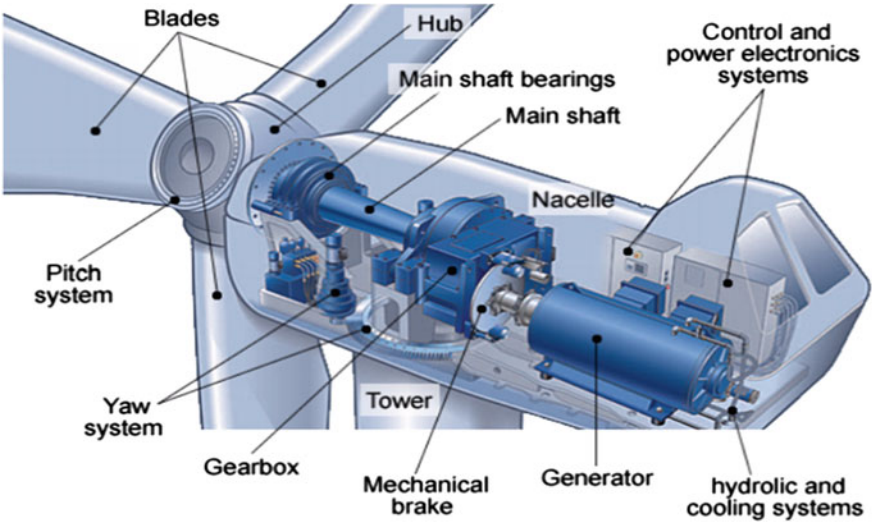

Fig. 3 Distinctive utility-scale wind turbine basic mechanisms [18]

[16] which in their design work shows that vibration is one of the major challenges faced by a wind turbine, due to its mechanical structures.

2.1 Effects of Vibration on a Horizontal Axis Wind Turbine Blades

A lot of researchers have carried out an experimental study on the causes of the occurrence of sound on the wind turbine during operation. The authors concluded that the flowing air passing through the blades (i.e., aerodynamic shape) has effects on the turbine blades, which causes the vibration in the form of sound waves [19, 20]. One of the most significant aspects of the impact is the atmospheric turbulence striking the blades of the wind turbine during operation (i.e., the influx of the sound turbulence) and also the air rolling at the surface of the blades (trailing edge).

- Turbulence at the back or trailing edge of blades is created on the grounds that the wind stream at the blades surface forms into a tempestuous layer. The recurrence with the most noteworthy (capable of being heard) sound vitality content is generally in the scope of a couple of hundred Hz (hertz) up to around 1000–2000 Hz. At the edge tips, conditions are to some degree diverse because of air streaming towards the tip; however, this tip commotion is fundamentally the same as trailing edge clamor and more often than not recognized as a significant separate source.
- Inflow disturbance is produced on the grounds that the blades slice through fierce whirlpools that are available in the inflowing air (wind). This sound has a most extreme sound dimension at around 10 Hz.
- Thickness sound outcomes from the relocation of air by moving blades and is irrelevant for sound creation when the wind streams easily around the blades. Notwithstanding, quick changes in powers on the blades result in sideways developments of the sharp edge and sound heartbeats in the infrasound district. This prompts the normal wind turbine sound "signature" of sound dimension tops at frequencies between around 1–10 Hz. These pinnacles cannot be heard, yet can be found in estimations.

Tartibu et al. [19] presented a work of flap-wise, edgewise, and torsional basic occurrences of variable length blades that have been acknowledged. Subsequently, initiators can guarantee that characteristic vibration won't be near the recurrence of the fundamental excitation powers so as to maintain a strategic distance from reverberation. The fixed part and moveable bit of the variable length of blades are approximately a strong bar which can be slide in and out. Ten unique setups of the variable length blades, speaking to ten distinct places of the moveable part, are examined. A MATLAB program was created to anticipate distinctive frequencies. Thus, three-dimensional models of the variable length of blades have been created in the limited component program Unigraphics NX5. Simultaneousness among MATLAB and Unigraphics NX5 results has been found for the recurrence scope of intrigue. This implies that a viable technique to figure regular frequencies of a variable length of blades was generated.

The investigation of the impact of blades length on regular frequencies shown in Fig. 4 has appeared with expanding blades length, the normal frequencies decrease. This is most likely on the grounds that the blades turn out to be increasingly adaptable as its length increases. The excitation loads are moved in the interim 0.5–30 Hz.

Kumar et al. [21] the primary goal of this examination research is to present another material for wind turbine blades. Aluminum 2024 is chosen for the reasonableness examination. Limited component method or finite element analysis is a strategy utilized for the investigation of complex articles and geometries. Wind power or wind vitality is considered as a spotless wellspring of vitality which delivers no

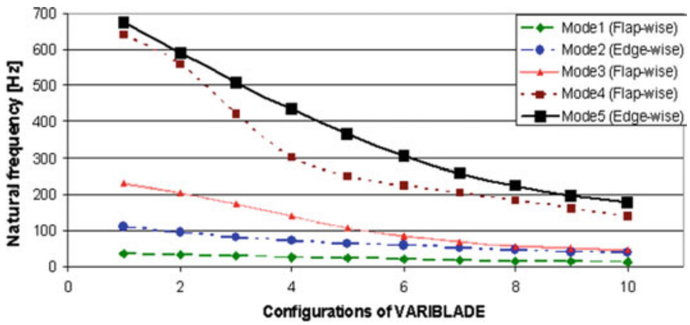

Fig. 4 Effects of vibration natural frequency on configurations of variable blade [19]

ecological damage amid activity. The complete wind control age capability of India at a tallness of 50 m is 50,000 MW. As of late Indian Government has concentrated on this inexhaustible well-spring of energy. The primary part of this exploration is to recognize vibration frequencies and regular vibration methods of the Aluminum 2024 wind turbine blades. Wind turbine blades configuration is a perplexing technique. For the plan of wind turbine blades, solid edge programming is utilized and the model is imported in ANSYS 14.0 for modular investigation. For the reasonableness examination of Aluminum 2024, the basic and modal investigation has been done. The significances of the investigation are utilized to confirm a structure's readiness for use.

The examination results were confirmed with experimental result accessible in writing. With the expectation of free vibration examination of Aluminum 2024, wind turbine blades modular investigation utilizing ANSYS 14.0 was directed. Through our examination, we have discovered the disfigurements, stresses, and normal frequencies for initial six modes state of Aluminum 2024 wind turbine blades as presented in Fig. 5a. The examination results were checked with an experimental result that has been done. Andrew [22] examined the on and seaward wind turbines. As indicated by the author's test examination, the most extreme happens at tip as shown in Fig. 5b, and the loads are extremely less for Aluminum lightweight materials.

Taware et al. [23] composite materials have different confounded attributes as indicated by the utilization of the constituent materials and limited conditions. In this manner, it is hard to examine the properties of composite materials, and the composite materials are outstanding by their superb blend of high auxiliary firmness and low weight. Their anisotropy enables the designer to tailor the material so as to accomplish the ideal execution necessities. Accordingly, it is important to create devices that enable the architect to get plans, thinking about the auxiliary prerequisites and utilitarian attributes, for effective utilization of composite materials in building applications, the dynamic conduct (e.g., normal frequencies) ought to be known. This paper centered around the conduct of little wind turbine blade fabricated from composite materials. Two little wind turbine blades are produced from the glass fiber reinforced plastic (GFRP) and GFRP with steel wire work support.

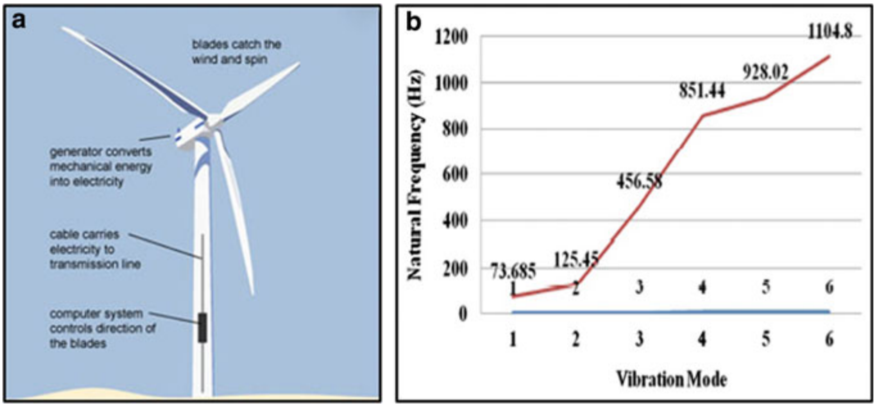

Fig. 5 **a** Wind turbine illustration **b** vibration mode v/s expected frequency of the AL 2024 alloy blade used for the development of the wind turbine [22]

Finite element analysis (FEA) was completed by utilizing the component programming ANSYS 16.0. From FEA, hypothetical normal frequencies and mode shapes of blades made from the GFRP and GFRP with steel wire work support were acquired. Test free vibration trial of produced blades was done to locate the useful regular vibration frequencies and mode shapes at last, the outcomes acquired from the FEA and exploratory test for the blade fabricated from GFRP and GFRP with steel wire work were carried out, and the result shows that the GFRP with steel wire has great performance when compared with the GFRP.

2.2 *Effects of Vibration on a Horizontal Wind Turbine Tower*

The horizontal wind turbine tower shoulders an essential role in supporting the energy-producing part, for example, blades, hubs, and nacelles. The tower opposes the wind loads produced by the rotational wind blades [23] and hence, to verify the auxiliary security and dependability of the wind on the turbine tower, which can be harmed by unanticipated solid winds, through basic wellbeing checking. For this situation, Kim et al. [24] contemplate the dynamic attributes of a wind turbine tower display with and without harm at different areas were examined. However, indoor trials with the end goal of damages evaluation and auxiliary well-being observing the test result were contrasted and those acquired utilizing limited component demonstrate as appeared in Fig. 6 which demonstrates the variety of the recurrence and the conceivable damages. The authors likewise proposed a fitting damage identification system for the wind turbine tower, recurrence base damage location strategies were connected, and the outcome was checked by utilizing the numerical model of a 3 MW airstream turbine tower working in Jeju Island, Korea. The comparison of the indoor experiment and the finite element (FE) model are shown in Fig. 7. The

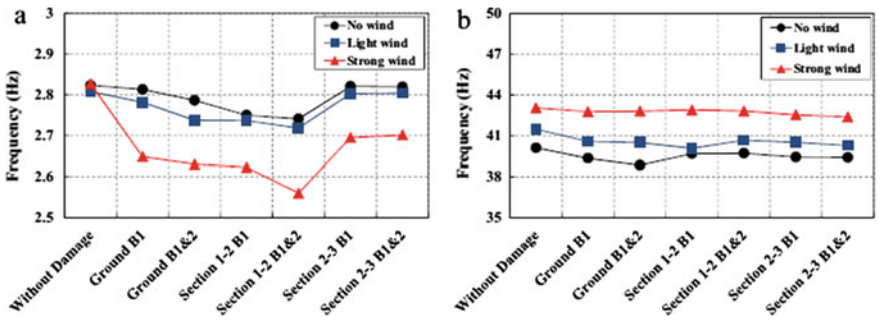

Fig. 6 The analysis of the natural frequency variations with the damage situations of mode 1 and 2 [24]

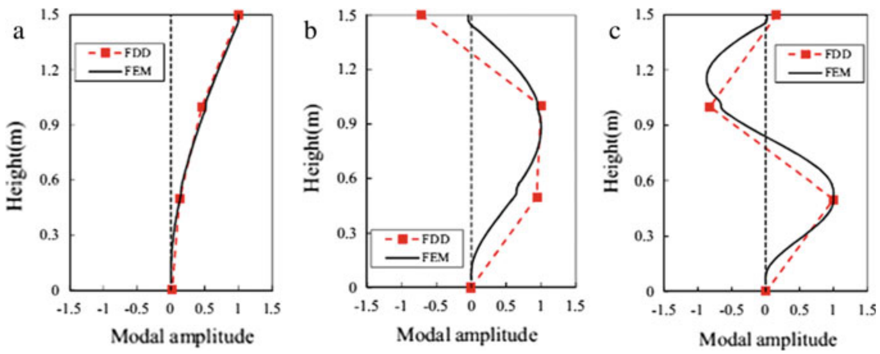

Fig. 7 Analysis of the first three shapes of the mode **a** mode 1, **b** mode 2, **c** mode 3 for the FE and FDD [24]

frequency-domain decomposition (FDD) technique was used for the identification of the natural frequency, damping ratio, and shape mode, which are the parameters of the modal; the result gotten from this technique were also analyzed and compared with FE model, and Table 1 gives the analysis of the first model.

Figure 8 shows a wind turbine tower that was greatly affected by the vibration during operation, as a result of unwanted vibration occurrences on the earth cross, coupled with other fault that was not detected before the failure of the wind turbine occurs.

Table 1 FE model and FDD comparisons result [24]

Wind environment	Model	FE	FDD	Percentage difference (%)
Light	1	2.7332	2.8224	3.2
676 (rpm)	2	54.669	40.103	26.6
	3	170.785	100.185	41.3

Fig. 8 Failed wind turbine tower during operation

Guo and Infield [25] carried out the examination of the early disappointment of key segments, for example, the tower, drive train, and rotor of a substantial wind turbine. In their work, the authors used the nonlinear state estimation technique (NSET) to determine the turbine tower vibration impact, giving a comprehension of the tower vibration dynamic attributes, and the fundamental elements affecting it. The created tower vibration demonstration involves two unique aspects: (1) a sub-display utilized for underneath evaluated wind speed and (2) for above-assessed wind speed as shown in Fig. 9. Supervisory control and data acquisition system (SCADA) applied the data obtained from a wind turbine from March to April 2006 to develop the model, and the model was validated with series of experimental analysis. The NSET method has been effectively demonstrated in this research work, which proves to be accurate and very efficient for tower vibration analysis. The tower vibration model developed was further used for spotting out blades angle irregularity, which is a common error that needed to be fixed in other to hence the performance of the wind turbine and help to eliminate or reduce fatigue damages. This study has demonstrated that condition checking will be improved greatly, if data from vibration signals is accompanied by the investigation of other applicable SCADA information, for example, energy performance analysis, rotor loads, and the wind speed.

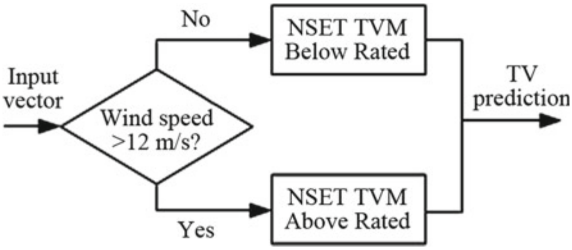

Fig. 9 NSET modeling and prediction for tower vibration [25]

Tibaldi et al. [26] used the aeroelastic simulation process to examined wind turbine vibration base on both frequency and time domain. Three different aspects were investigated such as there are need for a defined model in the operation of a close echoing condition; the presence of resonances identification and load estimation at low turbulence intensity during the wind turbine operation is very significant; and the external excitation response of the wind turbine. In the first phase of the analysis, the frequency and the damping of the aeroelastic modes were analyzed with three wind turbine models. Two different turbulent intensities were used to investigate the same models on fatigue loads to analyze the response from the wind turbine.

The second phase, to determine the modes that can be excited, an external force is introduced to the wind turbine model, and therefore, the minimal excitation frequency will be presented during operation The study shows that substantial sideways blade vibrations can happen on modern wind turbines even if the aeroelastic damping of the sideways modes is optimistic. When working close to echoing environments, slight changes in the modeling can take a large nuance on the vibration level. The sideways vibrations are less noticeable in great turbulent environments. Applying simulations with low-level turbulence concentration will hence the performance to avoid a redesign. Additionally, this is subjected to the external forces. The analysis is done using aeroelastic models equivalent to a 1.5 MW class wind turbine with insignificant differences in blade materials.

Pacheco et al. [27] work on a different amplitudes of sound time series through simulation of noise adding band-limit to the time series acceleration measured from the original experiment, and Fig. 10a, c presents the various wind speed, spectra time series of the acceleration connected at the tower tip, that is already polluted with sound. From the study at low wind speed, the adopted sound levels are higher to measure the accelerations; however, when the wind speed gets to 2.5 m/s, the acceleration goes beyond the first two sound levels. The acceleration signal is used to overcome the sound levels for a high wind speed.

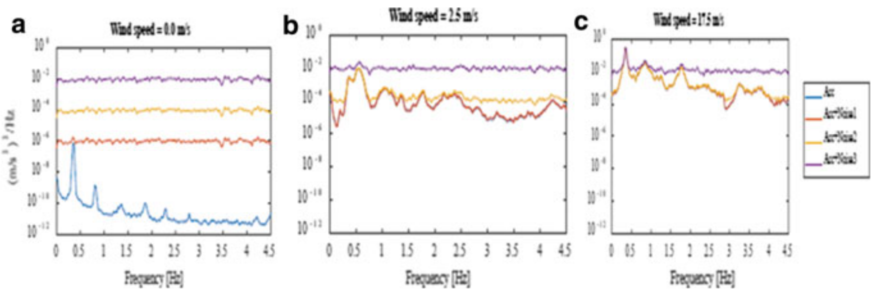

Fig. 10 Energy spectra of distinctive acceleration time series obtained at the tower tip for varying wind speeds: the real signal = Acc and original signal polluted with various sound levels = Acc + Noise1, 2, 3. For wind speeds of 2.5 and 17.5 m/s, the spectra connector with “Acc” and “Acc + Noise1” is practically equivalent

3 Structural Challenges Face During Operation of the Wind Turbine

The issues of reliability during wind turbine operations: The location of the 80% of wind turbine is in a remote area, which has great effects on the rate of maintenance that can be carried out. This will significantly affect the issue of reliability, because reliability is very significant in every machine that is design to rotate during operations (Fig. 11).

From this review study, it can be observed that over 80–90% of failure of the wind turbine (WT) is caused by vibration; due to the location area that most WTs are installed, this may be as a result from continuous contact of two metal objects during rotation. This continuous contact will affect the life circle of the turbine in operation [28].

The offshore wind turbine structure is always faced by various cyclic excitations, which includes the rotor operation, wind, currents, and waves, which can lead to high risks of damage, failure, and fatigue to the structures. This is one of the major challenges of the wind turbine on the offshore cite; however, the study of fatigue assessment needs to be strategically implemented in all operation of the offshore wind turbine; from several authors, wind turbine needs a well-developed standard model that can help control and monitor the wind turbine during operation, that will enable operator to detect any occurrences that will lead to vibration [29–32]. These continuous challenges of vibration occurrence in wind energy generation will affect the economic structure of the wind turbine development and its implementations, which will lead to high rate of manufacturing and maintainers cost.

Fig. 11 **a** Design of the planetary gear in the nacelles compartment. **b** The failure of the wind turbine (WT) during operation

4 Way Forward for Eliminating Vibration Frequency from a Wind Turbine During Operations

- One of the major things that must be done for a sustainable power generation from a wind turbine is to develop a standard model that can serve as a guild for wind turbine operations
- There is a need to carry out research on how to establish a good reliability and fatigue assessment process for wind turbine operations
- The basic areas for installations of wind turbine should be put into consideration during the design, in order to avoid the occurrence of vibrations which will lead to great loss of the wind turbine
- Material selection is one of the major factors in developing wind turbine, in the area of the blades, tower, and nacelles compartment. Most wind turbine blade is made with glass fiber; from this study, the authors observed that there are need to manufacture new materials which will serve as a better alternative to glass fiber, for example, the composite material of aluminum alloy mixed with glass fiber and a little percentage of titanium, for strength, flexibility, and firmness of the materials.

When vibration in the wind turbine is greatly reduced to the minimum, it will help to reduce the cost of maintainers during operation and after operations, which will serve as economic benefit to the manufacturers, industrial company (that makes use of the wind turbine for commercial purposes) and the nations at large.

5 Conclusions

Wind energy generation is one of the major and reliable sources of electricity generation, that is, environmental friendly. Through the application of wind turbine in energy generation, a lot of countries and continents have employed it which has a major source of supply in their home and official places in the world today; however, this promising system is currently facing a lot of challenges of vibration occurrence due to its complex nature. This paper has presented a comprehensive review on the effects of vibration on the wind turbine blades, tower, and nacelles compartment and also highlighted some major factors that cause the issues of the unwanted vibration occurrences and the possible ways to eliminate or reduce vibration during operation of a wind turbine.

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