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Condition monitoring and vibration analysis of asynchronous generator of the wind turbine at high uncertain windy regions in India

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ABSTRACT

Wind energy is abundant in nature and it is important to harvest the maximum quantity of energy from it. The loss of energy conversion occurs in a wind turbine is due to improper maintenance and lag of condition monitoring system. If the wind turbine is controlled appropriately then the efficiency will be eventually increased. The ultimate aim of condition monitoring and vibration analysis is to offer an advance warning of failures or performance issues in the generator of the wind turbine. The previous researches on vibration in wind turbine mainly concentrate on the vibration response of wind turbine blades and structure only based on their dynamic properties but this paper takes into account dynamic properties, operating conditions, and environmental impact to study the condition monitoring of the 250 kW wind turbine generator. The generator of the wind turbine is attached with the gearbox in a cantilever position and the chances of vibration and failure are high, once the generator is caught failure then it is beside difficult to de-erect it. Therefore, consistency in the running of the generator is very much significant. The replacement of the generator is too expensive and it ingests a large time. Hence the condition monitoring and vibration analysis of the 4 pole, asynchronous generator of the wind turbine is studied in this paper to diminish the key failure and augment the power generation of the 250 kW constant pitch and constant speed wind turbine in Muppandal, India.

1. Introduction

Wind energy is a clean and green energy resource. The extraction of power from wind is technically feasible and economically viable due to environmental concerns over burning fossil fuels to generate electricity. The technical development and the reliability studies craft opportunities for wind energy sources to be harnessed at the distribution level [1–3]. The catastrophic failure of the wind turbine system is studied through three stages for instance whole wind turbine (WT), sub-assembly, and parts [4]. The Markov Analysis implemented by drawing the different system state transition diagram to determine the failure states of discrete components of wind turbine with respect to time, it was witnessed that the failures depend only on the present state but it is independent of the past failure history [5]. The failure rate of wind turbine generators in indirect drive wind turbines is higher than the direct-drive wind turbines because in the direct drive, the multi-pole low speed generator is directly coupled with the rotor and the vibration is sizably truncated. The WTs have recurrent failure modes that are consistent with each other because of the common failure mechanisms behind them [6]. A realistic approach for machine condition assessment and continuous monitoring is obligatory to diminish failure [7]. The state-of-the-art wind turbines are slender and elastic construction structures that are tremendously susceptible to vibration [8]. The efficiency of a grid-connected wind-driven electricity generation system (WECS) has been done and the genetic algorithm and BAT algorithm were used for optimization. It is observed that to compare with GA, BAT algorithm congregates quicker and was able to categorize an enhanced optimal solution for analyzing dynamic characteristics [9,10].

The mathematical modeling affords clear information over the governing equation of vibration for the system [11]. From this study it is experimental proved that vibration is the important problem in WT which has its major influence in mechanical component failure. The components of WT reveals different vibration

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spectrum depending upon their dynamic characteristics [12]. So the WT has to be continuously monitored by SCADA for preventive maintenance. The prerequisite of vibration analyzer is inevitable for incessant vibration measurement in WT components at diverse load and operating conditions. The most important objective of vibration measurement is to find the root cause of vibration in individual components [13,14]. The main objective of this paper is to study the failure pattern experienced in the generator of a wind turbine at different load and operating conditions.

This paper aims to investigate the vibration characteristics of the 250 kW wind turbine generator at its different wind speeds and to record the vibration parameters such as velocity, acceleration, and displacement within the frequency range of 1–20 kHz. This paper also aims to identify key errors that distress the performance and to detect the faults of wind turbine generators to enhance the health of the generator (Fig. 1)

It is observed in the site that, the failure of the generator is mainly occurred due to stochastic fluctuations of the wind. In the main pass, the wind velocity and direction of the wind are frequently changed. If the wind velocity is suddenly increased above 6 m/s then the generator G2 (low Speed) will be switch over to the high-speed generator G1. Similarly, if the wind velocity decreases then G1 to G2 a switchover will be occurred [15]. If the switchover occurred continuously then the chances of failure will leads. The Unsymmetrical air gap between the stator and rotor, frequent brush failure, and control system failure articulates the failure in the generator (Fig. 2)

The wind turbine generator has one end fixed with a gearbox and another end free just like a cantilever structure. The fixed end will have Vertical reaction and Moment and Zero deflection and the free end will have deflection only.

The beams with one end fixed and the other free is known cantilever beam. The bending moment and deflection is expressed from the fundamental theory of bending using Euler Bernoulli beam theory as given Eq. (1), [16]

$$M = EI\frac{\delta^2 y}{\delta x^2} \tag{1}$$

Where,
E = Young's Modulus
I = moment of inertia.
The equation of motion for a uniform beam element is given as

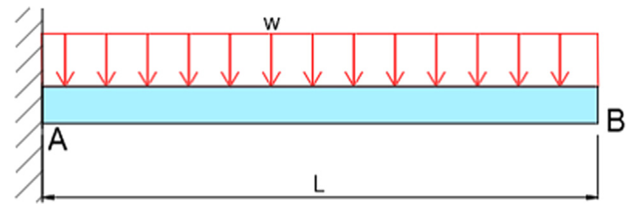

Fig. 2. Cantilever beam with UDL.

$$\frac{EI}{\rho A}\frac{\delta^4 y}{\delta x^4} + \frac{\delta^2 y}{\delta t^2} = 0 \tag{2}$$

Where,
ρ = Density of the mass
A = Area of the beam cross-section
The unbounded number of natural-frequencies for corresponding is given by

$$\omega = (\beta i L)^2\sqrt{\frac{EI}{\rho A L^4}} \tag{3}$$

Where
Table: 3 represents the values of first five roots of the equation. These values are constant and are utilized in finding out the natural frequencies (Table 1)

The moment of inertia is calculated as,

$$I = \frac{bd^3}{12} \tag{4}$$

The vibration produced by the different wind turbine components is measured by placing the accelerometer at the respective points. The accelerometer is mounted on the wind turbine components with the help of a magnetic mount or other mounting provisions. The accelerometer cable is connected with a vibration meter. The vibration meter is interfaced with the data acquisition system with the help of the data card. The readings are recorded and the respective graphs at different operating conditions are got (Table 2)

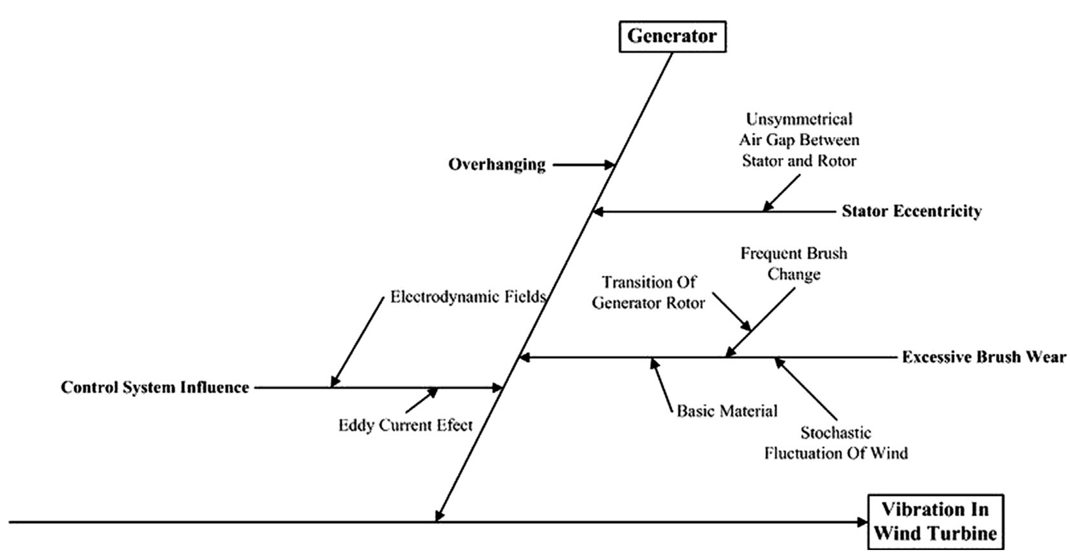

Fig. 1. Cause and effect diagram of the asynchronous generator wind turbine.

Table 1
Value of the Roots.

Sl. No	Roots (i)	βi l
1	first root	1.8751
2	second root	4.6940
3	third root	7.8547
4	fourth root	10.9955
5	fifth root	14.1371

Table 2
Pre-processing Data (250 KW).

Feature	Description
Data acquisition	Location : 250 KW, 30 m above ground Muppandal, TamilNadu Sampling rate: 2 min Signal length: 200
Preprocessing	Normalization: Signal mean is removed and standard deviation is normalized
Operating conditions	Wind speed:6.8 m/s Average rotor speed:31 rpm Average generator speed:1120 rpm

2. Experimental procedure

Wind speed and rotor rpm at the time of analysis are noted down from the control panel at the base of the tower. The connection between the accelerometer and the vibration meter is made and a suitable probe is attached with the accelerometer. By placing the probe at different parts of the wind turbine, vibration signatures are recorded by using suitable data acquisition systems. Likewise, the different modes are selected in the vibration meter and vibration parameters like velocity, acceleration, and displacement are recorded for a particular time interval in the generator. The graphical representation of recorded values is generated by the software for easy validation of the result.

The vibration meter with Piezoelectric accelerometer Transducer, 4 digit display with a velocity range 0.01–40.00 cm/s, acceleration range 0.1–400.0 m/s2,displacement range 0.001–4.000 mm and frequency range 1–20 kHz is used for measurement (Fig. 3)

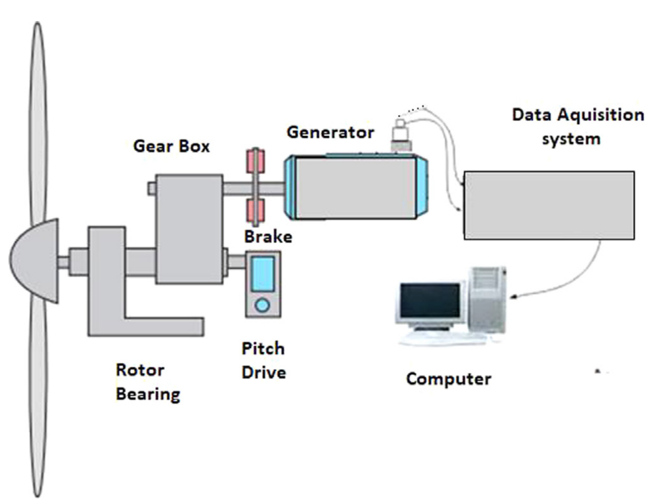

Fig. 3. Experimental setup.

3. Condition monitoring and vibration analysis of 250 kW wind turbine with the single asynchronous generator

Following Constraints are considered for vibration analysis of the generator [15]

a. The vibration of systems at wind speed exceeding 3.5 m/s (normal speed) i.e., wind speed > 3.5 m/s., rated wind speed 11 m/s
b. By applying the sudden brake.
c. During yaw mechanism activation.
d. Transition state from generator G2(750 rpm-40KW) to G1 (1500 rpm) and
e. Cut in wind.

In order to study dynamic characteristics and vibration response of generator system of wind turbine mathematical modeling of generator by taking into account different parameters like the moment of inertia, torsional damp coefficient, torsional stiffness coefficient and the mass of the system is done [17] (Tables 3 and 4)

4. Result and discussion

Some of the WT generator defects detected using vibration analyses are Unbalance, Bent shaft, Eccentricity, Misalignment, Looseness, Bearing defects, Electrical faults, Oil whip/whirl Hydraulic and aerodynamic forces.

The Vibration characteristic curve for the generator of a 250 kW wind turbine is shown in the graphs. From Fig. 4, the rise in velocity at harmonic intervals depicts the soft foot problem. Velocity is an important parameter that is extensively used for equipment diagnosis and is carefully related to the fatigue failure of equipment structures [18]

In Fig. 4, the velocity of 84 mm/s is obtained as its maximum and minimum of 4.5 mm/s. This velocity measurement graph indicated that problems like unbalance, misalignment, looseness, harmonics, and many other issues in the wind turbine generator. The velocity value of 84 mm/s occurred frequently that is two times within 2 min and it is exceedingly intolerable.

From Fig. 5, the steep rise at the initial stage of analysis delineates the cantilever effect. Acceleration data is very important to detect the faults with bearings, gear mesh, or electrical winding issues in the high-frequency ranges. The highest acceleration of 900 m/s2 indicated that there is a problem in the generator bearing that huge noise was obtained in the gearbox side generator bearing. The looseness in the bearing creates shaft imbalance that leads to harmonics.

The displacement measurements are recorded in three directions axial, horizontal, and vertical with respect to the velocity and it is used to detect the fault in low-frequency ranges. The varied fluctuation in displacement at a moderate level is due to varied operating speed due to fluctuating wind. Fig. 6 indicates that the maximum deflection of 4.5 mm is obtained once in 160 s which not acceptable.

Table 3
Specification of 250 kW Wind Turbine.

Type	Horizontal Axis, Upwind Turbine
Generator	Type :4 pole, asynchronous Rated power : 250 KW Frequency :50 Hz Rotational speed : 1500 rpm

Table 4
Generator observations.

S no	Component	Velocity (mm/s)		Acceleration (m/s2)		Displacement (mm)	
Frequency range :		Max	Min	Max	Min	Max	Min
1	Generator	84	4.5	900	2.6	4.5	0.265

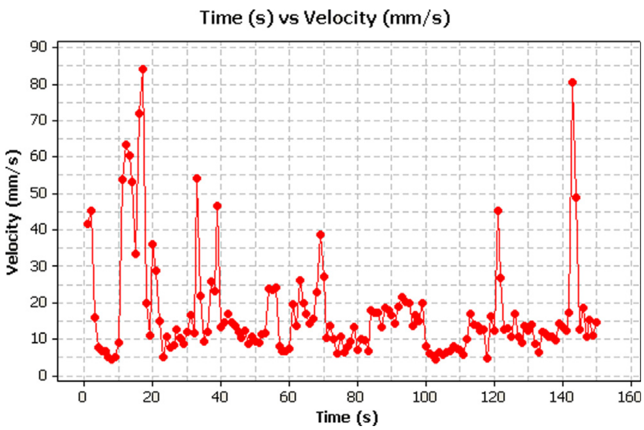

Fig. 4. Time vs. velocity.

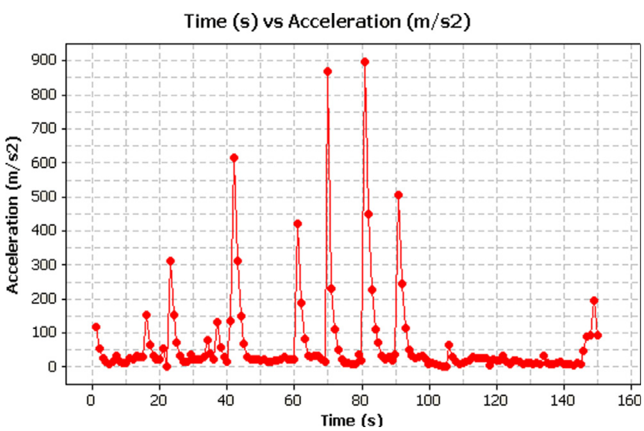

Fig. 5. Time vs. acceleration.

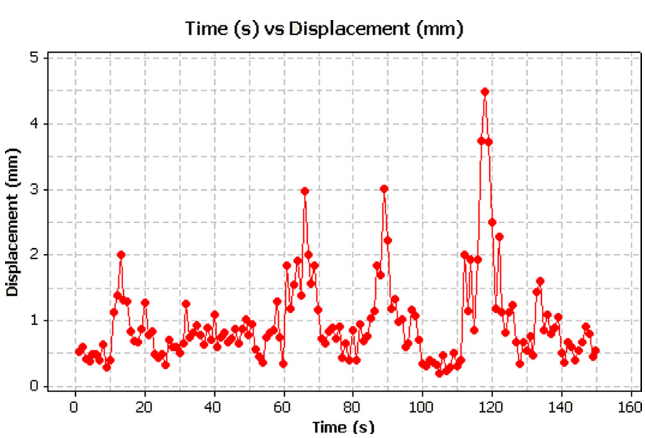

Fig. 6. Time vs. displacement.

Fig. 7 indicates that the maximum displacement of 0.48 mm is obtained at 2250 Hz that indicated the sources of potential failure. It designated the bearing fault frequencies, real-time spectrums,

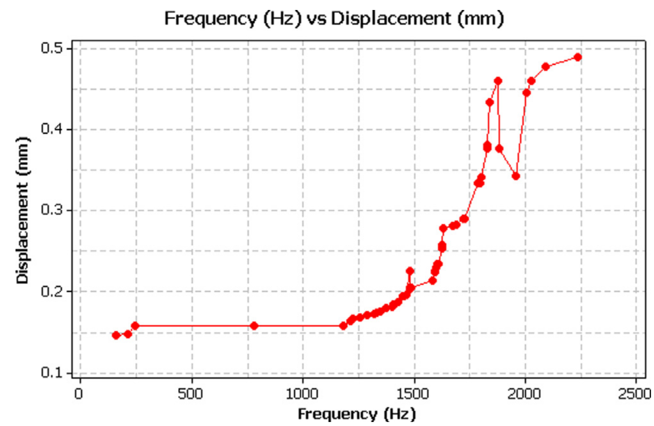

Fig. 7. Frequency vs. displacement.

shaft eccentricity, and generator current signature analysis. The vibration analysis of the generator shows that the cantilever constructional arrangement of the generator affects the healthy operation of WTGs and it leads to extremely heavy vibration. It points out that condition monitoring and error finding is necessary in order to minimize downtime and cost of maintenance while increasing the reliability and availability of the wind farms.

5. Conclusion

The investigational vibration analysis of generator wind turbine is done for the field-operated 250 kW wind turbine in its cut-in speed, rated wind speed, and cut-out speed at Muppandal site, India effectively and the vibration data are collected and documented on– site with the help of vibration analyser and vibration data characteristic curves are generated and analysed by means of customized data acquisition software. These vibration characteristic curves generated in this paper are studied to analyse their severity and effects. It is identified that the failure rates of the wind turbine generator have almost recurrently increased with respect to the age of the turbine. The fatigue failures are more in the generator. The acceleration reached the maximum of 900 m/s2 is intolerable and it leads to fatigue failure. The 0.265 mm to 4.5 mm displacement in the frequency displacement curve shows an indication of misalignment and bearing failure. The high value of acceleration shows the hazards of mechanical imbalance. The analysis revealed that the vibration in the generator is intolerable and it requires some kind of preventive measures. This proposal of this paper is to recommend an accurate error monitoring and condition monitoring system to detect an emerging failure of the generator and it further recommends a new design of soft starter based on thyristor technology to enhance the lifetime of the generator of the wind turbine. The vibration analysis of the generator revealed that the cantilever arrangement of the generator got the top-most obstacles that affect the healthy operation of WTGs and also recommends some static support with main-frame of the nacelle is mandatory.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] S.H. Latha and S.C. Mohan, ‘‘Centralized power control strategy for 25 kW nano grid for rustic electrification,” in Proc. IEEE Int. Conf. Emerg. Trends Sci. Eng. Tech. (INCOSET), Tiruchirappalli, India, 2012, pp. 456–461.

[2] T. Sunder Selwyn, R. Kesavan, Reliability analysis of sub-assemblies for wind turbine at high uncertain wind, Adv. Mater. Res. J. 433 (2012) 1121–1125.

[3] T. Sunder Selwyn, R. Kesavan, Computation of Availability and Performance of wind Turbine with Markov Analysis in India, Adv. Mater. Res. J. 488 (2012) 1702–1707.

[4] T. Sunder Selwyn, Kesavan, Failure modes and effects analysis system deployment in a wind turbine at high uncertain wind environment, Adv. Sci. Lett. 19 (8) (2013) 2166–2169.

[5] T. Sunder Selwyn, R. Kesavan, Availability analysis of wind turbines and its sub-assemblies with markov analysis at uncertain wind, Adv. Sci. Lett. 19 (2013) 2210–2214.

[6] P.J. Tavner, J. Xiang, F. Spinato, Reliability analysis for wind turbines, Wind Energy 10 (1) (2007) 1–18.

[7] Yanyong Li, Discussion on the Principles of Wind Turbine Condition Monitoring System, IEEE International Conference on Materials for Renewable Energy & Environment (2011) 621–624.

[8] T. Sunder Selwyn, R. Kesavan, Reliability Measures of constant pitch constant speed Wind Turbine with Markov Analysis at High Uncertain Wind, Proceedia Engineering –Elesevier 38 (2012) 932–938.

[9] S. Hemalatha, S.C. Mohan, Cost optimization of power generation systems using bat algorithm for remote health facilities, J. Med. Imaging & Health Infor. (2016) 1–6.

[10] Sunder Selwyn T, Kesavan R (2011) Computation of reliability and birnbaum importance of components of a wind turbine at high uncertain wind. Int J Comput Appl 32(4):42–49..

[11] Long Quan, Liu Yongqian and Yang Yongping ‘‘Vibration Response Analysis of Gear Driven System of Wind Turbine” IEEE Int Conf Intell Comput Intell System.2010; 3: 380–383.

[12] Andrew Kusiak, Zijun Zhang, ‘‘ Analysis of Wind Turbine Vibrations Based on SCADA Data” J. Sol. Energy Eng. Aug 2010, 132(3): pp 1-12, https://doi.org/10.1115/1.4001461.

[13] T. Sunder selwyn, R Kesavan, M. Ramachandran, FMECA Analysis of Wind Turbine Using Severity and Occurrence at High Uncertain Wind in India, International Journal of Applied Engineering Research. ISSN 0973-4562 Volume 10, Number 11 (2015) pp. 10250-10253.

[14] T. Sunder Selwyn, R. Kesavan, Analysis of failure and reliability for constant speed and constant pitch wind turbine, ASME Press Select Proceedings - https://doi.org/10.1115/1.859797, pp 1-6

[15] T. Sunder selwyn, R Kesavan, Vibration Analysis of a Constant Speed and Constant Pitch Wind Turbine, Springer- Lecture Notes in Mechanical Engineering-https://doi.org/10.1007/978-81-322-1007-8_40, 2012, pp 429-443.

[16] Wei Teng, Xian Ding, Hao Cheng, Chen Han , Yibing Liu, , Haihua Mu, ‘‘Compound faults diagnosis and analysis for a wind turbine gearbox via a novel vibration model and empirical wavelet transform” Renewable Energy Vol. 136, 2019, pp 393-402

[17] S. Shanbr, F. Elasha, M. Elforjani, J. Texeira, ‘‘ Detection of Natural Crack in Wind Turbine” Gearbox Renewable Energy (in press). DOI: 10.1016/j.renene.2017.10.104.

[18] S. Hemalatha, T. Sunder Selwyn, Computation of mechanical reliability for Sub-assemblies of 250 kW wind turbine through sensitivity analysis, Materials Today: Proceedings, pp 1-8, https://doi.org/10.1016/j.matpr.2020.09.392