ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Computation of mechanical reliability for Sub- assemblies of 250 kW wind turbine through sensitivity analysis

S. Hemalatha [a], T. Sunder Selwyn [b]

[a] Prince Shri Venkateshwara Padmavathy Engineering College, Chennai 600 127, India
[b] Prince Dr. Vasudevan College of Engineering and Technology, Chennai 600 127, India

ARTICLE INFO

Article history:
Received 8 June 2020
Accepted 16 September 2020
Available online xxxx

Keywords:
Sub-Assembly
Sensitivity
Reliability
Weibull analysis
Uncertainty

ABSTRACT

Wind energy plays a significant role in the renewable energy scenario of the planet. The wind turbine systems have multipart components which are repairable. The failure characteristics of the onshore wind turbines rely on the terrain and climatic conditions. Although mountain passes and hill areas are highly suitable for wind turbine (WT) installations, there is a substantial uncertainty in the wind pattern because of the frequent changes in the direction and velocity of wind. It creates a rapid failure in different components of the wind turbine. It is an amazement that the failure rate has rapidly increased in normal operating period of the wind turbines that placed exactly in the mountain pass and hilly area due to the recurrent uncertainty in the wind. Hence there is an urgent need for improving the reliability in wind turbine. For diminishing the lifecycle cost of a wind turbine and failure, it is significant to evaluate the reliability for all individual components in all respects. This paper deals with sensitivity analysis for major components of wind turbine system and its sub systems such as rotor system, gear box, brake system, generator, hydraulic system and yaw system. The Reliability analysis was carried out successfully based on Weibull analysis and Sensitivity Analysis on constant speed and constant pitch wind turbines with a capacity of 250 kW over a span of 19 years for at Muppandal main pass, Tamil Nadu, India.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Materials, Manufacturing and Mechanical Engineering for Sustainable Developments-2020

1. Introduction

The wind energy plays a vibrant role in the world renewable energy scenario. The existing wind turbine system (WTS) has intricate and repairable components due to sophistication and centralized control [1,2]. The renewable sources in power generation system are stimulated successfully because of environmental concerns over burning fossil fuels to generate electricity [3]. Tavner et al. [4] evaluated the failure rates for individual components of wind turbines by applying a Homogeneous Poisson Process. They concluded that the failure rates in WTs that the direct drive WTs have minimum failure rate than indirect drive WTs. The Failure Mode Effects Analysis meted out for 250 kW Wind turbine and its distinct components to evaluate the criticality of 250 kW WTs, located in Muppandal pass, India, over the span of 15 years [5,6].

By conducted the reliability trend tests, Wang and Coit [7] compared the effectiveness of the wind turbine for dissimilar data patterns. The target of their study is to worked out the pattern of failures is significantly changing with time. So as to increase the life of a WT, it is significant to evaluate the reliability in all level for entire individual WT components. The concept of Markov analysis was used to model the failure characteristics of the key components to calculate the probability, availability and reliability of various system states of WTs located in the area having high uncertainty in wind flow [8]. The modeling and simulation of a grid connected wind-driven electricity generation system (WDEGS) has been done and genetic algorithm and particle swam optimization is employed to optimize the real time performance [9,10].

Haverkort and Adrianus [11] analyzed the wind turbine parameters by means of sensitivity analysis and Monte Carlo analysis. They proved that the classical sensitivity analysis results are better than the Monte Carlo analysis. Foley et al. [12] studied the performance of Vestas V90, 2 MW WT by using the software TurbSim and evaluated 1.24% improvement on its total power generation was attained with reliability improvement. Ghaderi et al. [13] exemplified a new methodology for the reliability modeling of the large

E-mail address: hema.selwyn@gmail.com (T. Sunder Selwyn)

https://doi.org/10.1016/j.matpr.2020.09.392
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Materials, Manufacturing and Mechanical Engineering for Sustainable Developments-2020

system with multistate components. The individual component state had been studied by a Markov process. Vittal et al. [14] proposed a completely uniqe method in association with the performance and reliability of WTs by menans of Monte Carlo algorithms.

2. Electricity generation of a single 250 kW WT

The highest yearly generation of a 250 kW WT from the cluster of 5 MW wind farm at Muppandal in years of 2019 is shown in Fig. 1. The uppermost value is obtained from the location number 18 of twenty 250 kW turbine park. The generation totally depends on plant availability, grid availability, production hours, stoppage for preventive and break down maintenance and low wind hours. From the year 2005, the generation of the WT is reduced diminutive owing to its age and drop in reliability.

Total Time = PT + GDT + LWT + BDT + PMT

Where

PT = Production Time PT = Grid Down Time

GDT = Low Wind Time LWT = Breakdown Maintenance Time

PMT = Preventive Maintenance Time

The capacity factor (CF) of a WT is that the ratio of the actual output of a WT and its output if it had run at full capacity over that period of time [15]. The maximum capacity factor is generally obtained in the month of July as 46.92 and lowest is in April as 5.42. The average of CF is falls between 21 and 28 in Muppandal site. The maximum generation is obtained in the month of July. The maximum monthly generations are obtained in the month of January, May, June, July, August and September. The upward trend is obtained in the months of April-May, June-July and November – December. The downward trend is obtained in the months of January –April and July to November. In Muppanadal site, the generation is heavily affected in summer season (March and April) and autumn season (October and November).

Due to low wind, the 250 kW WT imports 846 kWh as of its maximum and minimum on July as 30 kWh. The high production hours were obtained high in July as 744 h and low in April as 309 h. The low wind hours were obtained in the month of March and April were 408 and 347.4. Mostly, the low wind is obtained both in summer and autumn season.

3. Reliability analysis

The Weibull cumulative density function (cdf) F (t) or Unreliability for three parameters is given by equation (1).

$$F(t) = 1 - e^{-\left[\frac{t-\rho}{\eta}\right]^{\beta}} \tag{1}$$

Then the reliability of the given by Equation (2).

$$R(t) = e^{-\left[\frac{t-\rho}{\eta}\right]^{\beta}} \tag{2}$$

$$MTTF = \int_0^{\infty} \frac{\beta}{\eta}\left[\frac{t-\rho}{\eta}\right]^{\beta-1} e^{-\left[\frac{t-\rho}{\eta}\right]^{\beta}} \tag{3}$$

$$Let\, y = y\left[\frac{t-\rho}{\eta}\right]^{\beta} \tag{4}$$

$$Then\, dy = \frac{\beta}{\eta}\left[\frac{t-\rho}{\eta}\right]^{\beta-1} dt \tag{5}$$

$$or\, MTTF = \int_0^{\infty} te^{-y}dy \tag{6}$$

$$Since\, y = \eta y^{1/\beta}$$

$$MTTF = \eta\int_0^{\infty} y^{1/\beta}e^{-y}dy \tag{7}$$

$$MTTF = \rho + \eta.\Gamma\left[\frac{1}{\beta}+1\right] \tag{8}$$

$\Gamma\left[\frac{1}{\beta}+1\right]$ is the gamma function

Similarly the median and mode are derived as Equation (4.9) and (4.10).

$$Median = \rho + \eta.(\ln 2)^{\frac{1}{\beta}} \tag{9}$$

$$Mode = \rho + \eta.\left(1-\frac{1}{\beta}\right)^{\frac{1}{\beta}} \tag{10}$$

Weibull failure rate function is specified by Equation (4.13).

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{\beta}{\eta}\left[\frac{t-\rho}{\eta}\right]^{\beta-1} \tag{11}$$

The desired reliability R is prearranged by Equation (12).

$$R(t) = e^{-\left[\frac{t-\rho}{\eta}\right]^{\beta}} = R \tag{12}$$

4. Sensitivity analysis for reliability

The Sensitivity Analysis (SA) is completed for reliability and availability of all sub- assemblies of WT. The SA is employed to investigate the robustness of the mathematical model of WTS.

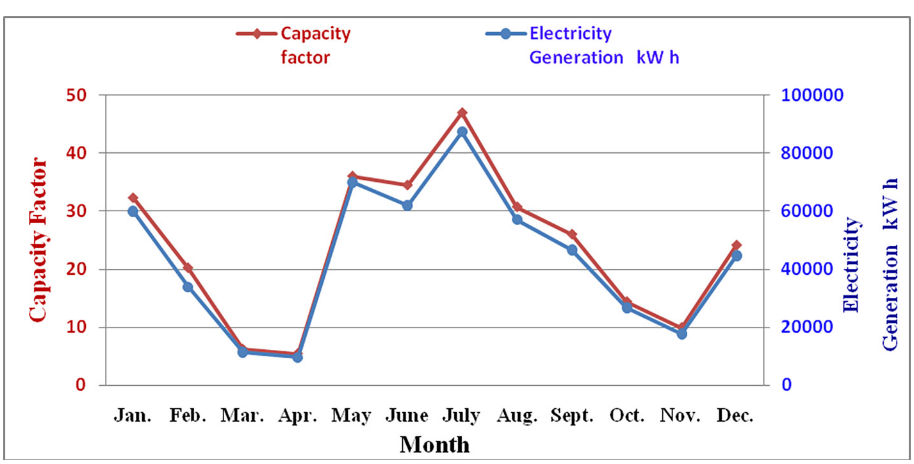

Fig. 1. Highest monthly electricity generation of 250 kW WT in 2019.

The SA helps to create confidence in the model by studying the uncertainties that are often related with parameters in models. The SA feature allows us to vary one or two constants across analyses during simulation runs. For analyzing reliability of WT, it is important to vary the time for reliability and availability, how different inputs will affect the final results. Likewise, it is alleviate to generate reliability or availability results for a range of times so as to look at the WT component's behavior over time.

4.1. SA for rotor system reliability

The Fig. 2 obtained through SA performed gives a transparent view on reliability been analyzed at various trials be equal to the result obtained through Weibull analysis. For example, in rotor system reliability the reliability through SA is 20.04% when done for 80,000 h, which is extremely nearer to the result obtained through Weibull analysis which is 20% so that the model created for Weibull analysis is fit and accurate for further study. To reinforce the life time of and generation of WT, it is very important to boost the reliability of the rotor. The rotor system and rotor hydraulic system are combined together. Therefore the failures are frequent to check with other components. Reliability of the rotor can be improved by advancements in design. The failure rate of rotor is obtained as 0.00007867 failures per hour over the period of 25,000 h.

4.2. SA for gear box system reliability

By comparing the SA graph with the Weibull analysis graph it is clear that the reliability value is about 40% to 40.1% at 80,000 h from the Fig. 3. The failure of WT gear box is happened because of many reasons such as augmented vibration, sustained fatigue and stress, unavoidable impact load and variation in shaft speed. The experimental analysis reveals that up to 15.4472% of gear box failures are due to high impact load occurred because of high uncertainty in the wind. The reliability of the WT gear box highly reduced due to sudden braking, body cracks and erratic gear meshing. From the result it is observed that the MTBF is in between 24,725 and 25,628 for the gear box system. The failure rate is in between 0.0000403 and 0.000467 per hour.

4.3. SA for brake system reliability

As of above the reliability value through SA is 70.05% when done for 60,000 h from the Fig. 4, which is much in correlation with the reliability value obtained through Weibull analysis, 70% so that the model for Weibull analysis is accurate. The failure rate per hour of brake system is in between 0.000122 and 0.000818. The Mean Time to Repair of brake system is in between 3 h to 42 h. In Weibull analysis, it is apparent that the brake system has a β value of 1.7459 and is due to accelerated wear. The failure occurred in the brake systems are stochastic. The failure rates of the brake system and hydraulic control of brake system is 0.0000861 failures per hour and 0.00008259 failures per hour over a period of 25,000 h. Similarly, the failure rates of the brake system and hydraulic control of brake system is 0.0001443 failures per hour and 0.0001257 failures per hour over a period of 50,000 h. The larger failure of brake system is happened due to frequent worn out of brake pads.

4.4. SA for yaw system reliability

The SA done for the yaw system gives the result 80.06% when analyzed for the period of 40,000 h from the Fig. 5 and when put

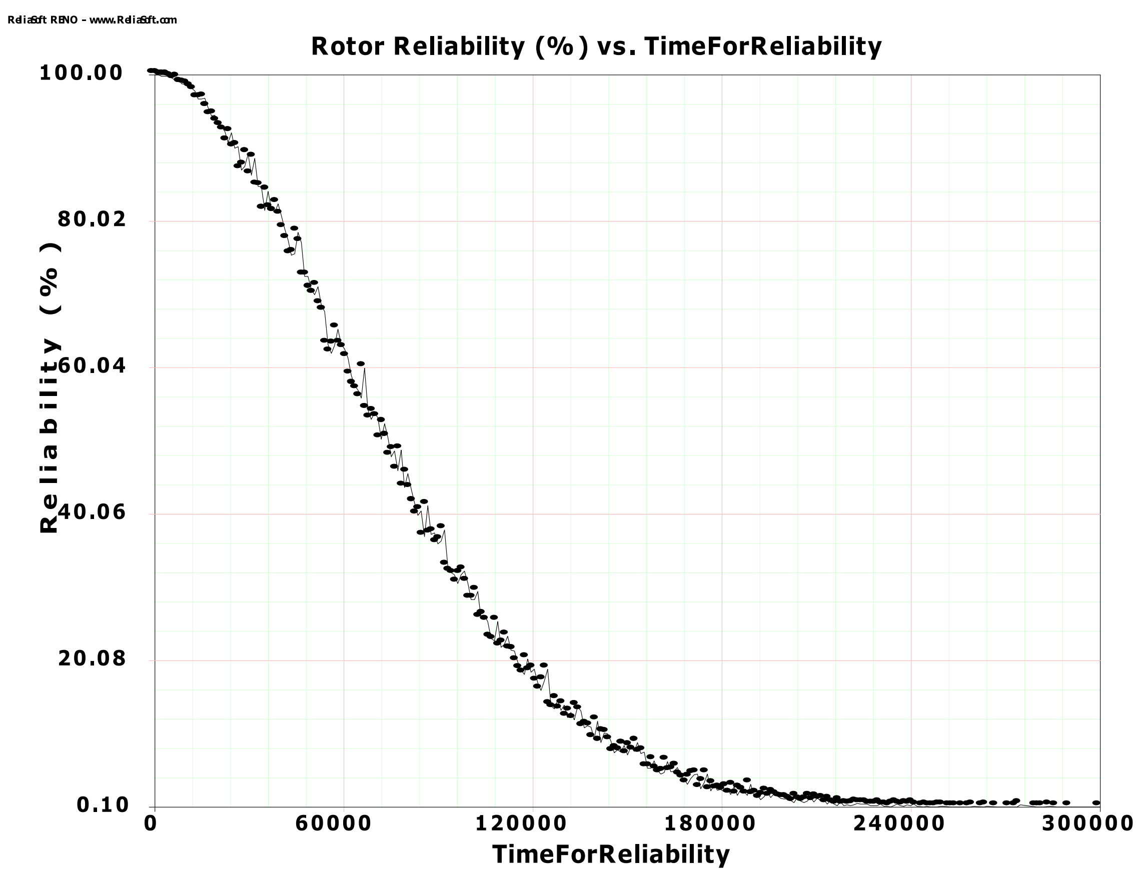

Fig. 2. SA for rotor system reliability.

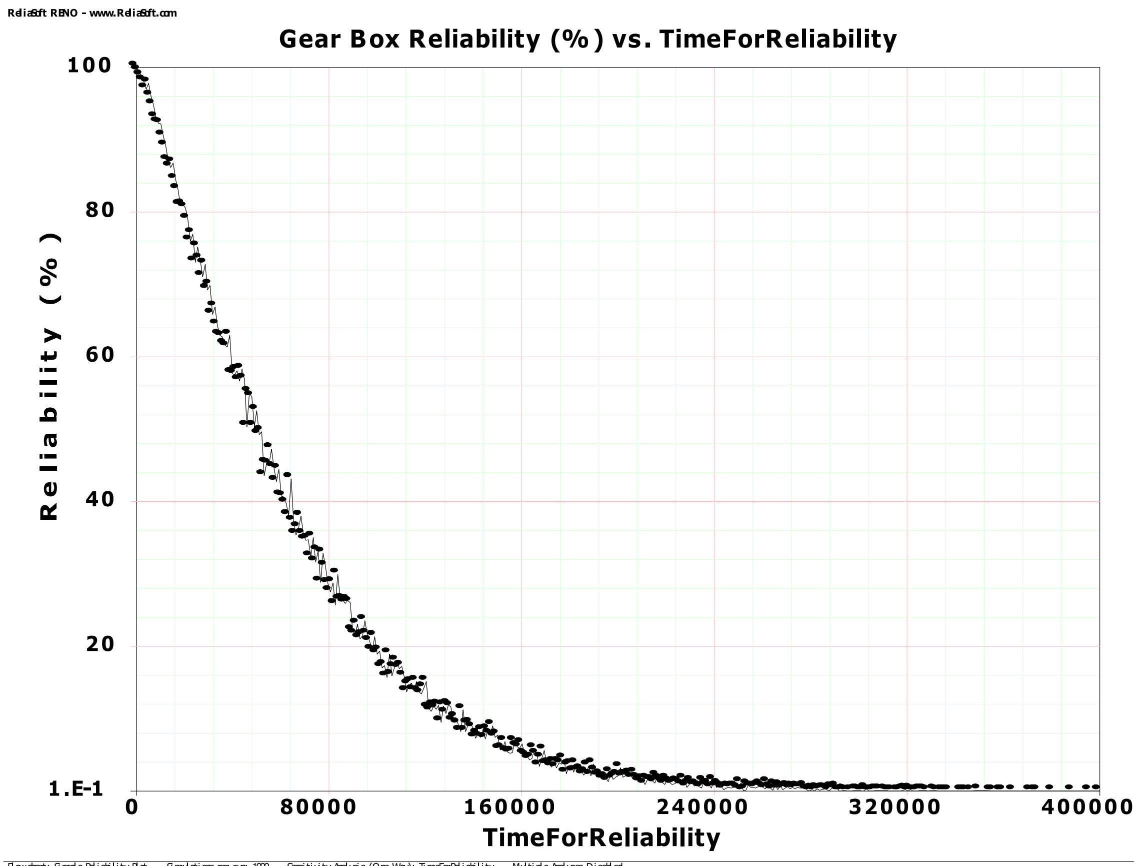

Fig. 3. SA for gear box system reliability.

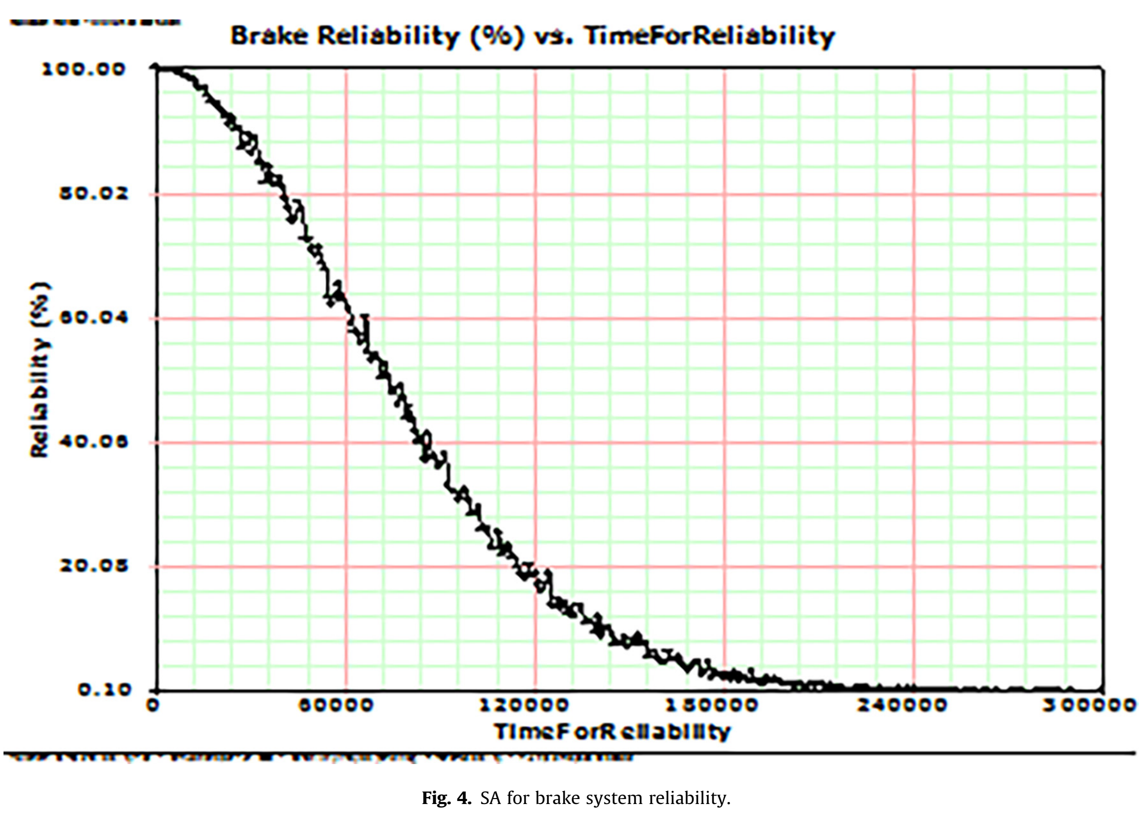

Fig. 4. SA for brake system reliability.

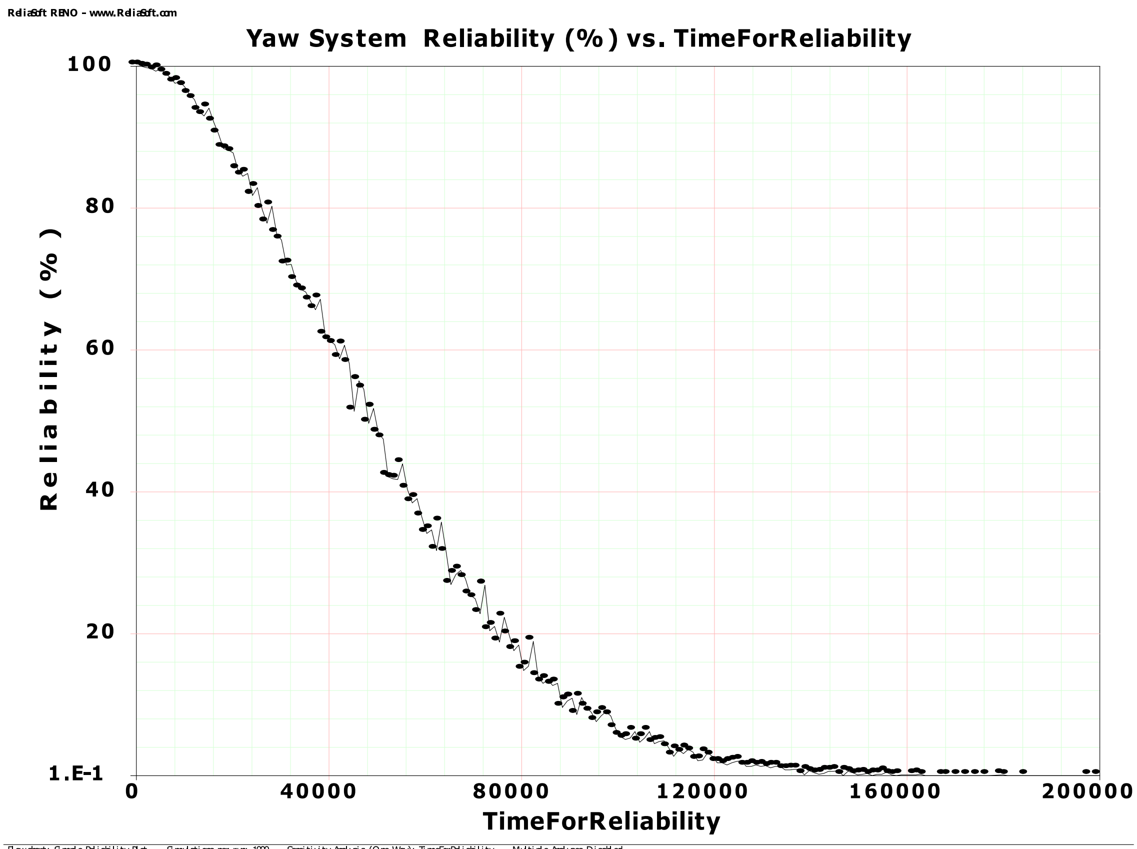

Fig. 5. SA for yaw system reliability.

next with Weibull analysis graph shows greater correlation since the reliability value by Weibull analysis is 80%. Accordingly the model for Weibull analysis proved that it very is accurate. The highest frequency of failure occurred in yaw system. In location number 18, the availability of the WT is 98.71% but the failure rate of is 0.000808 per hour. It is concluded that the rotor is overstrained because of the repeated failure of yaw mechanism.

4.5. SA for rotor hydraulic system reliability

The SA gives a reliability value of 49.05% when taken for about 60,000 h from the Fig. 6, when the same compared with Weibull analysis graph shows the result 50% which is nearer so that the model taken for Weibull analysis is fit. The tip of the WT blades is open when running due to inadequate pressure. Therefore, it is very essential to monitor the pressure of the hydraulic system of rotor, leakage and wear of carbon shaft. The hydraulic control system of the rotor failure are materialized due to malfunction of mechanism and process error, that results in the tip opening problem and blade rope cut.

4.6. SA for brake hydraulic system reliability

The SA for the brake hydraulic system gives the reliability of 69.8% at 60,000 h of analysis from the Fig. 7, when this is taken in correlation with Weibull analysis chart; it gave reliability value 70% so that the model generated for Weibull analysis is precise.

4.7. SA for generator system reliability

The comparison between SA graph and Weibull analysis graph shows correspondence in reliability value which is 40% in SA when done for 60,000 h from the Fig. 8 and 41% in Weibull analysis thus the deviation is more compared to other components but they are nearer so that the model generated for Weibull is robust.

The main components of the generators are the contactors, bearing, shaft, flexible coupling, cooling system of generator, top terminal box and control panel. The failure rate of the generator had falls between 0.0001547 and 0.0001241 failures per hour. The Mean Time Between Failure for the generator system are in between to 24,687 and 25,712 h. The highest failure rate is obtained in the generator is 0.000443 per hour.

5. Conclusion

The WT subassemblies had a failure rates in descending order as rotor System (Both mechanical and Hydraulic control), Brake System (Both mechanical and Hydraulic control), Generator System, Yaw System and Gear box System

In 25,000 h, the rotor system had less failure rates as 0.00007867 failures per hour, the brake system had 0.0000861 failures per hour and hydraulic control of brake system had 0.00008259 failures per hour. The designed life time of the WT components by adopting desired reliability of 95% gotten as result, which proves that the components such as gear box, generator and rotor hydraulic system suffers a nonexistence for a period of 25,000 h. Then the other components such as rotor system (16,643.3 h), brake system (15,178.55 h), yaw system (12,002.5 h) and brake hydraulic (14107.04 h) has a nominal deign life when the analysis is done for the same 25,000 h. The overall design life of WT system is obtained as 6772.33 through analysis. Finally, this study has recommends that there is a good scenarios of improving the reliability and availability of WTs by modifying, redesigning

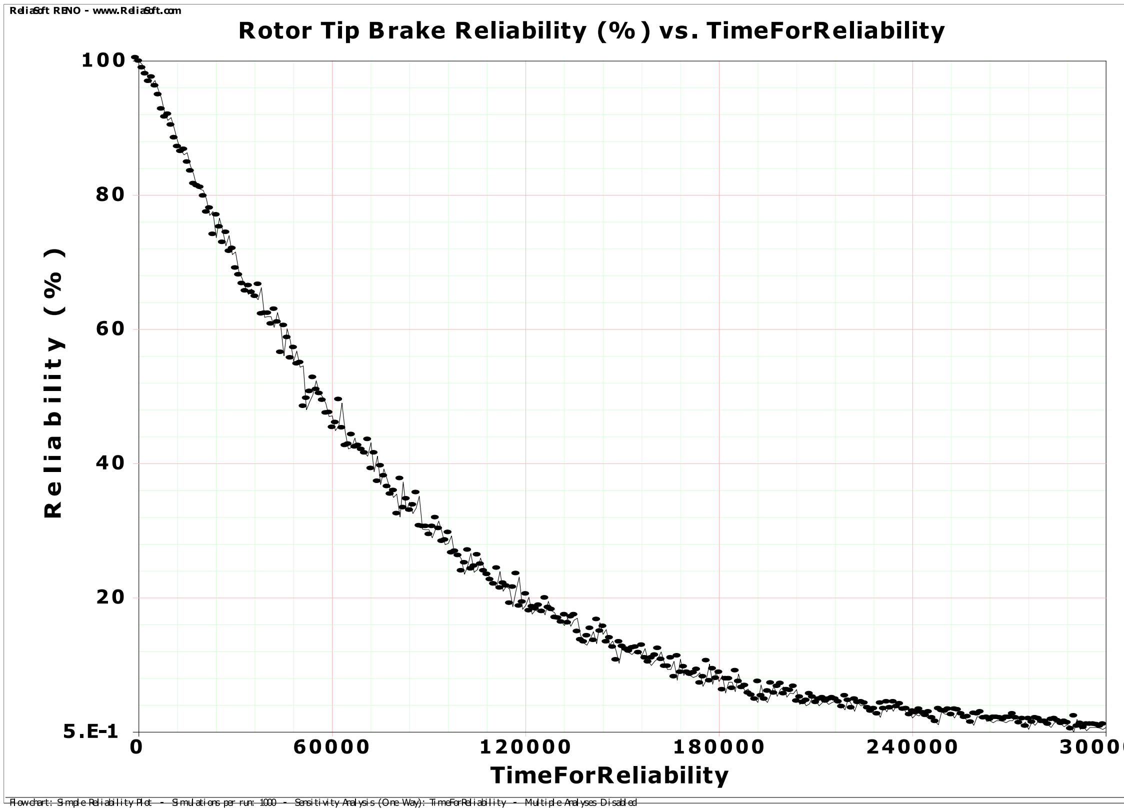

Fig. 6. SA for rotor hydraulic system reliability.

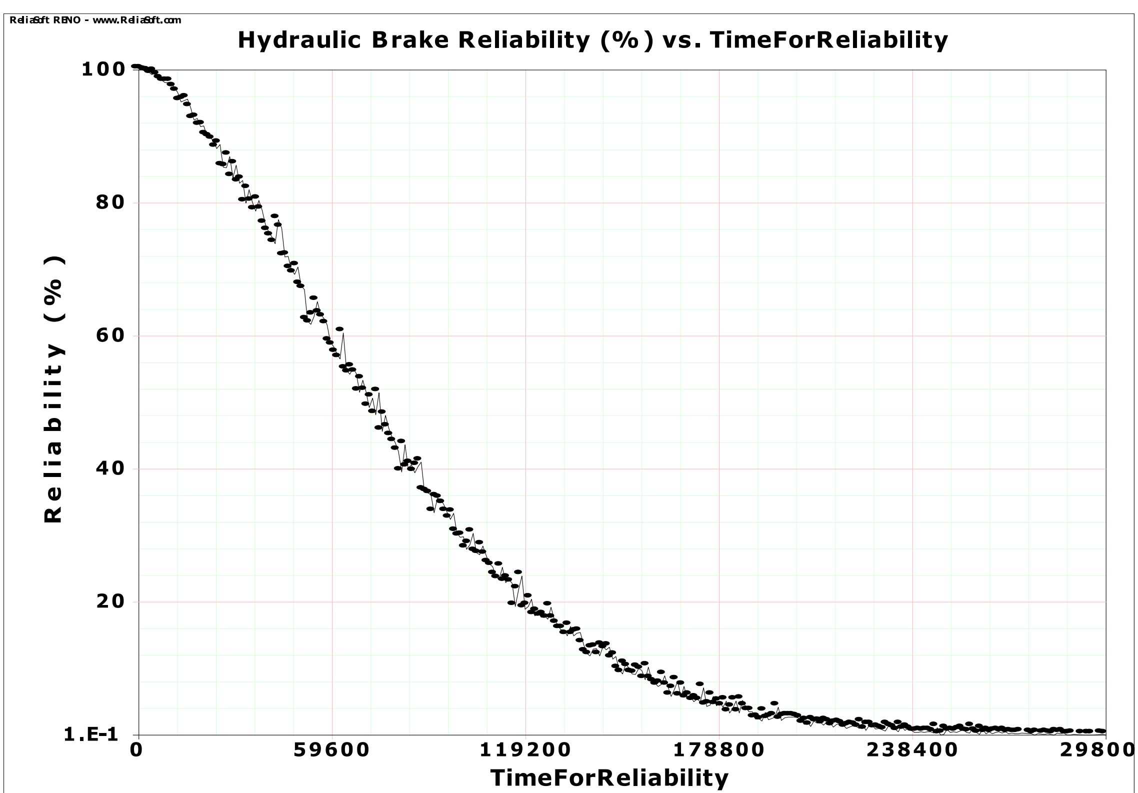

Fig. 7. SA for brake hydraulic system reliability.

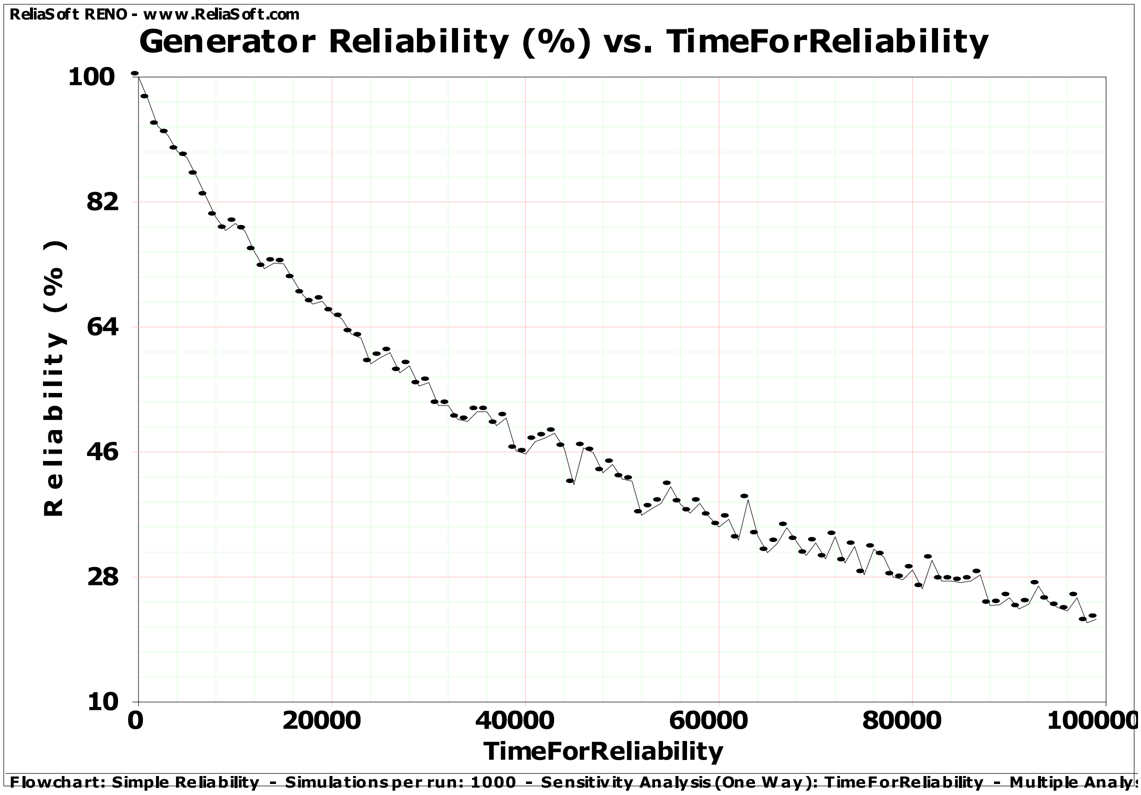

Fig. 8. SA for generator system reliability.

the components and introducing redundancy system. The effective monitoring mechanism and proper preventive maintenance to prevent the failure before occurring will increase the reliability of the system and it also recommends that the WTs need not be designed as common for all onshore plant it may design with respect to terrains, climate and average wind velocity.

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] T. Sunder Selwyn, R. Kesavan, Reliability analysis of sub- assemblies for wind turbine at high uncertain wind, Adv. Mater. Res. J. 433–440 (2012) 1121–1125.
[2] T. Sunder Selwyn, R. Kesavan, Computation of availability and performance of wind turbine with markov analysis in India, Adv. Mater. Res. J. 488–489 (2012) 1702–1707.
[3] S. Hemalatha, S.C. Mohan " Centralized power control strategy for 25 kw nano grid for rustic electrification" 2012 IEEE - International Conference on Emerging Trends in Science, Engineering and Technology (INCOSET), pp. 456-461, 2012.
[4] P.J. Tavner, J. Xiang, F. Spinato, Reliability analysis for wind turbines, Wind Energ. 10 (1) (2007) 1–18.
[5] T.S. Selwyn, R. 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.
[6] T.S. Selwyn, R. Kesavan, Availability analysis of wind turbines and its sub assemblies with markov analysis at uncertain wind, Adv. Sci. Lett. 19 (8) (2013) 2210–2214.
[7] P. Wang, D.W. Coit, "Repairable Systems Reliability Trend Tests and Evaluation", Proceedings of Annual Reliability and Maintainability Symposium, pp. 416-421, 2005
[8] T.S. Selwyn, R. Kesavan, Reliability measures of constant pitch constant speed wind turbine with markov analysis at high uncertain wind, Procedia Eng. 38 (2012) 932–938.
[9] S. Hemalatha, S. Chandramohan, Cost optimization of power generation systems using bat algorithm for remote health facilities, J. Med. Imaging Health Inform. 6 (7) (2016) 1646–1651.
[10] S. Hemalatha, S.C. Mohan, "Modelling of Nano-Hybrid Power Generation for Rural Zone" Int. J. Appl. Eng. Res. (IJAER) 10 (Number 11, pp.10254-10256, 2015
[11] B.R. Haverkort, M.H. Adrianus, Meeuwissen, "Sensitivity & Uncertainty Analysis of Markov-Reward Models", IEEE Transactions on Reliability, Vol. 44, No. 1, pp. 147-153, 1995.
[12] J.T. Foley, T.G. Gutowski, "The Impact of Reliability on Wind Turbine Life Cycle Analysis", in conference proceedings of WEC, Cambridge, pp. 1-4, 2004.
[13] A. Ghaderi, M.R. Haghifam, S.M. Abedi, "Application of Monte Carlo Simulation in Markov Process for Reliability Analysis", Proceedings of IEEE 11th International Conference on Probabilistic Methods Applied to Power Systems, pp. 293-298, 2010.
[14] S. Vittal, M. Teboul. "Performance and reliability analysis of wind turbines using Monte-Carlo methods based on system transport theory", 46th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, Austin, Texas, pp. 1-8, 2005.
[15] T. Sunder Selwyn, R. Kesavan, Computation of reliability and birnbaum importance of components of a wind turbine at high uncertain wind, Int. J. Comput. Appl. (0975–8887) 32 (4) (2011) 42–49.