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Research Article

Emerging trends and global challenges to predict drop in thermal performance of WTG gearbox

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ABSTRACT

The assessment of performance is the key role factor for the gearboxes in the field of wind turbine industry. The thermal performance depends upon the viscous forces of the oil; bearing with stand capacity of the gearboxes and unnecessary irrotational forces or movements caused during the rotation of the gears at intermediate stage and high speed stage. The generation of the power starts from 15 m/s to 25 m/s with the starting rpm of 15 rpm to 1150 rpm; from initial stage to high speed stage of the gearbox. Hence the reduction of torque at higher revolutions may tends to complete reduction in power; owing to the thermal performance drop occurred due to the reduction of oil viscosities; improper maintenance during the high load conditions. This may lead to cause higher maintenance costs for the investors who is coming in front to invest huge amount of money. This present experimental work deals with latest sensors utilization to analyse the data from master gear box to slave gear box. From the results it is observed that the implementation of latest technology sensors tends to improves the maintanence costs by 20% as compared to conventional sensors. Hence it is adviced to implement the latest technology sensors which is capable to measure the wind speed loads of 20 m/s to 45 m/s. This gives range of resolution for downloading the past data and predicting the futurized data for evaluating the thermal performance drop; leads to save the maintanence costs 20% as compared to conventional methods.

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INTRODUCTION

The entire world depends upon the production of power from the various sources of energy. The sources of energy is the best choice which must very cheaper in terms of generation and utilisation [1]. The generation costs depend upon the nature of the loads and applications required. Al though there are various sources of energy available in the market [2]. The people were quite interested to focus on emission less sources during the production of power. The main advantages of generating the power from wind-based power plants is zero pollution and less generation costs [3]. The generation per unit is very cheaper in terms of Rs 4 per unit for wind power plant. But for generation per costs per unit for solar based power plant is Rs 15. It is understood that the three times the cost is higher as compared to wind-based power plants [4]. The main part of the wind turbine power plant is gearbox. It turns the lower rpms to higher rpms by the rotation of higher thrust factors. Hence the generation of power depends upon the stages of the gearbox. The higher the stages give higher the rpms and lower the stages gives lower the rpms [5]. Depending upon the rated power the gearboxes are designed well by the young researchers and field analysis is done before the erection of the gearbox. The field analysis is done on the test bench to analyse the thermal drop performance and prediction of any bearing failures [6]. The prototype gearbox is tested on the gearbox for 120 hours with running speeds of 25%, 50%, 75% and 100% rated speeds. The test trials are done on day period with anemometer and eddy current dynamometers setup [7]. The well skilled trainers are required to predict the possible failures and root causes to over the thermal performance drop. The essential thing in the gearbox during the rotation of high loads is high viscous oil [8]. The higher the viscous forces of oil give the reliability of the gearbox. Most of the gearboxes gets failed due to the irrespective less viscous forces caused during the restrictive shear forces occurred by the oil [9]. Hence the change in oil is an essential factor; which improves the reliability of the gearbox that prevents the gearbox from the permanent failures [10]. The implementation of the latest LDD based technology sensors gives the high reliability of the gearboxes. This saves the higher cutting costs from breakdown maintenance and improves the superior life of the gearbox [11]. The objective of this research is to identify the possibilities of thermal drop in performance of the gearbox with latest sensors [12]. The field data for one year is tooked jan 2022 to December 2022 to conduct the analysis. The novelty of this analysis is to implement the LDD sensors to sense the all loads caused during the higher turbulence wind speeds ranging from 35 m/s to 40 m/s. The implementation of the latest sensors with minute accuracies acts as a highly intensified performance drop prevention; which leads to higher cost savings for the investors coming in front to invest the wind turbine.

TESTING METHODOLOGY

Figure 1 represents the testing methods of the gearbox with neccessory loads. The source of data required for the analysis is wind LDD data with latest sensors. The test

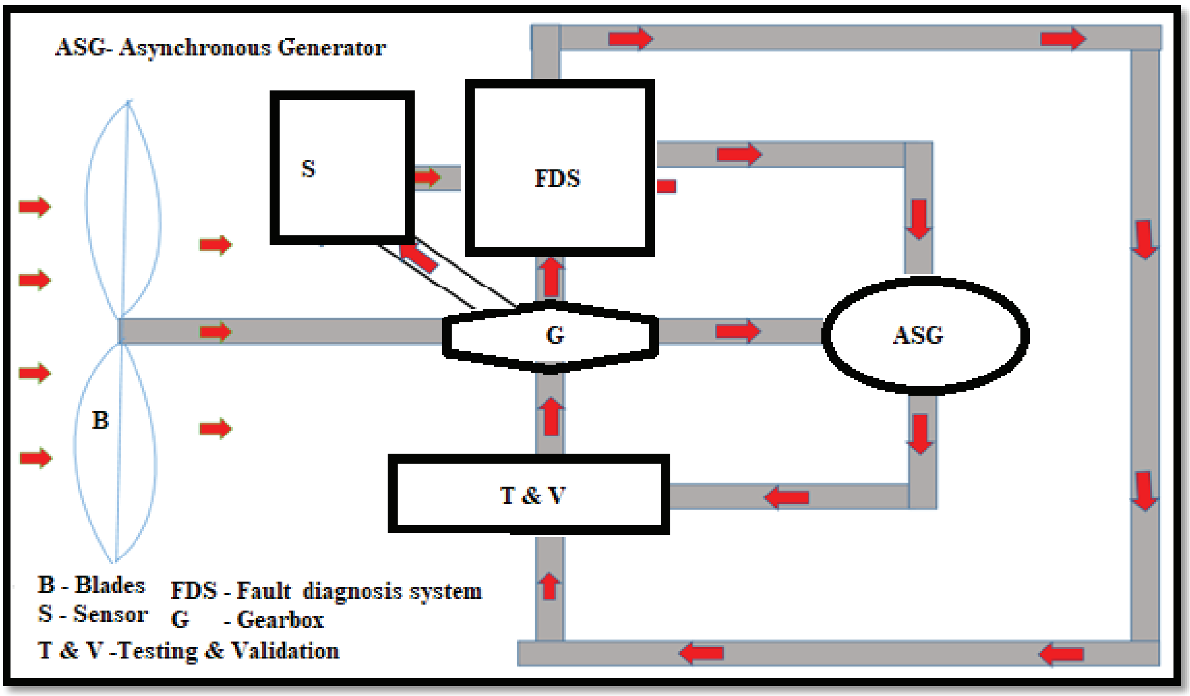

Figure 1. Testing methods.

setup is carried with master gearbox as well as slave gearbox equipped with diagonisis system. The uncertainty analysis for the entire setup is done with the help of well-trained skilled persons from the original manufacturers of the testing equipment's. The accuracy of the test bench is measured with the help of FFT analyzer; which allows in the range of 3-5%. The test bench reports are compared with the final results achieved by the field or master gearbox. If there is any deviations occurred in the gearbox; the data such as wind velocity, speed and deviations are validated in the validation channel of the gearbox system. The setup is operated by the well qualified trainer for achieving the optimised best results. The accuracy of the calibrated instruments and types of its errors in percentages has been discussed in the separate section called as uncertainty analysis section. From this section every researcher can be identified the different types of process involved for achieving the best output calibration of the equipments and the importance of its measured values. Hence from Figure 1 it is easy to understood the different types of methods that can be adopted for improving the power generation and associated benefits in the field of wind turbine industry.

Wind Profile of Tamil Nadu

Figure 2 represents the potential of wind indicated by the bulletin arrows. From the profile it is understood that

Figure 2. Potential wind profile of Tamil Nadu.

there is lot of possibilities to achieve power by wind turbine installation in the various places of Tamil Nadu including south and west portions. Hence it is required to measure the anemometric devices with prefeasibility studies for achieving or predicting the wind velocities over the places of wind farms in Tamil Nadu [13].

Figure 3 represents the total installed capacity of wind power plants through various places. The installed capacity is gradually growing from wind stations Poolavadi to Muppandal. The gradual investments of wind turbine manufacturers have been increased due to the potential winds at various places of Tamil Nadu. Hence the investors are coming in front to invest huge amount of money to generate the power from wind turbines. It is necessary to get desired subsidies from the Tamil Nadu government before purchasing the wind turbine from turbine manufacturers. The wind turbine cost depends upon the capacity of the turbine; for achieving 1 Mw wind turbine the turbine cost is 5 crores, the gear box cost includes 1 crore, Hence the gearbox is the heart of the wind turbine, which generates the desired power at rated rpms. The significant role for designing the gearbox depends upon the number of stages varying from single stage to multistage, which planetary career acts as an important role [14].

Test Oils

The synthetic oils made up of very high viscous forces and testing methods adopted within the range of 290 mm^2/s to 400 mm^2/s is carried for this analysis. DIN 51501 standards are employeed in between the gearbox stages for effective measures of viscous forces and restrictive capabilities. The oil is well purified with clean adopting methods and cooled in dry storage for 120 hours with some additives for evaluating the assessment techniques.

Assessment of Additives

To improve the performance of the oil at various testing stages, the additives are essentially used. The type of additives used in this analysis is shown in Table 3. The observation and appearance of the oil is also elaborated in the same table 3. How ever it is notified that the drop in viscous property of the synthetic oil is found to be less at the running hours of 9000 hours. While exceeding these hours, the change in colour of the oil is observed and hence it is required to change the oil neccessory while exceeding these limits.

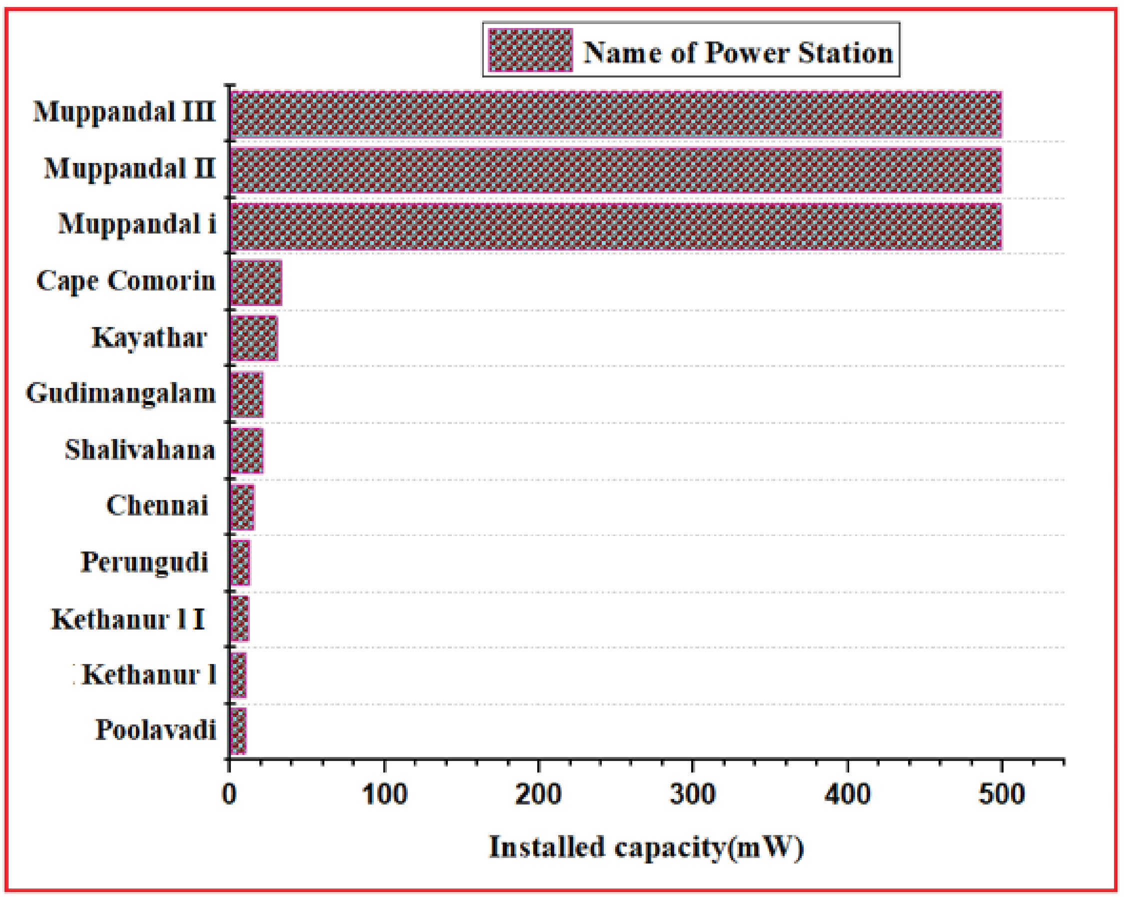

Figure 3. Total installed capacity of wind turbine in Tamil Nadu.

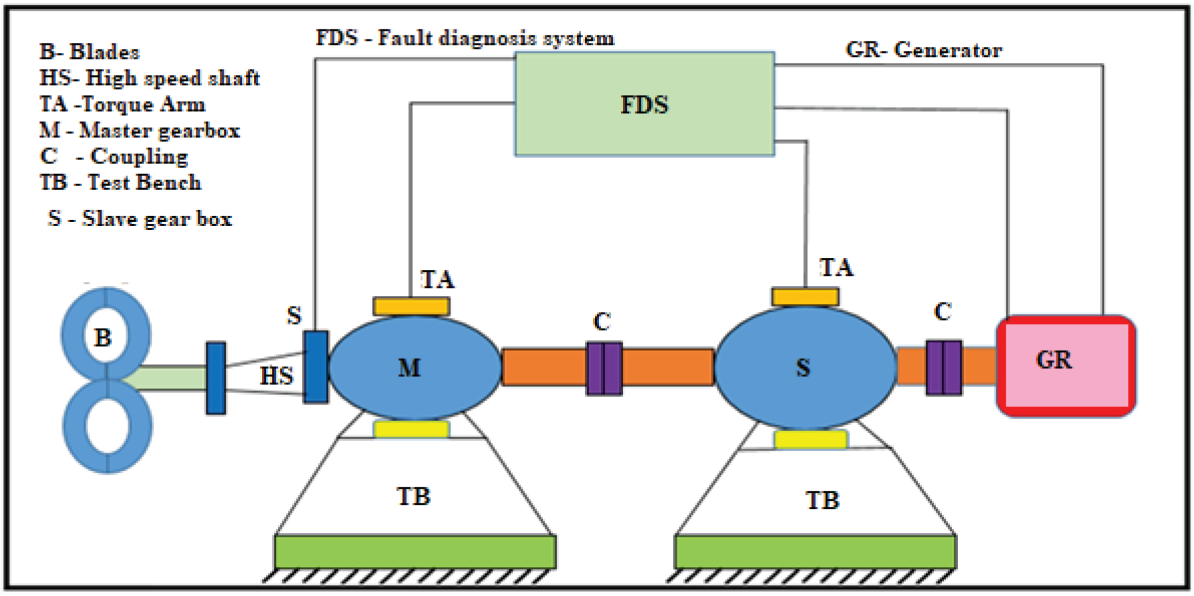

Figure 4. Schematic setup for experiments.

Actual Experimental Setup

The representation as shown in Figure 4 is experimental setup that required for carrying the analysis. The slave gear box is called as testing gearbox where the experiments and the necessary calculations are taken in to account. The wide amount of the data from jan 2022 to December 2022 has been stored using the latest technology sensors; the actual readings to be measured or live test trials can be done using this slave gearbox setup. The master gear box acts as reference gearbox where the past data is stored effectively for past one year or five years. Hence the measurements such as gearbox varaiations in speed, variations in resonance and deviations concerning the velocities have been tested and evaluated using this gearbox. The master gearbox acts as a reference and slave gearbox acts as a test trial gearbox or prototype gearbox; If there is any deviations found in the gearbox during the experiments; it will recycle the data by the use of fault diagnosis system. The least errors of the fault diagnosis system is found to be in the range of 1-3%. Torque arm acts as a best vibration reduction setup for reducing the major vibrations during the experiments.

Factors Concerning Performance Optimization

The performance of any gearbox depends upon the effective methods that require or necessity methods that requires to adopt, cool or dissipate the heat between the rotating parts of the machinery. The schematic representation of the factors affecting the performance of the wind turbine machine is shown in the Table 1. The reason behind the drop in thermal performance of the turbine gearbox is elaborately described in the last column

Table 1. Disturbed performance and faults

S. No	Event Code	Reason	Occurrence times	Type of event
1	82	Excess velocities.	200	Yaw damages
2	77	Bearing failures	300	Idle power
3	97	Gear teeth broken	321	Power shortage
4	85	Nacelle damage	400	Breakdown
5	94	Pinion failure	234	Pitch angle stop
6	101	Turbulent loads	651	Main shaft failure
7	123	Reduced viscocity of oil	234	Performance drop
8	99	LSS damage	134	Performance drop
9	83	Resonance in gearbox	121	High costs in breakdown
10	121	Generator failures	134	Idle machine

Table 2. Failures occurrences

S. No	Failure Type	Reason	Reference
1	Teeth Root damage	Less mechanical properties	[15]
2	Spindle worn	Low material life	[16]
3	Inner bearing ball worn	Insufficient oil	[17]
4	Root dia worn	Less mechanical stiff	[18]
5	Arm wear formation	Low mechanical properties	[19]
6	Worm wheel rust	Less stiffness capacity	[20]
7	Ring gear brokem	Low quality	[21]
8	Resonance at Ims	Lack of resonance calculations	[22]
9	Generator damage	Inadequate material weight	[23]
10	Drive shaft damage	Insufficient materials properties	[24]

Table 3. Oil properties

S. No	Duration in hours	Oil Used	TAN Observation	Additive Appearances	% change in viscocity
1	9000	PAG	No changes	-	85%
2	9000	PAG+17 PPM MZDPP	0.32 mgKOH/g	P: 25% S: -18%	80%
3	9000	MZDPPS +17 PPM	0.22 mgKOH/g	P: 21%, S:22%	71%
4	9000	High synthetic Oils	No changes	P: 8%	35%

of the Table 1. The majority of the failures occurred due to the lack of wind velocities resulting the uncontrol of cooling terminology of the wind turbines and associated parts. The one more major reason that affecting the performance of the turbine is heat distribution is overloaded for the bearings and associated parts due to the interrupt vibrations that caused. These interrupt failures cause overall drop in thermal efficiency of the wind turbines resulting poor formations of power outputs that affects the turbine and associated parts. The majority of the wind turbines starting from 100 kw to 1 Mw; due to the excessive vibrations and uncontrollable vibrations; the torque arms setups is disturbed and tends to propagate the cracks uniformly. From these failures, it is understood that the materials behaviour is the main concern for improving the performance of the wind turbine and associated parts. The faults concerning the teeths and associated terminology due to the excessive vibrations is shown in table 2. From Table 2 it is understood that the uneven distributions of loads caused by different terminologies seriously affects the performance by 6% compared to conventional methods. Hence it is need to prevent the failures of teeth and softwares by implementing strength-based materials and latest technology sensors for preventing the failures of the gearbox and entire turbine systems.

Uncertainty Analysis

It is required to conduct un certainty analysis of the gearbox and its associated parts to determine the thermal efficiency of the gearbox for predicting the known accuracies with calibrated accuracies denoted by equation (1) refered from [25],

$$\sum R_{b=\frac{2\sigma_e}{\bar{r}_b}*100} \tag{1}$$

Rb =Data of realistic that occurred.

σe= Data that procured by the attainment of deviation.

$\bar{r}_b$ = Attained data pertaining analysis.

σ_r = Concerned deviations measured from different variations.

The equation (2) refers some of the deviations deliberately achieved from the accuracies of testing equipments from the calibrated data refered by [26]

$$\Delta R = \sqrt{(\frac{\partial R}{\partial x_1}\Delta xb_1)^2 + (\frac{\partial R}{\partial x_2}\Delta xb_2)^2 + (\frac{\partial R}{\partial x_3}\Delta x_{b3})^2 + \cdots (\frac{\partial R}{\partial x_n}\Delta xb_n)^2} \tag{2}$$

Table 4. Instruments and its accuracies

S. No	Instrument	Accuracy	Required Range	Uncertainity %
1	Ims sensor	±2 °C	0 -280 °C	1.1
2	Gear encoder	± 4 deg	40-410deg	0.75
3	LDD sensor	±3 mm^2/s	0-30 m/s	0.90
4	Encoder of IMS	±3 deg	100-400 deg	0.20
5	Encoder of HSS	±4 deg	320-710 deg	0.22
6	Viscocity indicator	±3 mm^2/s	0-2000 mm^2/s	1.5
7	HSS indicator	±3 °C	0 -370 °C	1.1
8	Stopwatch	±0.7 s	-	0.3
9	Oil sump temperature sensor	±2 °C	0-200 °C	0.91
10	Anemometer	±3 m/s	0-35 m/s	1.1
11	Helical gear	± 3 deg	30-390deg	1.1
12	Tachometer	±12 rpm	0-12000 rev/min	0.21

RESULTS AND DISCUSSIONS

Rotor Speeds Distribution

The active power generation is the major dependent factor concerning the performance indication of the gearbox and its associated parts. Figure 5 depicts the factors that affected the gearbox due to the rotation of the gearbox average speeds caused due to different rotating speeds. At very low speeds ranging from 5 to 10 rpm, there is no power generation as shown in Figure 5 and it is called as idle stage. When the speed on the rotor increased from 5m/s to 10m/s the rotor speeds also increased from 10 rpm to 15 rpm causes the rotor to generate the power that shown in yellow colour in the figure 5; When the speeds exceeds the desired limits it causes heavy turbulence and the majority of the

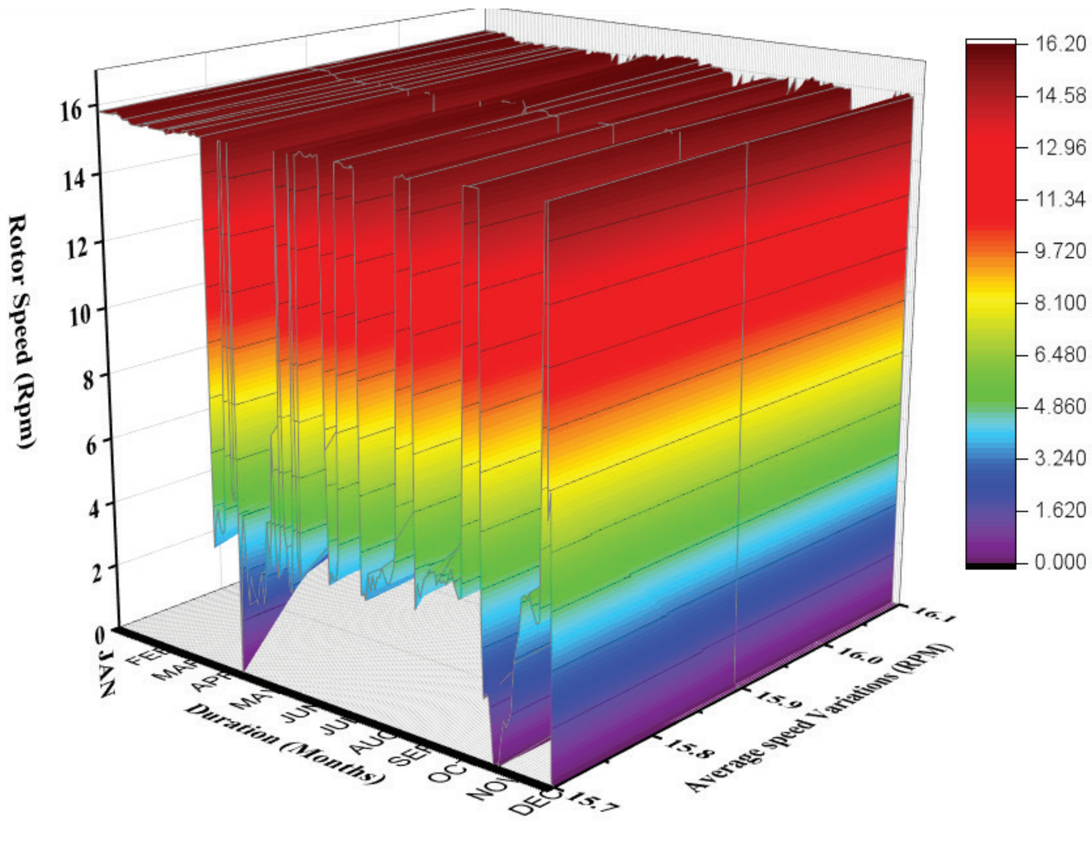

Figure 5. Average rotor speeds at inlet of gearbox.

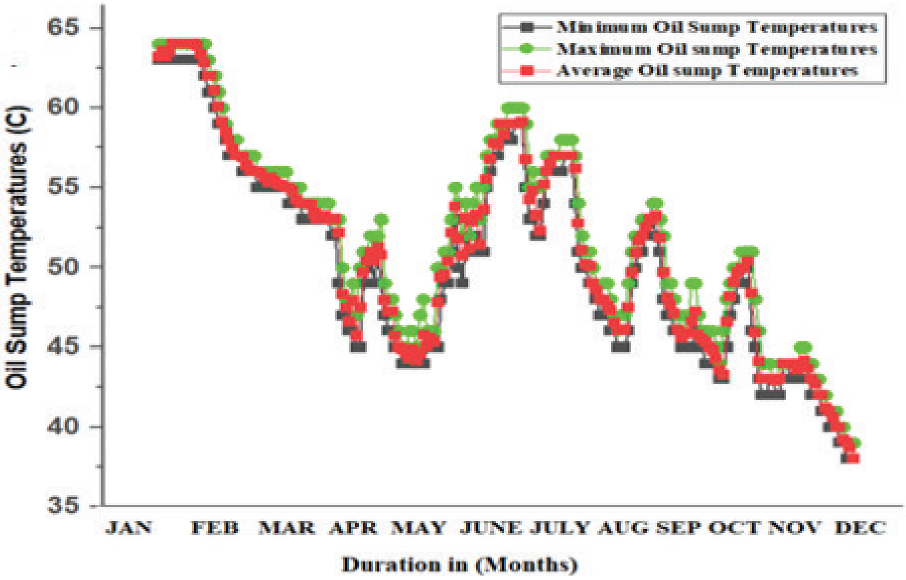

Figure 6. Oil sump temperatures**.**

breakdowns and failures caused due to the shutdown maintanence is occurred in this stage [27]; From the studies the measured velocities is 40m/s and the performance factors that affected is shown in Figure 5 highlighted in red colour. Hence the performance of the gearbox associated with rotor speeds depends upon the wind velocities and the materials used for achieving the power of the entire system. From the figure 5 it is also understood that the average rotor speeds achieved in this system is limited to 16m/s; because of high stiffened materials used in this analysis to manufacture the gearbox and turbine system causes interrupt power generations and routine maintanences and heavy breakdowns occurring in the system [28].

Oil Sump Temperature Distributions

The measurement of temperatures of oil is required to evaluate concerning the thermal performance of the gearbox and its associated parts. Figure 6 represents the obtained oil sump temperatures of the gearbox subjected to different temperatures. From the Figure 6 it is understood that the maximum oil sump temperatures is found to be 62 °C when the gearbox is subjected to starts rotating the power [29].

The average temperature distributions for the gearbox subjected to variational loads has wide substantial effects in terms of decreasing the viscocities, decreasing the low grades of the oil; decreasing the synthetic content of the oil grades and reducing the kinematic viscocities of the oil subjected to different elevated temperatures. Hence for the month of jan the substantial temperature difference is found to be 62 °C, but for the month of december the substantial temperature difference is found by 28 °C. Hence a gradual temperature difference is found for the different months starting from January to December 2022 [30]. Because of reduced power will be attained at intermediate stage and high speed stage causes the different fluctuations tends to reduce the temperature levels at different months. This phenomenon will affect the performance of the windturbine by 5% compared to other methods of breakdown systems [31].

Wind Speeds Velocities

The necessity of measurements of wind velocities is essential to estimate the performance of the wind turbine, The average velocities defines the amount of power that can able to generate and also it represents the actual wind velocities that should be required for development of power from initial stage to final stage [32]. Figure 8 represents the obtained minimum, maximum and average velocities of the wind turbine gearbox at different velocities. The maximum velocities is found to be in the month of march for attaining the maximum power of 1200 kw; the corresponding maximum velocity is found to be 13 m/s. Similarly, the minimum velocities is found at the month of July due to lower the surface temperatures on the surroundings of the earths atmosphere; the corresponding velocities is found to be 1.5 m/s. It is understood that the performance of the windturbine depends upon the maximum wind velocities and the higher the grading of the oil viscocities. From Figure 8 it is clearly understood that the maximum, minimum velocities concerned to the different months depends upon the wind velocities of the turbine [33].

IMS DE and NDE Temperatures

The performance of any wind turbine gearbox depends upon the temperature distributions of oil and its associated physical properties. The physical properties such as kinematic viscocity plays an important role for dissipation of heat [34]. The higher the viscocity causes higher the

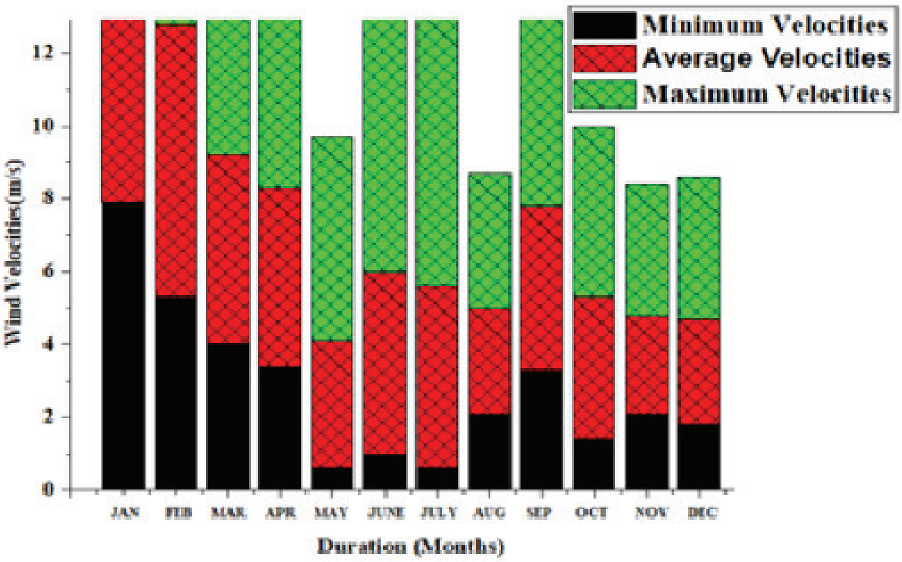

Figure 8. Wind velocities.

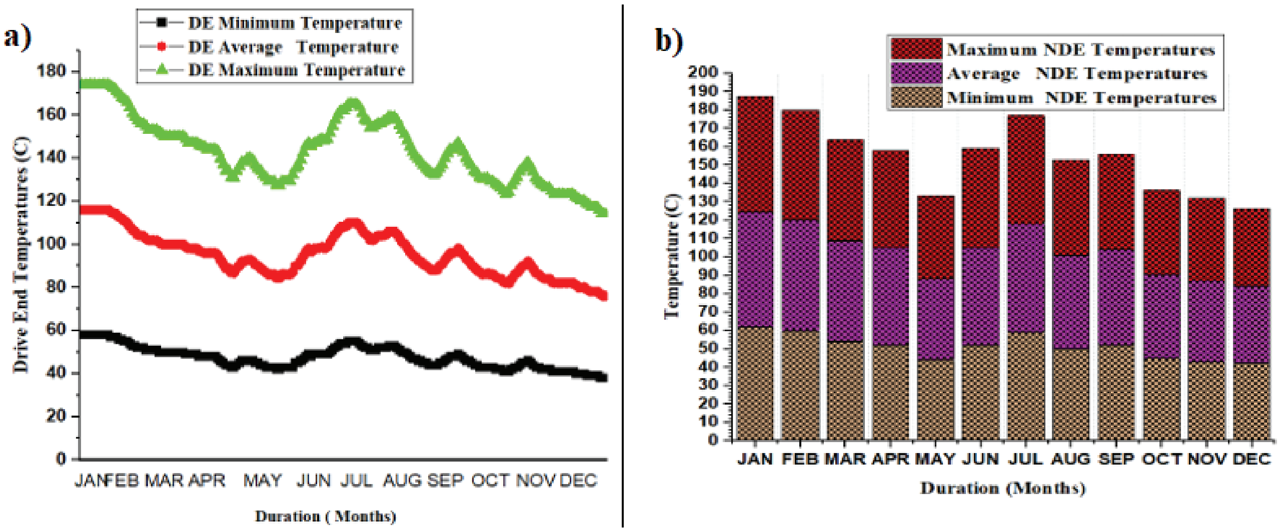

Figure 9. Ims temperature distribution a) DE b) NDE.

performance; but many of literatures significantly proved that the viscosity of oil is gradually decreased due to the turbulence effects of oil that circulates between the rotating parts of the meshed gears and its associated parts of the rotor [35]. Figure 9a depicts the temperature distributions of the intermediate shaft subjected to different fluctuations. The temperatures of the oil is maximum at the month of January in the range of 170 °C; but the temperature gradually decreasd to 140 °C at the month of December 2022, The temperature difference is seen that 30 °C for the entire period. Because of the viscocities of the oil is reduced gradually according to the time concern. It is also observed from the figure 9b; the gradual decrement of oil at drive end affects the performance of non-drive part of the gearbox by limited percentages as shown in Figure 9b. Hence it is understood the oil viscocities plays an important role for acheiving required outputs of the active power [36].

HSS Stage DE and NDE Temperatures

The 90% of active power generated from generator depends upon the high-speed shaft rotation and its maximum power attainment. The reliability of the high-speed shaft depends upon the definite endurance limits and its acceleration speeds [37]. Figure 10a represents the HSS temperature distributions of non-drive end and drive end stages. Figure 10a defines the attained temperature distributions from non-drive end. Figure 10b represents the

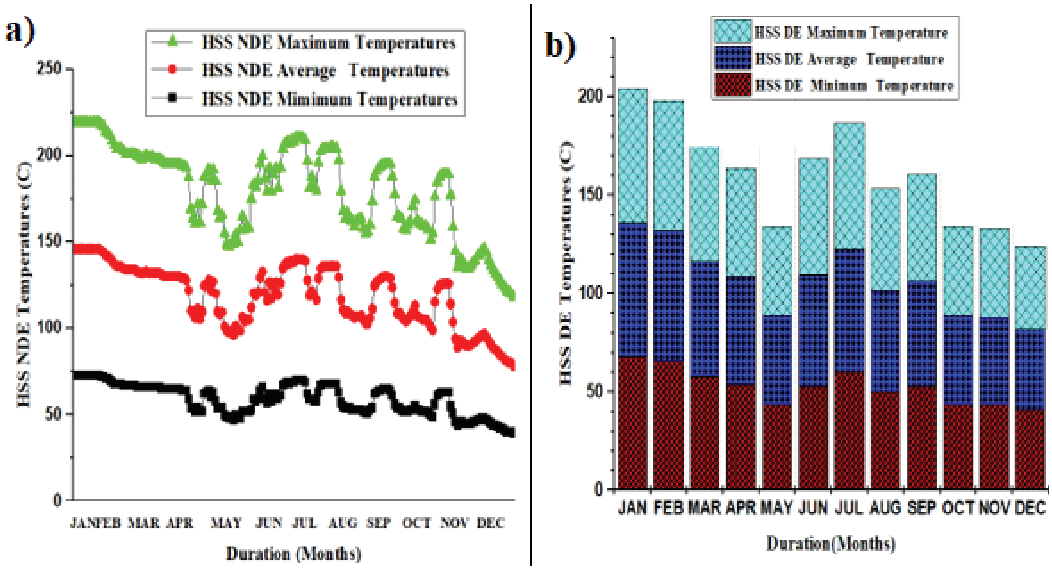

Figure 10. HSS temperature distribution at a) NDE b) DE.

attained temperatures of HSS from drive end. From these figures it is understood that even at elevated temperatures in the period of month January the temperatures dissipation of non-drive shaft is seen to be 220 °C and at the month of January and the month of December the temperature is gradullay decreased to 150 °C. The temperature drop is found to be 50 °C, Between the starting month to end month. Hence from these two figures Figure 10a and 10 b, it is understood it is required to use latest synthetic oil mixed with latest additives for dissipating the heat more than 100 °C for atleast 6 months. The cost and reliability of the oil is sufficient enough for overcome these difficulties concerned to investors for investing the money in the field of wind turbine industry [38].

Active Power Generation

The maximum power output of the wind turbine and its associated factors is explained with the help of terminology

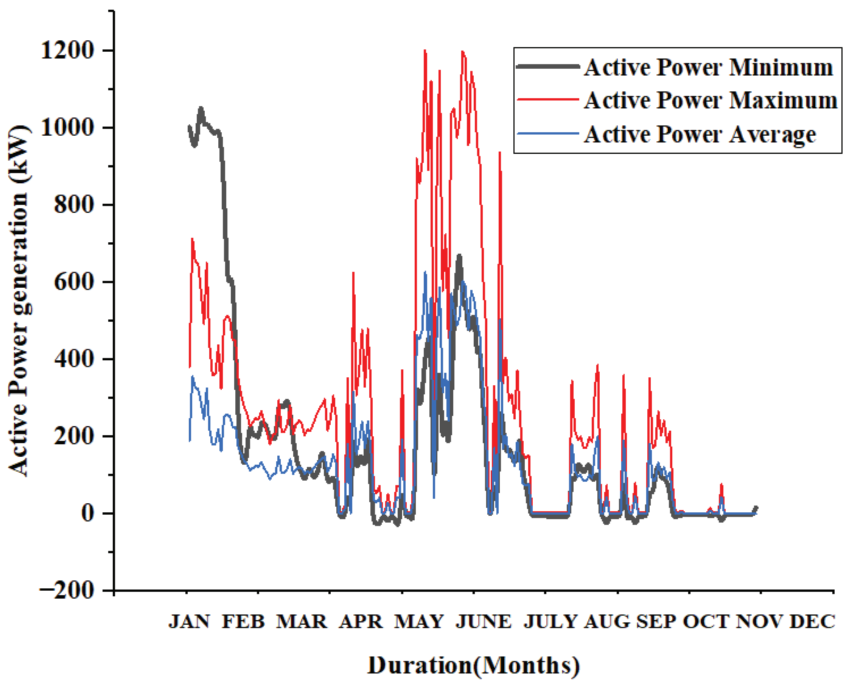

Figure 11. Power generation.

called as active power generation of the system. Figure 9 represents the obtained active power generations during the year of Jan 2022 to Dec 2022.The active power generations is minimum during the month of April and may compared to other months as shown in Figure 11. The reason behind the low in active power generations for this month is the wind generation is nearly 10m/s; but the oil sunp temperatures has exceeded beyond the desired limits; Hence the maintenances terms has been done for this particular month tends to reduce the performance drop of the system [39]. It is also noted that the active power generation is quite high for the period of May to June in the range of 1200 kw; because of good wind velocities were obtained for this period causes higher the performance of the wind turbine and associated parts. The adequate cooling's in terms of oil sumps, nacelle and good dissipations were achieved in this particular month compared to other months. Hence we can able to obtain maximum power during this period. How ever the moderate power generations is found in the period Jan 2022 to Feb 2022; Because of good conditions for the wind turbine and good fuel properties in terms of high viscosities were found in this period [40].

CONCLUSION

The LDD data of the period jan 2022 to Dec 2022 from the master gear box has been downloaded. The factors such as temperature data analysis for this period has been evaluated with the help of latest FFT technologies. From this analysis the gearbox performance from drive end stage and non-drive end stage is evaluated with the help of past one year data. The measurement of rotors speeds, wind speeds, average drive end and non-drive end speeds for the rotor, intermediate stages and high speed stages has been thoroughly investigated with the arrangements of master gearbox and slave gearbox setup. The most of the failures from 30-40% depends upon the poor replacement of oil due to failures of sensing the viscosicty of the oil, which results permanent failure and increases globally the frequent replacement costs. Hence it is required to adopt latest technology sensors with adequate synthetic oils for improving the overall thermal dissipation performance factors. This will rectify the root causes of several problems in the master gearbox. From this analysis it is understood that the following conclusions has been arrived.

- ❖ The conventional oils have very less viscous even the heating temperature exceeds 100 C and the life time to change the oil is restricted to less than 5000 hours.
- ❖ The synthetic oil with the combination of PAG+17 PPM have greater potential to restrict the frictional resistance of the heat occurs frequently.
- ❖ The implementation of oil (PAG+17 PPM) with the help of latest technology sensors gives better reliability of the gearbox owing to operate the gearbox at elevated temperatures exceeding 100$^{\alpha}$C.
- ❖ The implementation of LDD sensors with proper validations avoids breakdown maintanence frequently. This will boost up the generation of active power and keeps the wind turbine manufactures and investors always happy.
- ❖ It is found that active power generation depends upon the important factor such as wind velocity profile and the stages of the gearbox. The potential wind locations are choosen with the wind velocities of 20 m/s to achieve active power generations.
- ❖ The planetary gearbox setup with two stage is essential for achieving the rated power of the gearbox coupled with generator. The generator may be used here asynchronous generator which is easy to replace and maintains uniform power throughout the period of active power generation.
- ❖ The implementation of latest technology LDD sensors predicts the flexible torques and reduces the break down costs in the range of 11-15%; when the gearbox is operated at elevated temperatures.
- ❖ Hence it is adviced to implement the latest technology sensors which is capable to measure the wind speed loads of 20 m/s to 45 m/s.
- ❖ Almost 70-75% of active power generation depends upon the rotational speed at high speed shaft as well as dissipation of heat entrained between the intermediate shafts and bearing temperatures, oil sump temperatures, drive end and non drive end temperatures of the high speed shaft
- ❖ This gives range of resolution for downloading the past data and predicting the futurized data for evaluating the thermal performance drop; leads to save the maintanence costs 20% as compared to conventional methods.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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