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Research Article

Measurement of temperature flow analysis by condition monitoring system for WTG gear box to evaluate the thermal performance associated with plant load factor

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ABSTRACT

This research work is mainly focused on the performance of the wind turbine power plant. The performance of the plant will depends on the working of wind turbine gearbox. Hence the parameters taken like inlet velocity of air, inlet temperatures and inlet pressure of the air entering into the gearbox. For experimentation a three stage gearbox has been considered and the data has been recorded for the period of 5 months. These results has been recorded with the help of SCADA software and the results are imported from SCADA for analyzing the minimum and maximum oil temperatures. Since these parameters effects directly on the thermal performance of the wind turbine power plant. From the analysis it was found that the temperature sensors for monitoring the oil TM1 and TM2 within temperature limits of 250°C and also the TS1 and TS2 Promises the sensing capacity within temperature limits up to 200 °C and response time is 30 minutes, also the coupling temperatures TC1 and TC2 gives very promising results upto 150 °C for 30 minutes response time.

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INTRODUCTION

Temperature management or temperature monitoring plays an crucial role, while performing the gearbox role in the field of wind energy power generation. Since the temperature distribution of the lubricant flowing through the gearbox is increased, as stage of the gearbox is increased from single stage to multi stage gear box. Hence it was neccessory to monitor the temperature and pressures periodically, before the occurance of failures of the gearbox, The major issue behind the failure of the gearbox was crucially

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found that, down time management, and erection of gearbox from the wind turbine [Guo et al. [1]. Hence it was neccessory to test the gearbox completely as per the standards and regulations, which meet specific requirements for effective and smoother power transmission without fault diagnosis, it was observed that well automated fault detection system was to implemented for the prevention of failure Jiang G et al. [2]. Several research and reviews were conducted according to the statics of the recent failures caused by drastic wind velocity and turbulent behaviour of the wind. The study also reveals that the wind accident has been drastically increased from the year of 1996 to 2016, due to improper maintanence and substantial drop of lubricant proved by Wang et al. [3]. Most advanced techniques with latest sensors must need to employ to found fault diagnosis techniques, to prevent or minimize the downtime of the turbine. It was found that downtime maintanence of wind turbine gearbox has been rapidly decreased in the states due to latest and advanced technologies has been adopted, hence it was required to adopt those technologies in india, According to Nie et al. [4] and Kumar et al. [5], Fault tree analysis is the root cause method to identify the possible occurance of the failure to be occurred while the gearbox is running at very higher speeds, and the information also predicts may provides the maximum possible failures of gearbox parts such as bearings and higher speed fastners, bolts subjected to higher elevated temperatures proved by Zhi-Ling et al. [6]. The major downtime of the gearbox may occur due to the improper or poor maintanence of temperature, pressure and health monitoring sensors, leads to uncontrol the debris particle of oil resulted in increasing the down time of the wind turbine power plant represented by Feng et al. [7]. Hence it was neccesssory to monitor the temperature distribution of the oil from sump to all three stages, inlet stage, intermediate stage and high speed stage of the gearbox periodically. The viscocity drop of the oil was to be investigated by the SCADA 354 data analyzer to predict the drop in viscous of the oil, during the running of the gearbox at elevated temperatures. They have made analysis with two types of analysis with mineral oils and synthetic oils Sequeira et al. [8]. According to Tang et al. [9], the phenomenon of inefficient thermal drop in performance of the gearbox is due to the highest temperature of the oil that leaving from the low speed shaft into intermediate shaft through the bearings, to absorb the frictional resistance of the heat dissipation during the rotating parts, bearings and associated parts is monitored with the aid of outdoor temperature unit. Hence it was neccesory to monitor the debris of the contaminated particles that passing through the oil, when turbine rotating at elevated higher speed range, the three important factors such as condition of oil, Position of contaminants and wear rate of the rotating parts were carefully monitored Barrett and Stover [10]. The oil sump temperatures was quite increased as the load on the turbine increased, but there was an abrupt decrease in change in temperature of the oil sump was to be found, this is due to the phenomenon of average wind velocity turbulent behaviour may cause to cut off the wind turbine at higher velocity ranging above 35m/s proved by Beik and Al-Adsani [11]. The maximum generation of active power also depends upon the plant load factor, wind load fluctuations and several factors which may slightly improve the overall performance of the wind turbine Chen et al. [12]. The latest technology sensors has been introduced for measuring the wavelet frequency and harmonics to monitor the vibration was introduced by the scientist salem et al. [13]. According to the Fu et al. [14], forecasting of the wind turbine is a mandatory for all the wind turbines to predict the temperature analysis of the wind turbine, he also made a simple investigation on the field data for particular period of time and he was found that the temperature of the A06 gearbox was found to be higher in scenario reached to the temperature limits of 70°C. According to Kumar et al. [15], in depth investigation was done to found out fault diagnosis, FMECA studies and fault prognisis for different wind turbines and they developed a special algorithinm for monitoring the data of the gearbox and associated components, the temperatures of the main bearing and residual magnitude of the gear box were analysed. The key parameters such as temperature of the main bearing, temperature of the nacelle and temperature of the hub with respect to the active power of the system was to be analysed with respect to different residuals given by Muniamuthu et al. [16]. The analysis with respect to vibration analysis as key factor with respect to the temperature for healthy and faulty turbines was to be investigated and concluded that the RMS values were tooked into account for predicting the failures of gear tooths and gear pitting and crack in the shafts, pitting cracks in the HSS shafts and the tooth fracture of the bearing was tooked into account, due to the excessive temperature limits of the oil and the debris from the oil sump present the wind turbine gearbox. It was found that the maximum temperature can be attained up to the level of 120°C, This is due to the viscocity of the oil was been decresed due to the repetitive temperatures absorption and continuous debris in oil circulation Chougale et al. [17]. The authors suggested to implement latest technology sensors with higher accuracy; which promotes the prevention of breakdown maintanence to reduce the costs and generate the electricity.

METHODOLOGY

Wind blows at very higher velocities 13.5 m/s to 25 m/s at various coastal areas of tamilnadu in India. The field analysis was to done periodically 5 days to measure the average velocities of the wind that blowing, mean while if excess wind blowing from different positions will affect the average plant load factor, may damage the bearings of the gear box, neccessory of yawing system control also be studied Sunil Kumar et al. [18].

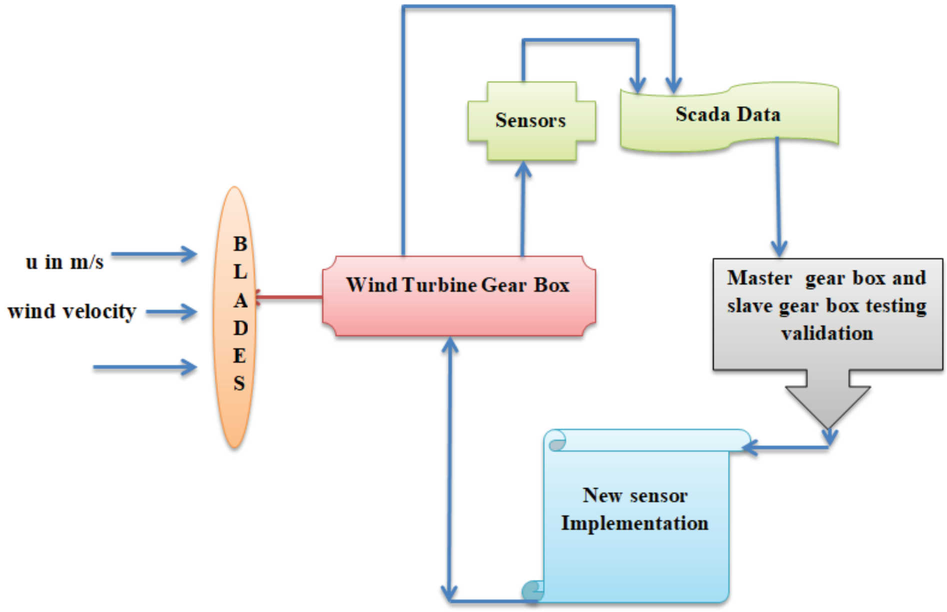

Figure 1. Methodology.

Figure 1 represents the methodology of the analysis with respect to test bench parameters for master gearbox and slave gear box. An WTG gearbox was to be investigated by test bench based on the past historical LDD data that downloaded from scarab and the average wind velocities were considered for this analysis. The temperature data was the main source of the analysis, Since majority of the gearbox failures may occur due to the oil sump temperature reduction Arun et al. [19]. The load distribution data [LDD] with respect to the outdoor temperatures, Nacelle inlet temperatures and oil sump temperatures were to be investigated for 5 months in the regions of tamilnadu and graphs were plotted as shown in below. The minimum, maximum and average temperature values of the outdoor, oil sump and HSS DE, HSS NDE, IMS DE and IMS NDE, Nacelle with respect to the rotational speed of the gearbox with average wind moving velocities were considered for this analysis.

EXPERIMENTAL SETUP

Figure 2 represents the schematic arrangement of test bench that can be evaluated to measure the thermal properties of the gearbox .The master gearbox and slave gearbox

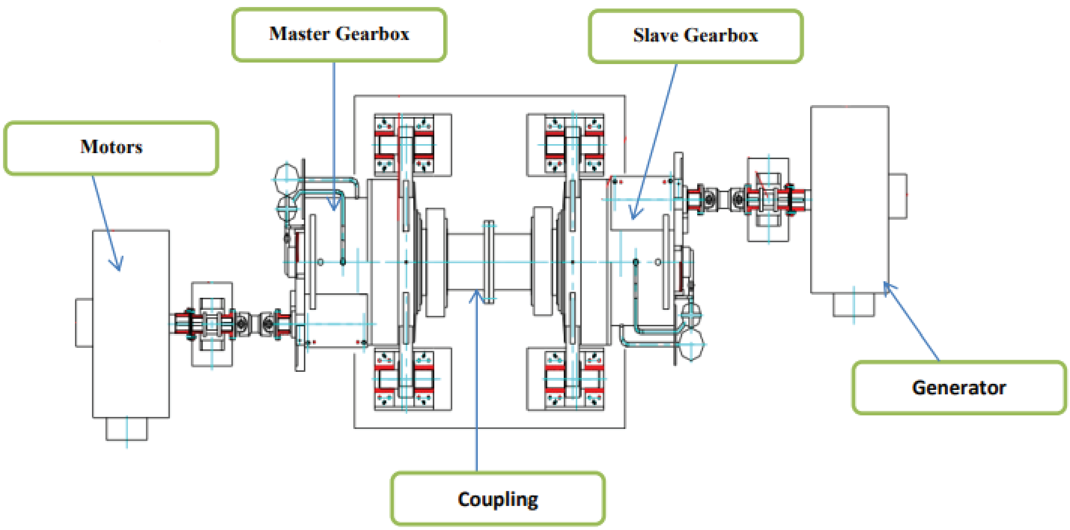

Figure 2. Experimental Set up.

were coupled together to transmit the power and the data was monitored with the arrangement of FFT analyzer and sensors. A probe of 5 KHz was employed to measure its dynamic charecteristics and the temperature sensors TM_1,TM_2 to master gear box temperature limits upto 250°C and sensing time 30 minutes. TS_1,TS_2 was employed to monitor the slave gearbox temperature limits within the limits of 200°C and sensing time 30 minutes given by Kumar et al. [20]. A specially employed temperature probes of TC1 and TC2 was kept inside the coupling sensor with the temperature limits of 150°C and sensing time 30 minutes. Hence the entire setup and experiment was analysed in the period of 5 months and compared the test bench results with LDD field analysis data. It was observed that the temperatures analysis from the LDD data can replace the exisisting sensors that reduces the break down maintanence and maximize the energy yield for entire average wind velocities. Table 1 represents events to be considered to evaluate the condition monitoring and Table 2 represents field analysis of the WTG turbine.

Figure 3 represents the pie chart representation of LDD data of active power distribution with different loads varying from 0% into 100% load conditions. Since the wind velocity was very high at the month of june, since there was a higher velocities was achieved during this month at rate of 18 m/s and hence it was possible to generate the average active power.It was noted that there was an sudden fall in power due to the higher wind velocities ranging from 35m/s to 45 m/s leads to cut of the wind turbine gearbox rapidly, and hence 37.5 % of the power generating period was considered to analyse the reason for breakdown and maintanence setups demonstrated by Kumar et al. [21]. It was clearly noted that the average outdoor temperature was maintained in between 34°C, and average oil sump temperature was maintained by the 60°C during this period.

Table 1. Events to be considered for conditon monitoring of Gearbox

SNO	Description	Units	Measured Values	Duration in months
1	Average Outdoor Temperature	C	33.38	5
2	Average Oil Sunp Temperature	C	59.33	5
3	Average Wind Speed	m/s	6.62	5
4	Temperature HSS DE Average	C	67.76	5
5	Temp HSS NDE Average	C	67.70	5
6	Temp IMS DE Average	C	54.92	5
7	Generator Speed Average	rpm	1184.2	5
8	Nacelle Temp Average	C	34.47	5
9	Rotor Speed Average	rpm	12.44	5
10	Generator Speed Average	rpm	1184.8	5
11	Active Power Average	kW	492.8	5

Table 2. Field Analysis for WTG turbine

SNO	Load in %	Power in kw	Range in %	Active power in %
1	**0**	**< 0**	**<0**	**37.5**
2	0	0	0	2.3
3	10	210	0 - 10	16.9
4	20	420	10 - 20	10.6
5	30	630	20 - 30	8.2
6	40	840	30 - 40	6.3
7	50	1050	40 - 50	4.7
8	60	1260	50 - 60	3.3
9	70	1470	60 - 70	2.3
10	80	1680	70 - 80	1.7
11	90	1890	80 - 90	1.5
12	100	2100	90 - 100	2.2
	Above 100		>100	2.6

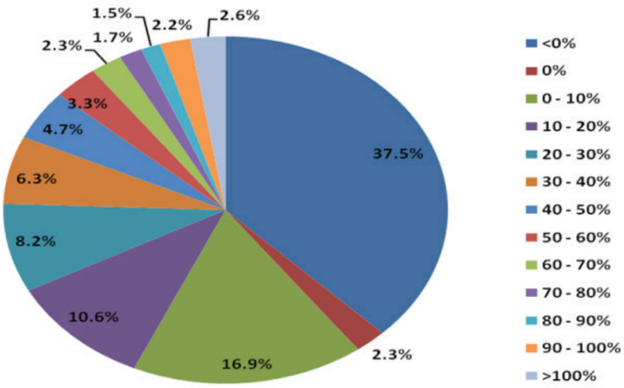

Figure 3. Active Power distribution for the average 5 months duration.

UNCERTAINITY ANALYSIS

The uncertainity analysis is essential to estimate or measure the accuracy of instruments to be used for testing period of 5 months. Table 3 represents instruments used and its uncertainities; Table 4 uncertainties in measured parameters. The actual readings and deviation in readings for the repeated during experimental process is given by Eq (1).

$$\sum R_{n=} \frac{2\sigma_r}{\overline{r}_n} * 100 \qquad (1)$$

R_n= Realistic reading during testing.
σ_r= Deviated data after testing.
$\overline{r}_n$= Obtained uncertainity data from analysis.
σ_r= Standard deviations respect to accuracy of instrument.

The parameters to be measured and correlated to evaluate the deviations and exceeded uncertainty within limits is evaluated by Eq (2) as

$$\Delta R = \sqrt{(\frac{\partial R}{\partial x_1}\Delta x_1)^2 + (\frac{\partial R}{\partial x_2}\Delta x_2)^2 + (\frac{\partial R}{\partial x_3}\Delta x_3)^2 + \cdots (\frac{\partial R}{\partial x_n}\Delta x_n)^2} \qquad (2)$$

Table 4. Measured uncertainities

Measured parameters	Percentage uncertainty
Inlet wind speed	±0.45
Inlet shaft speed	±0.24
Oil sump temperature	±0.1
Ims temperature DE	±0.27
Ims temperature NDE	±0.3
HSS temperature DE	±0.6
HSS temperature NDE	±0.7
Generator speed	±0.34
Active power avg.	±0.3

RESULTS AND DISCUSSION

This part includes the discussion of measurement of outdoor temperatures with respect to nacelle and IMS, HSS stage and measurement of plant load factor for the active power average during 5 months. From the measured data the efficiency or plant load factor depends upon the debris size of the oil particles and life of the oil with higher viscocity; in addition to that less break down maintanence of the plant. The necessity of checking the oil temperatures from the latest technology sensors leads the prevention of break down maintanence; leads to improve the overall efficiency of the turbine.

Table 3. Instruments and its accuraties with uncertainities

Sno	Instrument	Accuracy	Range	Uncertainity %
1	Tachometer	±10 rpm	0-11000 rev/min	0.2
2	Stopwatch	±0.6s	-	0.25
3	Anemometer	±2 m/s	0-40 m/s	1
4	LDD sensor	±2 mm²/s	0-30 m/s	0.85
5	Encoder of IMS	±2 deg	200–400 deg	0.16
6	Encoder of HSS	±3 deg	310-610 deg	0.18
7	Oil sump temperature sensor	±1°c	0- 210°C	0.85
8	Ims temperature sensor	±1°c	0 -310°C	1
9	HSS temperature indicator	±2°c	0 -410°C	1
10	Planetary gear encoder	± 3 deg	50-400deg	0.85
11	Helical gear	± 4 deg	50-400deg	1
12	Viscocity indicator	±2 mm²/s	0-1000 mm²/s	1.3

Measurement of outdoor, nacelle with respect to active power

The measurement of Outdoor temperature, oil sump temperature and Nacelle temperature was important behaviour in terms of measuring the overall thermal behaviour of the gearbox oil with respect to different temperature limits Marques et al. [22]. From Figure 4 it was found that the outdoor temperatures of the oil was been increased upto 54°C, Where as the oil sump temperature was reached to maximum of 64°C and Nacelle temperature of the WTG was to be increased upto the maximum of 40°C and average of 32°C. This is due to the friction of rotating parts and the concentration of debris particles in 40 µ may increase the temperatures of the oil at different flowing phenomenon. Outdoor Temperature monitoring is a preliminary key factor that required to control the wind turbine gearbox.

Figure 4 represents the temperature distribution analysis of oil that passing through the several stages of the gearbox, starting from single stage of the gearbox to the final stage of the gearbox housing. It was observed that outdoor temperature was quite low at the starting of the turbine and quite increased during the peak hours of the turbine that reacts to generate the power. The drastic wind velocity may sense the yawing system to cut of the wind turbine from power generation and turbine was quite running with idle for specific period of time.

Measurement Of IMS DE And NDE Maximum Temperatures

The measurement of Intermediate shaft drive end and non drive end is the important key factor to evaluate the thermal performance of the gearbox. The 75% Active power that generated depends upon the intermediate stage of the gearbox, and also the torque that generated in this stage should be adequately maintained for next stage of gearbox (HSS) through non drive end. Figure 5 represents intermediate stage of drive end and non drive end temperature distributions of the 2.1 MW gearbox.

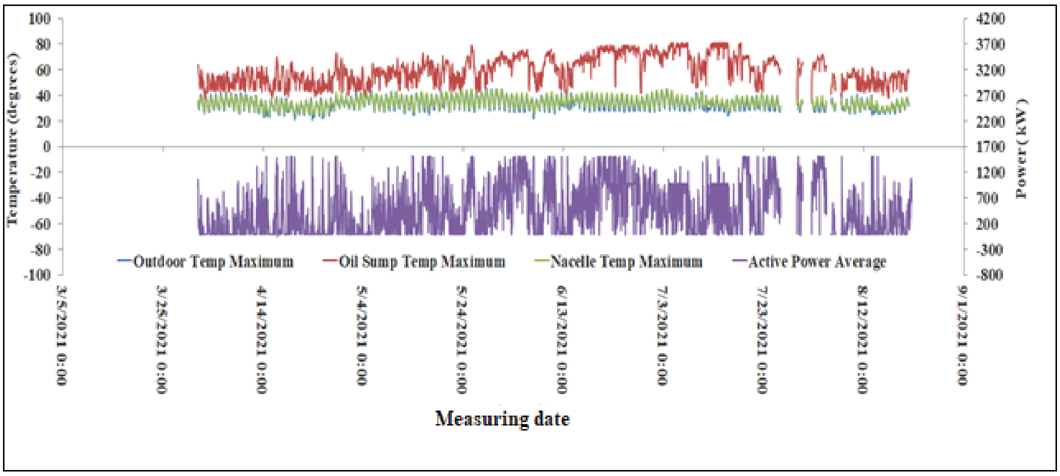

Figure 4. Outdoor, Nacelle and Active power temperatures with respect to Active Power (kW).

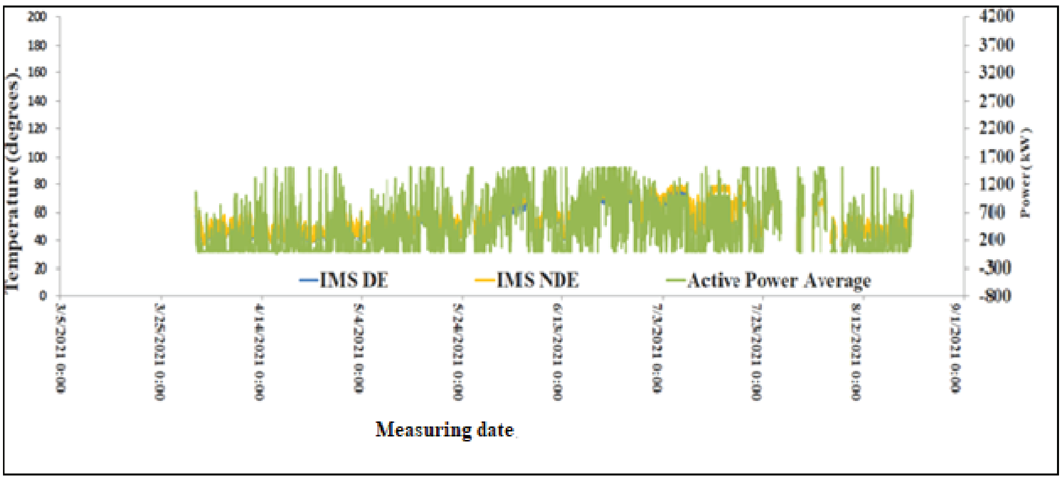

Figure 5. IMS DE and NDE Maximum temperature distribution.

Measurement Of HSS DE And HSS NDE Temperatures

HSS DE means for High speed shaft drive end, where the rate of torque inputs were to be given inadherence to lower velocities ranging from 5 m/s and HSS NDE stands for High speed shaft non drive end, where the rate of torque and it was an indication of the measurement of temperatures at the High speed shaft with respect to rated torque and power Feng et al. [23]. Figure 6 represents the high speed shaft drive end and non drive end temperature distributions. The temperature and pressures after leaving the IMS drive end is connected to the HSS drive end where the rate of the power is to be increased with respect to initial velocities and the temperatures that attained during this time period was attained up to a maximum of 110°C. This is due to the less viscous in nature given by de Azevedo et al. [24]. Hence the temperature distribution for the HSS drive end and HSS non drive end projects the overall performance of the turbine with respective Active power, however in case of failure in sensors results the heavy breakdown maintanence in the period of fall in wind velocities given by Kumar et al. [25].

Measurement of Plant Load Factors

Plant load factor PLF is key factor to estimate the performance of WTG. The plant load factor simply called as plf was defined as the ratio of power obtained at the HSS to the overall capacity of the plant, in other words it can also called as capacity factor proved by Gupta [26] and Meng [27]. Figure 7 represents the plant load factor for the duration of the 5 months. Here it was observed that the maximum plant factor

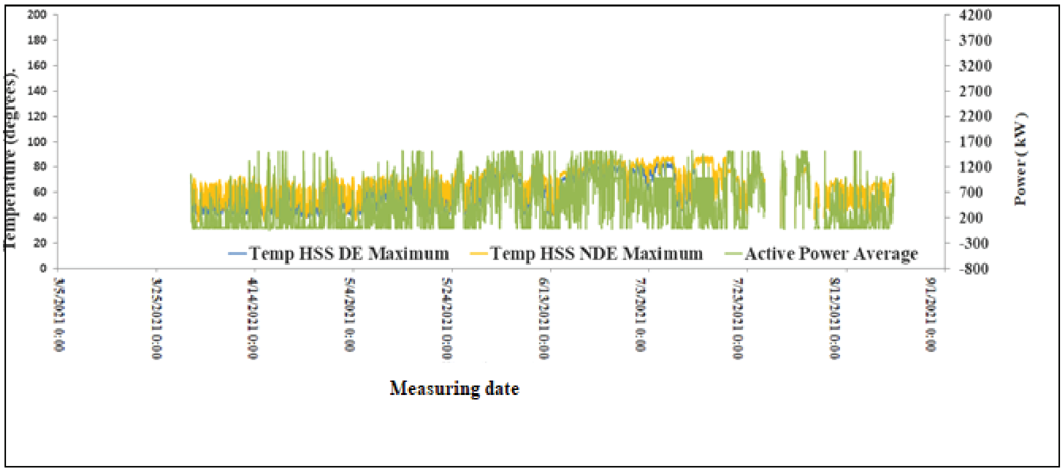

Figure 6. HSS and NDE temperatures distribution.

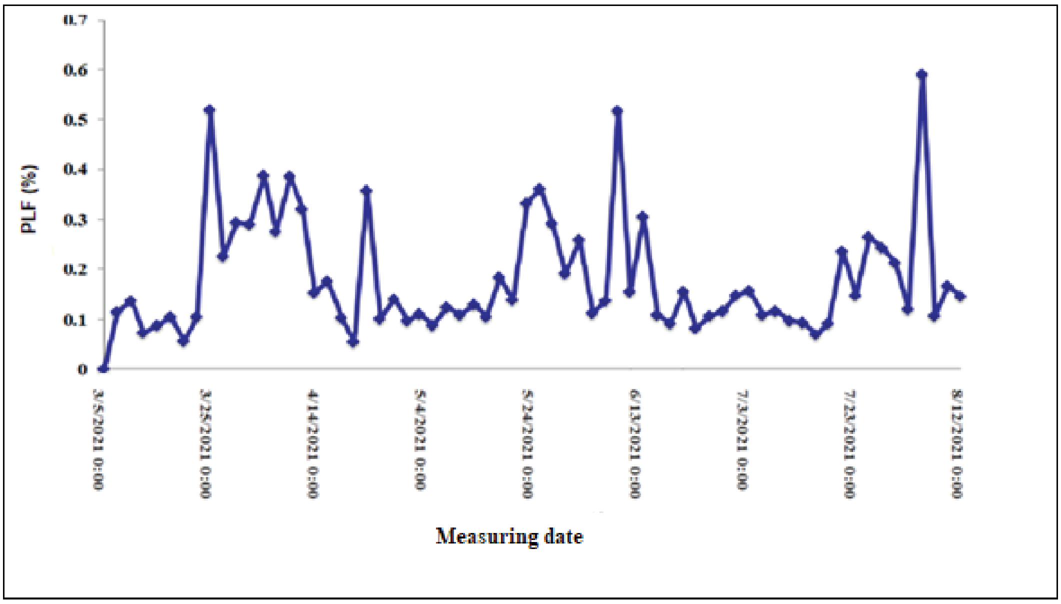

Figure 7. Plant load factor representation.

was 0.6 at the end of 5 month .This was due to the phenomenon of higher range velocities at the month of july and august. So it was observed that the wind flow during the month of august will improve the overall performance of the WTG and associated performance factors proved by Kumar et al. [28].

CONCLUSION

Condition monitoring for the three stage gearbox for the wind turbine was to be analysed for the period of 5 months and average LDD values of outdoor temperature, oil sump temperature and indoor temperature was to be analysed. The parameters such as HSS DE, HSS NDE was also analysed with respect to average values of active Power and also the parameters such for IMS DE, IMS NDE was also to be analysed for the period of 5 months. It was found that the temperature sensors TS1 and TS2 have the withstand capacity of 200°C, Whereas the temperature sensor for coupling can able to withstand the temperatures limits of 150°C. How ever the design limits for the temperatures to be maintain was giving promising results to prevent breakdown, but the response time of the sensors is limited due to lower limitation capacity of debris particle sizes upto 50μ. Hence it was suggested to introduce the new technology sensors having greater response time ,and to control minute debris particles of the oil particles.

NOMENCLATURE

TC_1	Temperature of the coupling sensor at inlet in °C
TC_2	Temperature of the coupling sensor at outlet in °C
TM_1	Temperature of the master gearbox at inlet in °C
TM_2	Temperature of the master gearbox at outlet in °C
TS_1	Temperature of the slave gearbox at inlet in °C
TS_2	Temperature of the slave gearbox at outlet in C

ABBREVATIONS

mW	Megawatts
DE	Drive End
SCADA	Supervisory Control and Data Acquisation
LDD	Load Distribution Data
WTG	Wind Turbine Gearbox
IMS	Intermediate Stage
HSS	High speed shaft
WTG	Wind turbine gearbox
NDE	Non drive end
PLF	Plant load factor
RMS	Root Mean Square
FMECA	Failure mode effects And critical analysis
FFT	Fast fourier transform

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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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