Operation & Maintenance Tool of Wind Turbines: Condition Monitoring Techniques

[1]Abhijeet J Patne, [2]R S Ambekar, [3]Mukteshwar N Patil, [4]Rajesh M Holmukhe,
Department of Electrical Engineering, Bharati Vidyapeeth (Deemed to be University) College of Engineering,Pune

Abstract

Wind turbine generator is rotating machine. It consists of number of electrical, mechanical and electronics part. Some of them are very sensitive to electrical power fluctuation and environmental conditions. Temperature of mechanical and electrical component raises to higher value due to atmospheric condition or problem in components like lack of lubricant in gear box, improper setting of pitch motor, yaw motor brakes in wind turbine generator. If it persists in system for longer time then it may lead to permanent failure of generator bearing, gearbox, pitch and yaw motor. Gear box, generator and main bearing are main and costly part of wind turbine generator and located on same shaft called drive train. Its destruction and erection is not simple .It takes more time to restore from breakdown into service. That mean it is time consuming as well as expensive process. So it is possible to eliminate these problems by adopting condition monitoring techniques. These techniques also help to understand health of wind turbine. In this paper, Author discussed vibration analysis of wind turbine, oil analysis of gear box, temperature and thermography analysis of different components of wind turbine generator and also stated the benefits of condition monitoring to service provider, customer. Finally author provided suggestion to improve condition monitoring techniques.

***Index Terms*— Wind Turbine Generator, SCADA, Vibration Analysis, Oil Sampling**

I.INTRODUCTION

Wind power generation system is structure of various components which used to convert kinetic energy of wind into electrical energy. Wind resource is one of the reliable energy sources for energy generation in world. As per report of WWEA world wild wind generation capacity was 456 GW in mid of 2016. India, Germany and Brazil are leading countries in wind energy generation. Wind energy contributes 5% to world energy demand. Wind companies have target of 12% of wind energy contribution to energy demand by 2020. Power generation in world is 80 to 90% from non renewable source. Power generation with non renewable sources is major reason of global warming. Govt are introducing better policies to produce clean energy and also requesting to energy investors for investing in renewable energy source. Wind energy is large power generation source as compared other renewable power generation source. It requires less space as compared to solar power plants. Suzlon, Vestas, Gold wind, Enercon, Siemens are wind turbine generator manufactures and service providers.

There are different models like 600kw, 1.5, 2.1Mw, 3Mw in wind turbine which define generation capacity of wind turbine. Customers can easily purchase their choice model of wind turbine as per their budgets. Wind turbine generator is a complex machine. There are costly components and most of the components are located in Nacelle and Hub. Nacelle and hub is the top portion of wind turbine generator. Hub is assembly of three blades with pitch drive and hub panel and it is rotating part of wind turbine generator. Nacelle is assembly of gearbox generator or DFIG, main bearing, nacelle panel. Nacelle rotates in 360 degree with help of yaw drives. Bearings and gears are parts of this components and its help to smooth operation of wind turbine. Suppose wind turbine generator runs with damaged bearing, broken teeth gears then it create serious problem with company asset and life of turbine. Condition monitoring is a process of checking health of wind turbine and its auxiliaries. It is used in thermal power plant, wind power plant, manufacturing industries etc. In this paper discussed technique of condition monitoring and tool of condition monitoring.

.

II. Need of Condition Monitoring in wind farm

Wind farms are major sector of investment for customer to make money. There are different power sector where investor can invest their money but now day renewable energy (wind Energy) is best for investment due to availability of subsidy, relaxation on rules regulation, no need of fuel cost and also get higher price for selling unit. It is around 8 to 12 INR per unit. Customer has higher expectation from service provider that their wind farms should be available maximum time for generation. So it is big responsibility for service provider or operation and maintenance team to maintain stability and reliability of wind farm and maximize performance of wind

Abhijeet J Patne, M Tech in Electrical- Power System, Bharat Vidyapeeth Deemed university College of Engineering, Pune, Maharashtra, India (email: abhipatne3@gmail.com)

R S Ambekar, is associated prof. with the Electrical Engineering Department, Bharati Vidyapeeth Deemed university College of Engineering Pune, Maharashtra, India (e-mail: rsambekar@bvucoep.edu.in)

Mukteshwar N. Patil, M Tech in Electrical- Power System, Bharati Vidyapeeth Deemed university College of Engineering, Pune, Maharashtra, India (e-mail: mnpatil888@gmail.com)

Rajesh M. Holmukhe is Prof. with the Electrical Engineering Department, Bharati Vidyapeeth Deemed university College of Engineering Pune, Maharashtra, India (e-mail: rajeshholmukhe@hotmail.com)

farm. Customer satisfaction is main aim of service provider and manufacturer. They carry many activities and programs for improving the performance of wind farms. Condition monitoring is part of activity running by operation and maintenance team. Condition monitoring helps them to early identification of faults or abnormal conditions in wind turbine. It also helps to OMS team to prepare for complete operational and maintenance need. There is chance of vibration in wind turbine generator due to higher level of wind fluctuation. Jerky wind, sudden grid failure cause higher stress on main bearing, gear box, NDE, DE bearing. There is chance of misalignment of generator, loosing of tower bolts, vibration. It is very important to carry vibration analysis of wind turbine regularly to avoid critical breakdown. Wind turbines are available in different designs and techniques which changes with wind turbine manufacturer. Some wind manufacturers are using hydraulic pitching of blade and other are using electrical pitching. Other part of condition monitoring is temperature analysis of wind turbine generator. Temperature of wind turbine is increased due lack of lubrication, improper setting of brakes in pitch motor, yaw motors, lack of cooling fans , used of damaged part in operation. If it continuous persists in system then it may lead to major breakdown of system component of fire. It is very important to carry temperature analysis and corrective major to avoid major issues. Vibration and temperature analysis is part of condition monitoring of wind turbine generator and it has high importance towards performance of wind turbine generator.

III. Condition Monitoring Principle

Condition Monitoring is defined as regularly or intervals observation and measurements of components parameters, study and analysis of measured data of components in wind turbine generator.

- It helps to Increase the time between failures of machine. (Reduce the frequency of breakdown)
- Early fault detection help to reduce repair time.
- Arrangement of material gets easy due to early fault detection. Machines will not stop due to material requirement.
- It helps to eliminate secondary fault generation in system.
- It helps to increase the system availability and performance of system.

Figure 1 show the components condition with respect to time. Regularly or periodical condition monitoring in wind turbine help to detect fault alarm before it converts to major breakdown. Time between alert level to danger lever is called lead time before failure. There is necessary action required against fault detection at alert level or fault warnings.

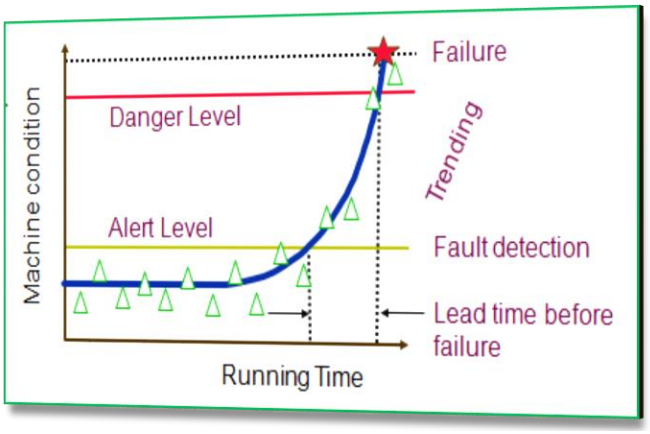

Figure 1

IV. Most Critical Parameters in Wind Turbine Generator

Followings are the most critical parameters of wind turbine generator which are essential to be monitor.

1. Over speed
2. Vibration
3. Cable Twist
4. Fire
5. Low Production

1. **Over speed**: Wind turbine starts to rotate at cut in wind speed. It is vary with capacity of wind turbine and types of blades. It gives maximum output generation at rated wind speed. It is mostly between 12 to 20 m/s. lastly cut out wind speed in wind turbine automatically stopping operation due to higher wind. In over speed operator lose control over wind turbine. It happens due to malfunction of wind turbine blade. It will be less critical in low wind speed but in high wind or at rated wind speed there will be chance of wind turbine damage.
2. **Vibration:** wind turbines stand with heavy weight of nacelle and hub at a height of 70 to 120 meters. Jerky wind, feeder jerk or sudden grid failure cause creates problems like loosing of bolts, disturb in alignment of generator and gearbox. Vibrations occurred due to use of damaged components, misalignment of components, and lack of smooth pitching of blade. If the blades are not properly calibrated then it will be produce higher vibration at wind turbines production state. Vibration problem can be mitigated with proper lubrication, greasing, proper alignment of wind turbine components which help for Smooth operation of bearings and gears.
3. **Cable Twist:** Yawing is process of moving nacelle 360 degree horizontally to catch the wind speed. In this process if nacelle goes continuously in one direction then there will be generate stress on cables which are provided for bottom to top supply. This can

damage all cables insulation or cables, chance of fire. Condition monitoring plays important role to control the continuous yawing. For this purpose SCADA is used which tool of condition monitoring.

4. **Fire:** Fire introduced due to increase in temperature level of wind turbine components, poor insulation power cables, improper wiring in panels, and use of damaged components in panels. Like damaged capacitor. Turbine manufacturer already given facility to detect temperature at early stage with help of sensor. PT100 sensors mostly used for determine Nacelle, Capacitor panel, power panel. SCADA is used to monitor temperature condition of wind turbine.
5. **Low Production:** Customer invested their money in wind farm for making more money. But sometimes wind turbines can't produce rated output power even at rated wind speed. Cause direction of nacelle not aligned to wind direction. Second reason is improper blade pitching or wrong calibration of blade. Wind farm is group of number of wind turbine so it is impossible to physical observation of individual wind turbine is not possible. Condition monitoring with help of SCADA tool is possible which help to take early action and avoid major breakdown.

Figure 2 categorized the frequency of breakdown with components of wind turbine. From fig we can conclude that maximum breakdown occurs in rotating part where lubrication, alignments is required. We can observe that these components are main part of wind turbine generator and they are costly.

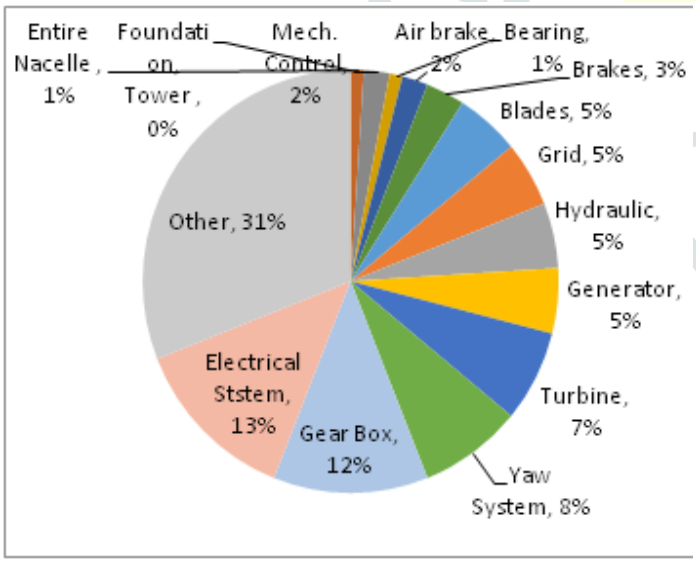

Figure 2

VI. Condition Monitoring Techniques

1. Oil Analysis

Lubricating oil is part of machine which used to smooth operation of machine. It creates film between two or three loaded surfaces. It is work as coolant and also clear containments. It protect machine from corrosion and rust. Part of wind turbine works under heavily loaded conditions so there will be greater wear and tear. Lubricant protect to these wind turbine part at some level after that there will be build up containments due to wear and tear which lead to decline of oil property. If we ignore condition monitoring of oil and its analysis then there may be chance of degrade the performance of wind turbine.

Oil sample testing is required regularly to maintain the property of oil in wind turbine components. Oil testing ensures us about quality of oil used in component, Level of oil, about machine cleanness. Proper lubrication help to increase performance of wind turbine, avoid breakdowns, increase the life of wind turbine, and improve performance the maintenance activity.

Oil test are mostly carried out through taking sample oil from gearbox and other auxiliaries of wind turbine. This oil sample test is done through visual check, smell of lubricant. If results are found ok then there is no need to lab testing.

Following are the test carried out in Oil Analysis:

Oil Viscosity test: Oil viscosity is property of lubricant which determine the level of thickness between two loaded surfaces. Viscosity of oil changes with temperature in machine. Oil viscosity test is important to improve machine efficiency.

Total Acid Number: It is done for determination of total weak and strong acid present in lubricants that are produced as results oxidation. It attacks and corrodes the metal part of machine components.

Moisture test: Water contamination in oil can damage both oil and wind turbine component. It also reduces life of components. Causes of moisture in oil are leakage of oil coolers, ingress, and water in new oil, condensation.
Particle quantity fire index: It is used to determine total ferrous or iron contents in oil sample.

Oil cleanness: Oil cleanness of oil is defined as the number of particles present in oil. SkF recommends NSA class 6 or ISO 4406 class 15/12 for circulating in gearbox and other wind turbine components.

2. Vibration Analysis:

Vibration is mechanical parameter which defines as oscillation occurs about equilibrium point. Vibration monitoring is technique of condition monitoring which used to determine the vibration of rotating part. Rotating part of wind turbine includes drive train assembly – Gearbox, generator, fluid coupling, rotor shaft, tower and blades.

It is very difficult to measurement of vibration data because continuously changing wind speed and load condition on wind turbine component. Any machine's vibration analysis can be successfully done only when current reading data can be compared with data sheet and it should not be exceed to data sheet value. There may be chance of false alarm of vibrations

due to high wind speed fluctuation. Mechanical Drive train vibration, mechanical tower vibration errors normally occurred at high wind speed about more than 23 m/s.

In wind turbine three types of vibration are measured by using PCH vibration sensor. These Vibrations are Axial Vibration, horizontal vibration and vertical vibration. Displacement, velocity, acceleration, frequency and phase are the parameters are considered for vibration analysis.

Method of vibration analysis:

1 .Overall Vibration
2. Phase
3. Acceleration Enveloping
4. SEE Technology (Accoustic Emissions)
5. High frequency Detection (HFD)
6. Other Sensor Resonant Technologies

3. Temperature Monitoring

Wind turbine or components temperature is another critical factor. There is need of continuously monitoring of wind turbine. Negligence in monitoring of temperature related alarms leads to fire in wind turbine. In wind turbine there is possibility of temperature rise in control, power, capacitor, Nacelle and hub panels, generator windings and bearings both Non-drive end and drive end, Gear box oil, Main bearing, and fluid coupling. Temperature values are measured with help of PT 100 sensor, RTD sensor. Temperature rise in mechanical part of wind turbine is mostly due to decline in lubricant property or wear and brake of teeth, gear, rolling ball. Temperature increases slowly and if it goes beyond specified limit then wind turbine gets to breakdown. So condition monitoring through SCADA help us to find root cause of alarm.

Figure 3, 4 represents the temperature analysis of wind turbine generator. Figure 3 gives the detail the temperature analysis of generator winding. Temperature readings are taken through winding sensors and figure 4 shows temperature analysis of gearbox non drive end bearing. Gearbox bearings and gear oil play important role to smooth working of gears. Both cases data obtained from sensors should not be exceed slowly and continuously above manufacturer stated temperature value. Some case of temperature rises was obtained due to sensor malfunction.

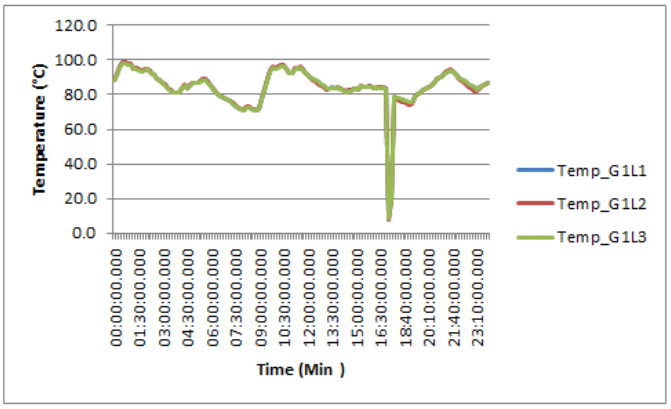

Figure 3 Temperature Analysis of Generator Winding

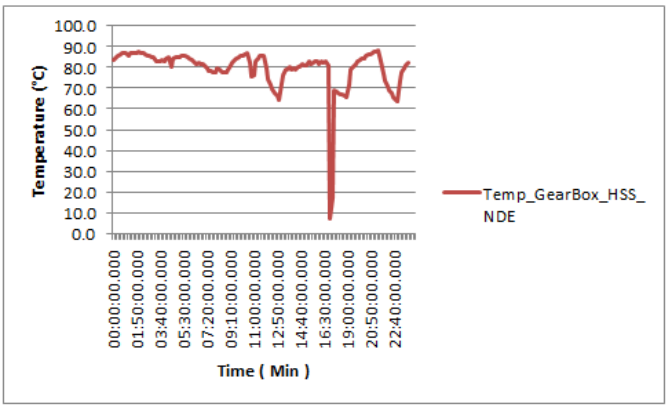

Figure 4 Temperature Analysis of Gear Box NDE

4. Thermography Analysis

Thermography is tool of condition monitoring; it is used in both mechanical and electrical equipments. It is used to identify loose connection, loaded equipments, faulty components, overheat or temperature in mechanical and electrical components in normal operation condition. This method can be done without shutdown of wind turbine generator so it is not affecting on wind turbine performance. It gives exact results in wind turbine. It is helpful to identification of overheat spot and to analysis of quality of electrical contacts, busbars etc. Fig 5 shows the thermography analysis image of electrical circuit. We can see red spot at second phase contact which indicates the higher temperature. So we can easily found the quality issues with power panel, electrical contacts, electrical motors, gearbox etc. Other application of electrical thermography is identify faults in transmission line, electrical wiring system, electrical transformers, electrical generators, electrical Substations, Capacitor bank. Mechanical thermography is another type of thermography analysis. This thermography analysis is used to identify the problems mechanical part of electrical motor, gearboxes, mechanical part of generator, bearings, gears, and lighting system.

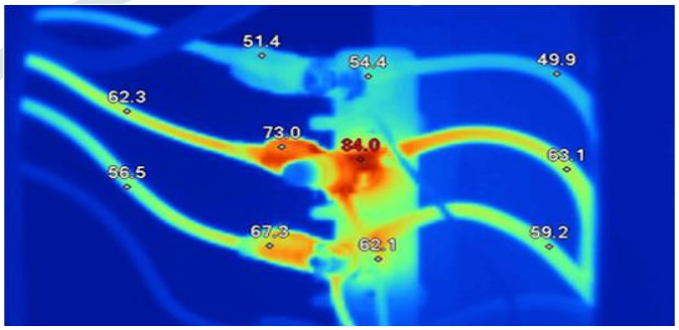

Figure 5 Thermography Analysis

5. Condition Monitoring Based on SCADA

There are some worst conditions or errors in wind turbine generator which reduce the performance of wind turbine. If we ignore these errors then it lead to major breakdown and it will increase breakdown time which is not acceptable for investor or owner of wind turbines. So Condition Monitoring is

required to reduce the frequency of alarms. Apart this condition monitoring technique there is SCADA based condition monitoring. This paper also discussed the SCADA based monitoring of wind turbine or wind turbine farms.

Following are the list of worst conditions in wind turbine generator:

Rotating Part: Blade crack, difference between blades angle, temperature of Hub Panel,

Gear Box: Wear and Brake in teeth, displacement, Eccentricity of toothed wheels

Generator and Fluid Coupling: Rise in Temperature of windings, winding Damage, Terminals brake, Rise in NDE / DE bearing temperature, over heating

Nacelle: Failure of Yaw drive or motor, Rise in temperature of yaw motor and drive, malfunction of yaw sensor, wear or brake of yaw ring teeth

Tower Vibration: Broken or loose of shell connected bolts, broken of tower foundation bolts, crack in tower shell.
Bearings and shafts: Wear and defect of bearing and its rolling elements, cracks, and fatigue in bearing and shafts, rise in temperature of bearing.

This paper discussed techniques of condition monitoring which help us to minimize the errors in wind turbine generator.

Wind farms are located in remote areas, hilly areas, forest where it is unable to make control on each wind turbine. So operation maintenance service provider operates wind farms through central monitoring system. CMS is a small part of SCADA which constructed nearby wind farm area. So operator can easily responds over error alarms. Central monitoring services are structure of computers which connected to wind farms through Optical fibber cable or wireless. CMS is control room where group of technical persons responds to error alarms, monitoring of wind turbine conditions, and analysis of data. Central monitoring Services give information about real based condition of wind turbine.

Figure 6 SCADA

SCADA is supervisory control and data acquisition system which collect data from wind farms through wired and wireless communication. Wind turbine parameters can measured with help of sensors in wind turbine and then these reading sends through Remote terminal Unit to Master Terminal Unit. Optical Fiber Cable, VSAT, LAN are communication medium between RTU and MTU. It is real time based condition monitoring system. It is big control room where group of technical person operate or responds the error, analysis of wind turbine parameters. SCADA has great advantages that data can be recorded or stored in data base from commissioning of wind turbine generator.

SCADA system is used for condition monitoring of wind power plant, thermal power plants, water pump house, solar power plants and process industries. It is tool of condition monitoring. It helps to increase production of pant and process of work. It helps to avoid major breakdown of wind turbine components by detecting fault at early stage. It reduces the breakdown time and overall maintenance cost of wind turbine.

VII. Suggestion

We have discussed condition monitoring techniques which are very helpful to increase the performance of wind turbine generator. But sometime they are unable to achieve the performance of wind turbine because of use unskilled manpower, use poor quality lubricant, transportation of material, use of repaired material. Service provider should have to consider this point during implementation of condition monitoring techniques in wind turbine generator.

Unskilled manpower: Skilled manpower play important role in performance of wind turbine. Unskilled manpower can create problem during application of condition monitoring techniques due to lack of technical knowledge, procedure. They can create new fault in wind turbine during wind turbine condition monitoring techniques which affect on availability of wind turbine. We degrade performance of wind turbine by condition monitoring instead of increase it. So author has advice to use skilled manpower while implementing condition monitoring techniques.

Use of poor quality lubricant: we observed that some time poor quality of lubricant oil, grease was used in oil or grease changing process. Due to complex structure of wind turbine generator, there is difficulty occurred during greasing and oil changing process. So there should be use of standard quality of oil and use proper tools to make easier process of oil and grease changing. Otherwise there is no meaning of application of condition monitoring techniques.

Replacement of faulty part with other old spare part: we observed that due unavailability of spare part during process of condition monitoring. Service provides or engineers try to fix it with old or repaired material which is less reliable. So author advice that if we have got any faulty part in process of condition monitoring then it should be replaced with new part.

Transportation of material: Wind turbine is complex machine. It has different kind of part like electrical, electronic and mechanical. Normally wind turbines are located far away from store. We need to transport material safely from store to wind turbine and lifting form bottom of wind turbine to nacelle. There are two main reason of material failure. One poor road condition and material strikes on wind tower due to higher wind force while lifting by winch. So use of rope to control over winch for lifting of material and use pallet jacks,

four way pallets, air bag packing for electronics and electrical equipments, use rubber mat with wood boxes for transporting of mechanical heavy material.

VIII. Conclusion

This paper is discussed about condition monitoring of wind turbine. Form this study we can conclude that major breakdown occurs due to ignorance of small alert alarms in wind turbine. Service providers will take more time and money to resolve major breakdown. It gets affect on availability, performance of wind turbine as well as financial condition. This paper discussed the critical alarms in wind turbine generator and condition monitoring techniques. These condition monitoring techniques help to increase availability of system.

IX. Acknowledgments

The authors would like to thank Mrs. R.S Ambekar & Mr. R. M Holmukhe for his valuable guidance in this research. Also I would like to thanks staff of Bharati Vidyapeeth Pune.

X. References

[1] S. Sheng, "Wind Turbine Gearbox Condition Monitoring Round Robin Study – Vibration Analysis", National Renewable Energy Laboratory, July 2012

[2] Martin Kluge ,Michael Danitschek "Condition Monitoring Systems (CMS) in wind turbines" ifm electronic gmbh, 2010

[3] Brogan Morton," Understanding Wind Turbine Condition Monitoring Systems" Renewable NRG Systems

[4] Bodil Anjar, Mats Dalberg, Magnus Uppsäll," Feasibility study of thermal condition monitoring and condition based maintenance in wind turbines" Elforsk rapport,May 2011

[5] Arezki SMAILI, Ali TAHI," Thermal analysis of wind turbine nacelle operating in Algerian Saharan climate", Energy Procedia 18 (2012) 187 – 196

[6] Pierre Tchakoua , René Wamkeue , Mohand Ouhrouche "Wind Turbine Condition Monitoring: State-of-the-Art Review, New Trends, and Future Challenges" Energies ,2014

[7] Loutas, T, Kalaitzoglou, J, Sotiriades, G,"The Combined Use Of Vibration, Acoustic Emission And Oil Debris Sensor Monitored Data Coming From Rotating Machinery For The Development Of A Robust Health Monitoring System." (2011)

[8] ANNE JÜNGERT "Damage Detection in Wind Turbine Blades using two Different Acoustic Techniques" The e-Journal of Nondestructive Testing,Dec 2008

[9] Bjarke Nordentoft Madsen "Condition Monitoring of Wind Turbines by Electric Signature Analysis" October 2011

[10] Christopher A. Walford ,"Wind Turbine Reliability: Understanding and Minimizing Wind Turbine Operation and Maintenance Costs" Sandia report ,March 2006

[11] Peng Guo , David Infield ,"Wind Turbine Tower Vibration Modeling and Monitoring by the Nonlinear State Estimation Technique (NSET)" Energies ,Dec 12

[12] John Barton "Vibration Analysis of Gearbox and Generator of a 25kW Wind Turbine" Loughborough University, September 2011

[13] Steven Lara-Lee Lumley," Oil analysis in wind turbine gearboxes", energize - July 2014 - Page 71

[14] Rainer KRANKENHAGEN, Mathias RÖLLIG," Thermographic rotor blade inspection from larger distances – a promising tool for the maintenance of wind turbines", 19th World Conference on Non-Destructive Testing 2016

[15] Dr Bogi Bech Jensen , Mathew Lee Henriksen "Thermal Modeling and Analysis of a Wind Turbine Generator", Technical University of Denmark.