Health Monitoring System for Wind Turbine through Vibration and Power Quality

A. Mutharasan, P. Chandrasekar

Abstract: Increase in the demand for electricity and shortage in the fossil fuel promotes implementation of renewable power generation sources. Converting the Wind energy into electricity is the major source for renewable energy, which can be generated almost all ends of the world. Moreover, cost for generating electricity through wind turbine is simple and cost effective when compared to other renewable energy source. Rapid researches and development are introduced in the wind turbine. Even though the wind energy generation is more comfortable, the location of implanting the wind turbine makes the condition difficult. Maintaining the wind turbine from fault occurrence is more important. The fault occurs in the wind turbine affects the power quality of the generated power. The reduced power quality affects the transmission lines, grids and loads connected to the renewable source. So fault monitoring and detection in wind turbine plays vital role in power generation and power quality maintenance. Vibration based wind turbine gearbox fault monitoring system to improve power quality is introduced in this work. Wavelet is performed to map the vibration signal along with the current sensor signal to find the difference in power quality based on the vibration level in the wind turbine. The entire proposed work is simulated in MATLAB. The results taken support our claim in the proposed work.

Keywords: Wind Energy, Vibration, Gearbox, Wavelet, Power Quality

I. INTRODUCTION

In the development of renewable energy resources, wind energy plays a vital role in power generation. The technologies used in wind power generation is the important research undergone all around the world, several developments are introduced to utilise the wind power effectively. Even though several developments have been introduced in the wind turbine, it is highly prone to physical damage especially due to gearbox failure.

The wind turbine comprises of several sections in which the gearbox causes longest downtime and the cost for maintenance is too high. Thus, the researchers should concentrate on the development of fault diagnosis methods to reduce the downtime of the gearbox and increase the reliability of the wind turbine. Early detection of failure in the gearbox can reduce the possibilities of catastrophic failures in wind turbine.

Fig 1: A) Gear box B) Wind turbine

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II. FAILURE MODES AND CAUSES IN WIND TURBINE GEARBOX

The wind turbines are placed in harsh environments like mountain tops and near to sea beds were the transportation is extremely difficult to perform, which indirectly increases the maintenance cost of the system. The generation of the wind turbine varies due to factors like environmental air pressure, temperature, and various load operation conditions. Thus, the transmission system was under unbalanced condition due to the impact of environmental factors over wind power generation. Common failures generated in the wind turbine are gearbox failure, bearing failure, shaft failure, and higher coolant oil temperature and oil leakage in the turbine. And most common occurrence of failure is gear and bearing failure.

III. GEARBOX FAILURE

Gearbox failure occurs due to pitting in gear surface, occurrence of wear in the tooth surface and the tooth breakage.

- Wear on tooth surface: This fault occurs in three main conditions they are, when the turbine is in extreme low temperature the lubricant oil gets solidify thus the lubricant oil cont reach the gear tooth surface that result to wear on the mechanical surface. And in next condition, due to higher temperature in turbine due to continues run causes increase in temperature of lubricant system which fails to lubricate the moving surfaces in the turbine. This leads to wear on the gear surface and the final cause is due to the entry of foreign objects within the turbine.
- Pitting on tooth surface: The tooth pitting is caused due to the extreme stress applied over the tooth of the gear system which leads to the generation of cracks in the gear tooth which leads to pitting on gear surface.
- Tooth Breakage: Due to the overloaded action over the gearbox or bending stress, expansion of cracks in the gear tooth leads to tooth breakage in the gearbox.

IV. BEARING FAILURE

Bearing failure is caused due to wearing, pitting and fracture.

- Wear: Wear is caused due to insufficient lubrication in the bearing system or by due to entry of foreign objects like dust into the bearing system.
- Pitting: Pitting occurs due to the dynamic load condition and lack of lubrication oil.
- Fracture: applying dynamic loads, heavy loads, lack of lubrication and due to fatigue rupture.

V. LITERATURE SURVEY

In connections survive middle of the positive & negative string impedances of voltage can be obtained from power converter primarily, in the small frequency domain to the nonlinearities & the small-bandwidth reign curve as the phase-locked bend. This advanced method, built on harmonic transfer method, for perusal of linear time recurrent systems accord, so this system easy to handling the connection. If a equitable three-phase structure, there is only one relationship expression, but unbalanced structure, there are huge connections, so interactions in the middle these both connections a matrix-construct technique should be followed. No need statistics concerning the fabric, converter only required & elements are model black boxes accompanied familiar terminal features. This technique suitable for both power quality (harmonic & inter harmonic discharges).[1]

Power quality concerns distributed creation techniques build on the renewable energy origin, solar & wind spark. The power quality problems and move behind by the discoured of fundamental standards. This paper also covered with dc and renewable sources. Power quality observing capability, and feasible to solve the problem of power quality of power techniques are studied here. After that we examine the techniques of reduction of the issues used by custom power appliance such as, TVSS, DVR, UPS, UPQC, and micro grid structure also. The several advantages, renewable energy structure STATCOM can possible choice. In traditional systems power quality is upgrade the spinning reserve. And we are studying about power quality in dc structure. DC system have two main advantages Simpler arrangement and higher reliability and it faces different power quality problems, such as vulnerability and low diagnosis of errors.[2]

This own power quality distraction perception & illumination, in power issuance structure cross-correlation–based approach in concurrence with the fuzzy technique. When compared with standard perspective for recognition of disturbances, the advanced method required least number of characteristics. PQ distractions are eight fundamental and nine together total 17 types, it’s close to actual situations are examine for illumination. The original life uncorrelated unwanted sounds, incorporation of the transverse spectrum statistics of the existing stage. Calculation based on actual functioning conditions fetch out the scientific equipments manipulating data accession method for test by using this advanced technique. This method also applied IEEE 33-bus distraction structure and endorse by a situation of simulator. This techniques attained 100% accuracy and constraint outperform assorted modern techniques for the PQ distraction of illumination.[3]

Probabilistic threat rating power quality disparity & functions appear due to huge photovoltaic distribution creation (PVDG) assimilation in a small voltage distraction network (LVDN). Because the spatial profane conduct of PV creation and load request, such as estimation essential, such as first integrated PVDG at the existence of load buses. The voltage magnitude difference and phase unbalance the two power quality variations connection with PQ unusual event review as the PQ impression metrics. The two Pand Q indices are determined. PQ impact matrices. The probabilistic risk assessment has applied on Monte Carlo based simulation. From the results, impact to perceive as PVDG integration expands in site voltage. If 100% penetration level is 0.5 and the chances of 20% of customers contravene 1.1 p.u.
Such as analyzed with not or small PVDG penetration, integration of PVDG minimise voltage unbalance. This probabilistic method can be used as a like PVDG assimilation antagonist the worst-case scheme. [4]

Its diagnose regularly experienced power quality distraction case together single as well assorted types. Designed hardware set-up developed in the laboratory, in the existing method signals containing various types of power quality distraction functions. Diagnosis of various power quality distractions from the developed function creator have been compared to extinct useful Information. To maintain the extract actual disturbance, this advanced method using a signal tracker cabable of regularly tracking usual level of the signal. In this diagnose power quality disturbances effectively used for designed the Ddetrended Fluctuation Analysis. The success in changing power quality functions decidedly not involving standard statistics result least computational burden analyzed to the extinct method. Finally this advanced method test on notable number for captured signals carry various methods of power quality distractions and acceptable result has been perceived.[5]

A standard power factor correction rectifier such as the tri-switch, tri level PWM rectifier with type is proposed for the improvement of power quality in telecom loads. Input voltage data outcome in dependable & vigorous technique. In this advanced system active front-back converter outcome in minimized switching pressure and DC wrinkle by the feasible switching states are identified. Sinusoidal shape no need of observing input voltage, a triangular conveyor construct control logic used to apply the input current reached. Equivalent circuit analysis carried out detailed statistics of front-back PFC converter. Hardware design guidelines helped to the total loss and coherence of the converter. If the event failure in one-phase of the main checked by the MATLAB simulation and get results gained once this advanced and capability to operate satisfactory. [6]

Electric aircraft system are actively analysed the problems in the present technology. Throughout these aircraft operation the concept of power quality and maximized level of sacking despite the huge power supply. The limited control model denotive control technique with current control approach for SAF drafted. The developed infusion gives different advantages aircraft electrical network on embedded programme, its directed characteristics with domain current particular period of time, these providing the impose current harmonic contribute side over a given divination horizon, modular design and sacking functionality. Control techniques helps to better extinction time effectiveness connections with small responsiveness upon the optimization equation through an integrated statistic programming solver. Where the robust behaviour of manipulating harmonic currents connect regard to contribute impedance and basic frequency differences is reached. The time of simulation and explotory corrections for the four-level three phase we discussed about the shunt active power filter.[7]

From the testing power quality insulator evaluating industries areas at remote location using, for detection of high-voltage. It’s one of the major test to each insulator at designing periods for huge-voltage power frequency flashover test, in ceramic insulator. Insulator industries detected the flashover visually. For the detection of flashover, for testing operator can be present physically. Flashover in insulator detects high – voltage test measured, without using quantity. This system provides improved flashover diagnosis system, without visual observation detects the flashover. Using the power quality from the test rig the flashover phenomenon is detected. Power quality statistics of high voltage insulator industries, the explotory investigation based on working. To the power frequency flashover experiment & lightning impulse experiment.[8]

The Power quality requirements in the distribution system to meet proper functions are presently requires micro grids construct renewable vigour sources. The power system utilizes necessary control actions, in order to conserve the power generation & need stable operating such as voltage & frequency for micro grid. Power produces and developers who need to built a micro grid for stable function in together grid-off models and grid-tie modes, we requires a present practice requires. The grid-off micro grid, substantially voltage and frequency reign purpose in an unconventional super active power quality domination programme. From these power conversion structure with proceeds into interpretation these control states and ceiling are manipulated the active and reactive power.[9]

When the quality is minimum at load side it could affect another side apparatus also damaged the devices. In a distribution of power system the power quality of the electric arc furnace increased, so that reactive power compensation techniques followed here. Instantaneous SVC problem can solved by the active filter, the active filter and the static var compensator its changes the simultaneously changes the three phase currents and the power factor. Using this advanced techniques we finally got the simulation results of balancing the load currents and the correcting of the power factor simultaneously. Field measurement statistics in metal factory was corrected. SVC could minimize the power quality of that active filter.[10]

The power electronic design developed, for methodical and cost-successful photovoltaic structure is inspired. DC-DC converter is a building integration & dispensed maximum power point tracking with novel characterized work resulted. Its systems orders are huge energy methodological and huge power quality is essential features. Solar radiant energy for power conversion methodological its maximum power, as a function of this switching frequency optimally modulated. Conversion efficiency target the rise of radiant energy of this frequency is minimized. Its determine those optimal switching frequency, the search algorithm is developed. Increased the ripple content, minimizing switching frequency, and the MPPT methodological. The converter cells are activated, to attained uniform huge power quality at every operation. The overall cost is low, simulations results DC standalone and micro grid applications its high value module. Power conversion, efficiency above 95%, Maximum Power Point Tracking measurement and control design, 400W prototype was implemented.[11]
The power quality problem is increasingly with integration of renewable energy and use of non-linear loads in power systems. Individual power quality indexes are set in china. Individual indexes cannot directly reflect a comprehensive level of power quality, when evaluating power quality. To obtain a unified parameter from an overall perspective for describing the characteristics of power quality, analysis of various indexes is conducted. Combining the subjective and objective weight, values of power quality indexes weight are calculated. The projection techniques of boundary statistics to be calculated based on the principle components. Finally evaluating the power quality, grade range for power quality data is located, using these projection values.[12]

To found the small overshoot & low settling period, is on the non-linear slip mode managing action, DC-link capacitor voltage accompanied to the dissimilarity of damping ratio & allowed, DC link voltage to helped. Unified power quality conditioner is existing method, for new non-linear sliding surface mode control and switching energetic reign is this advanced method. With combines NLSMC technique and novel synchronous-reference frame. Voltage source converters of UPQC have designed by new switching dynamics controls strategy. Switching dynamics reign constructed voltage source converter, and this structure to minimize the violation. NLSMC SRF method an effective compensator for voltage/current harmonics. This UPQC validated by MATLAB, finally we attain ordinary - hysterisis controller. [13]

Three phase Induction motor drives build on single phase AC-DC-AC convertor. The single phase IM, fuel distribute units its low methodological and torque swinging, its causing distribute for the other place. Short life process & non success of huge induced voltage supply or loads disconnection immediately, we need standard 3 phase IM drive requires huge voltage DC tank capacitor need. For break single phase to 3 phase inconsistent speed persistent v/f managed open end bend induction motor, a new stream converter energetic rectifier used. Advantages are minimized the voltage stress covering every capacitor, distributed voltage stress, minimized leakage current, load disconnection. D-Q frame for the authority depiction to access the practicability to drive functions need detailed stability analysis is present. Unbalanced motor loading consequence transients or intermittent functions across the embedded reign forces balanced drive operation. [14]

Utilizes electric field to interact with polarisable particles, manipulation of particles using dielectrophoresis is a well known technique. The arrest of bacterial dungeon & virus spot developed a nano structured DEP device. Carbon nano fibers macroscopic indium tin oxide counter electrode point and lid arrangement, micro fluidic channel utilizing a nanoelectrode disposition made of vertically ranged, a high magnitude non uniform electric field was produced. When AC voltage (100 Hz to 1MHz) was turned on and off, reversible for 2 types of microbes including E, virus particles (80-200 NM in size) are the DEP capture. Coli bacterial cells (1-2 micron in size) nano electrode showed strength interaction with virus particles producing striking lightning designs, because of the high electric field strength focused.

Functionalized with polyclonal antibodies and anisotropic round shaped, iron oxide-old (IO-Au) core-shell nano particles was utilized.[15]

VI. METHODOLOGY

Several technologies were introduced to analyse and diagnose the faults generated in wind turbines to increase the power quality of wind power generation. In these technologies, monitoring vibration signal, acoustic emission and the oil quality analysis are widely used techniques to identify and measure the occurrence of faults in the wind turbine. Among these techniques vibration and acoustic analysis plays a vital role and provides maximum efficiency for the fault diagnosing mechanism for wind turbine gearbox.

VII. VIBRATION ANALYSIS

Vibration analysis is the most effective technique in identifying faults in wind turbine gear system. It provides more accuracy than other techniques involved in fault identification in gearbox. The vibration detection methodology requires only simple electronic structure for recording and monitoring the vibration signal generated from the gearbox. Improvement in the signal processing algorithms helps to increase the possibilities of identifying faults even in earlier stage itself. The vibration analysis can be performed in different modes, online, offline and periodic acquisition of data from the diagnosing system.

VIII. OIL ANALYSIS

Oil analysis is performed to identify the condition of lubricant, wear on the mechanical surface and contamination of lubricant oil. The performance of the system will be affected due to the conditional changes in the quality of the lubricant oil, so oil analysis is performed to check the condition of lubricant too overcome the failure in the system. The oil analysis is performed only at the gearbox section of the wind turbine because the lubricant oil was used only were the mechanical rotary devices are placed. Oil analysis system was directly installed in the gear system to monitor the oil contamination and degradation. The lubricant oil can be contaminated due to the debris of metallic subjects generated by bearing and gear fault. By measuring the sizes of debris material in the oil helps to find the level of deterioration. Fault due to pitting in gear surface can be effectively identified but locating the fault location is not possible through the oil analysis.

IX. ACOUSTIC EMISSION

Acoustic emission utilises powerful sensors to record the sound generated from the wind turbine. The variation in the generation of sound due to the occurrence of fault in the turbine can be efficiently analysed. Signal processing algorithms are utilised to process the fault sound signal from the environmental noise.
To increase the accuracy of the acoustic emission results, the technique was combined with other fault monitoring techniques like vibration analysis, current signature analysis or oil analysis techniques.

The fault generated in the wind turbine reduces the performance of the system and reduces the quality of power generated from the wind turbine. The fault in the turbine affects the performance of the wind turbine and reduction in power quality will affect the performance of grids and even loads directly connected to the wind energy. Poor power quality increases losses in transmission lines.

In order to overcome these problems, a vibration-based fault monitoring system is introduced. A continuous 1D wavelet analysis is applied over the recorded vibration signal and the decomposed result is compared with the readings collected from a current transformer at the load end. The decomposed results of the vibration signal and current transformer signals were compared to analyse the power quality of the wind power generation.

Fig 2 shows the functional block diagram of the proposed method.

![Block Diagram](image)

**Fig 2: Block Diagram**

A Wind turbine is connected to the gearbox system. The gearbox is used to convert low speed high torque mechanical energy to high-speed low torque mechanical energy. The output of the gearbox is applied to the generator and the power generated from the generator is transferred to the load.

The vibration level at the gearbox is recorded using an ADXL620 sensor and applied to the power quality correlation and the vibration signal is compared with the current sensor value in order to plot the power quality disturbance based on the fault induced in the wind turbine. Complex 1D wavelet transform is applied to analyse the input signal. The recorded gearbox vibration signals are more complex so wavelet analysis is required to perform fault diagnosis. Wavelet analysis applied to the gearbox fault detection and power quality control undergoes the following steps.

1. Fix the gearbox parameter conditions the signal as been recorded for normal and fault induced situations.
2. The recorded signal was then applied to 5dB wavelet analysis in order to generate high frequency and low frequency part. The high frequency part is removed by which the wavelet function acts like a low pass filter to remove the high frequency noises from the signal.
3. The low frequency signals of normal and fault induced signal were generated and compared the difference in amplitude modulation, pulse modulation or advanced pulse super position modulation.
4. Based on the output generated at step 3 the output was compared with the current sensor signal and the vibration level and the power factor levels were matched to find the effect of vibration or fault in wind turbine affects the power quality of the output power.

**X. RESULT AND DISCUSSIONS**

The vibration signal and current sensor signals were recorded from the gearbox and output load. The signals are recorded using Sigview tool and the signal was provided to the Matlab wavelet analyser tool to perform complex continuous wavelet transformation. Each signal was collected and applied in three different modes of analysis in complex continuous wavelet transformation. The modes of analysis are as follows:

- Step by step mode
- Power 2 mode
- Manual mode

Outputs of each mode is presented in term of Module and angle of the input signal.

Fig 3 shows the input signal provided to the complex continuous wavelet transformation to perform all the three modes of operation.

The continuous wavelet transform function $f(t)$ derived based on above wavelet function is given as

$$WT_f(a, b) = \{f(t), \varphi_{a,b}(t)\}$$

$$= \frac{1}{\sqrt{a}} \int_{R} f(t) \varphi^* \left(\frac{t - b}{a}\right) dt$$

$\varphi^*$ is the complex conjugate of $\varphi(t)$ and the $\varphi_{a,b}(t) = \varphi \left(\frac{t-b}{a}\right) dt$ is the fundamental function which depends on the parameters a, b.

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Step 3: The low frequency signals of normal and fault induced signal were generated and compared the difference in amplitude modulation, pulse modulation or advanced pulse super position modulation.

Step 4: Based on the output generated at step 3 the output was compared with the current sensor signal and the vibration level and the power factor levels were matched to find the effect of vibration or fault in wind turbine affects the power quality of the output power.
The coefficient for Module and angle is regenerated using power 2 mode and the output of these modes are displayed in Fig 7 and 8. The Fig 7 shows the modulud of the coefficient a,b and the Fig 8 shows the angle of coefficient a,b.

Fig 6: Module of coefficient lines (step by step mode)

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Fig 7: Module of coefficient (power 2 mode)

Fig 8: Angle of coefficient (power 2 mode)
The Module of coefficient clearly shows the maximum and minimum values of the coefficients and the angle of coefficients shows the spread of input coefficient all over the frequency range.

The Module of coefficient line is shown in Fig 9. The scale was set as 8 and the frequency was 0.037 which is more compared to the step by step mode.

Fig 9: Module of coefficient line (power 2 mode)

The Module of coefficient line is shown in Fig 9. The scale was set as 8 and the frequency was 0.037 which is more compared to the step by step mode.

Fig 9: Module of coefficient line (power 2 mode)

The Module coefficient in each case is investigated in detail in power module case 1 and power module case 2. The Module coefficient is high in the case of the second power module. The proposed simulation table provides a detailed report on the Module coefficient on further planning the system.

Table – I - Elucidates the results obtained through the simulation

| Module of Coefficient for power module 1 and 2 |
|-----------------------------------------------|
| Power Module 1 | Power Module 2 |
|----------------|----------------|
| A =32 Frequency =0.09 | A =32 Frequency =0.09 |
| 0.024 | 0.039 |

XI. CONCLUSION

The effect of fault generation in wind turbine over quality of output power is discussed in this work. Wind power generation is most researching topic all over the world were the fault monitoring and detection is the major task handled by the researchers to increase the efficiency of the wind turbine. The fault generated in the gearbox of the wind turbine leads to heavy loss of mechanical components and affects the grid and distribution system. The fault generated in the wind turbine affects the quality of output power, which increases the transmission losses, grid and load failures. A complex continuous wavelet transformation is implemented to analyse the vibration signals occurred from the gearbox of wind turbine and the current signal from current sensor connected at the load end. The output current signal and the gearbox vibration signal were compared to find the impact of power quality reduction due to occurrence of fault in wind turbine. The signals of current and vibration are collected with and without fault condition and complex continuous wavelet transform is applied to verify the effect of power quality due to fault in the wind turbine gearbox.

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