Virtual Reality as a part of Performance Analysis and Reliability for Designing Intelligent Wind Turbine Rotors

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Intelligent Wind Turbine Blades

Due to unreliable nature of wind energy, producing low cost energy from winds, its beneficial to develop sophisticated designing methodology of Wind Turbine System. The primary element turbine rotor blades can be designed with a strategy. Otherwise neither steady supply of electricity is achieved nor is the desired reliability and blade life is attained, apart from the damage from vibration, lightening, intermittent wind speeds, and directions. These environments may cause accidents, error operations, and damage to other components. In order to understand wind energy and the Wind energy Generators, their interactions can be minutely observed. As a new approach to design most efficient blades, the paper discusses the application of Virtual Reality-based models designing Intelligent Wind turbine Blades. This is implemented by first developing CAD Models, than transporting the system to MATLAB applications having VR Toolbox and than understanding the analysis using Head Mounted displays and SIMULINK graphs predicting effects of utilizing sensors in a rotor blades for desired reliability and optimum operations, life cycle of Wind turbine blades.

Keywords: Virtual Reality, CAD, Product Design. Wind Turbine Blades.

1. Wind Turbine Blades

There are four key drivers [1], which will shape the future of energy, determining what we might call the "solution envelope" for the next 50 years. They are the growth in demand for energy, the challenge of energy supply, concerns about energy security and environmental constraints, particularly the challenge of climate change. Technology and appropriate policies and regulations lie at the very heart of all solutions to these challenges.

This paper introduces a new virtual environment, which can further facilitate the Wind and Wind Turbine interactions. Simulated version of the actual facility, complete with the Noise, Vibrations, Lightening, and different operating conditions of the Wind Turbine System, will generate a robust feed back mechanism for Designing of a Intelligent Wind Turbine Blade and responsive Mechanical Systems related to it, for economy and longer Product Life Cycle. In the case of wind energy, there is great interest in deploying small and large wind turbines for generating distributed power for residential and rural areas. These turbines represent a significant capital these turbines represent a significant capital investment for the owner and the turbine must operate for up to 30 years.

2. Wind Turbine Environment

Most of the systems consist of people and machines, which performs a function to produce some form of output. Inputs are received in form of matter, energy and information. A wind Turbine System can be explained with the Figure 1.

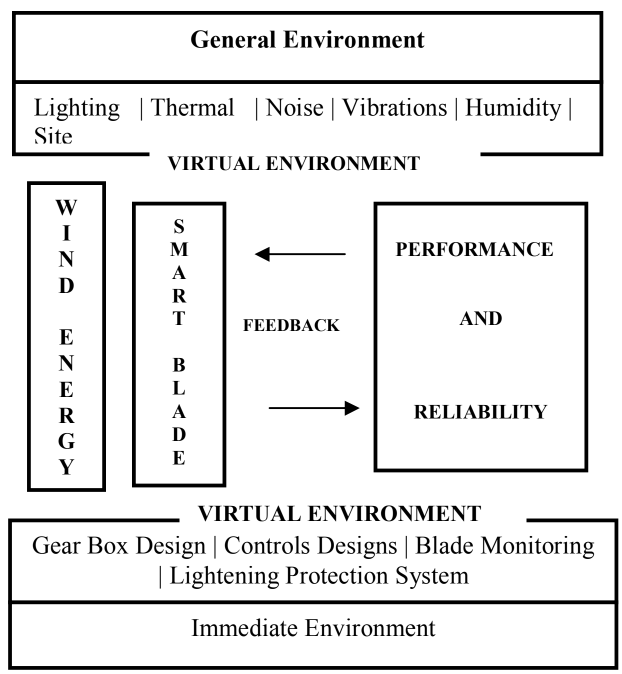

Fig 1 Wind Energy Environment adopted from Human Machine Model from prEN1436: 2002(E)

- Wind Turbines Designs that is usable and safe.
- Task that are compatible with people's expectations and limitations requiring minimum maintenance and operating involvements.

- An environment that is comfortable and appropriate for the task and free from any pollution.
- A system of work organization that recognizes a person's social and economical needs.

These four parameters are the cause of compatibility between user and the wind turbine system. The incompatibility can occur mainly due to design considerations or decisions taken at the design stage, for example

- Human requirements for optimum system functioning were never considered at the design stage like failure to consider Noise standards, Glaze from Rotor Blade, guidelines for operations and maintenance.
- Lack of prototyping like consultation with users at the design stage of product or site locality

In design of Intelligent Wind Turbine Rotor new approach is studied. The Wind Turbine Blade is the place for precise interface between Human and their expectations of energy. Virtual reality technology is assisting in design as well.

2.1 General Environment

General environment of operation of Wind Turbines are about Lighting conditions, temperature of the surroundings, Bird traffics, Noise levels, Vibrations, gusts, storms, dusts, humidity levels, Wind Speed, installation area geography.

2.2 Immediate and Virtual Environment

The Gear Box, controls and displays, sensors, lightening protection unit, nacelle, tower, Yaw Control, Brakes, low speed shaft form the immediate environment. The optimum readings of displays in different conditions are feed into their displays and information is generated on to virtual reality equipment thus, facilitating maintenance and operating monitoring of the Wind Energy system.

2.3 Virtual Environments

The environment in which machine operate can artificially developed, as the per the guidelines laid down by designers for that particular equipment. It starts with machine operations but, from designers approach a Virtual Environment as shown in figure 3 can be created. Here the immediate environment is the controls, rotor blades and gear and generator, where as the general environments are the lighting, humidity, noise, wind speed, wind directions etc. Here virtual environment visualization and immersions assists and educate the product apart from designers and operators to respond the situations of immediate and general environment by involving virtual environment. Virtual environments are computer-generated places where Humans interact in meaningful ways.

3. Intelligent Blade Features

For Wind Turbines the Intelligent Blade will be providing information for

- Wind Behavior Analysis
- Wind Rotor Steering Analysis
- Wind Speed Management Displays
- Lightening Monitoring System
- Noise And Vibrations levels
- Energy Output Analysis
- Equipment Safety Monitoring
- Virtual Installation of Wind Turbines

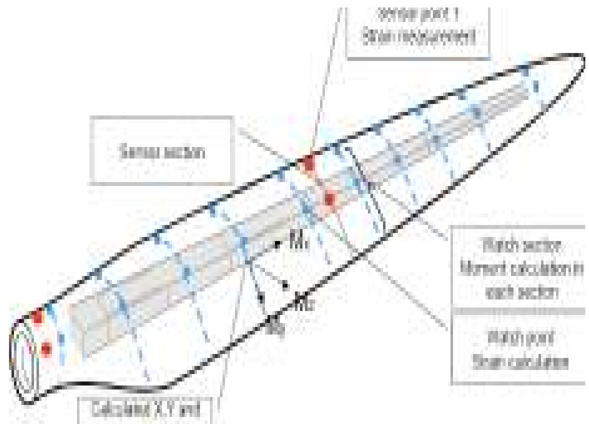

Figure 2. Intelligent Blade Design [10]
From L M Glassfiber Future Blade

The design of the wind turbine blade is an important factor in the performance (power produced) and reliability of the wind turbine. The trend in blade design is toward complex blade shapes to improve aerodynamic efficiency, and the use of combined fiberglass graphite, and balsa wood materials to improve strength and reduce the blade mass moment of inertia that will result in increased "wind capture." In other words, blade geometry and materials are becoming high-tech and complex, and structural over-design of the blade is no longer an acceptable approach. The push to increase wind turbine performance and maintain reliability is driving a need for installation of low-cost continuous health monitoring systems on wind turbine blades.

This system could provide critical information about the location and propagation of blade damage. If a blade fails, the rotor can become unbalanced, which can destroy the entire turbine. Wind turbine blades made of composites have sudden audible Auditory Environment during damage growth. This means that instruments can be affixed to the blades to detect and locate these emissions to prevent blade failure. Monitoring the blade for damage is also useful in static testing to determine at what location the blade starts to fail. This information can be used to improve blade design and manufacturing. Wind turbine blades are mostly composite structures with complex geometry, large size, and sections that are built of different materials. Any sensor system to be used on the blades must be low cost, simple, and operate over decades of use.

Incorporating these complex features at the design stage accurately calls for the use of Virtual Reality Simulation.

4. Virtual Reality Technology

Virtual reality technology (VR) produces a structured environment where visual, auditory and kinesthetic sensory information allow for seemingly lifelike experiences for the participant. People interact within these environments in specialized ways, typically through kinesthetic.

Mechanical devices, simulators are now heavily electronic and computer based. The machine's visual simulations, instrument feedback and physical movements can create various flying scenarios, including dire weather conditions and aircraft The virtual environment thus is a place to safe simulation, test, Experiment for Reliability issues of product.

4.1 Intelligent Blade VR Design Strategy

Virtual Reality approach to design can be methodically organized as follows

Stage 1: CAD Simulation and Modeling

1. CAD Model pf Blades and Subsystems
2. FEM Model of Blades
3. FEM Model with Sensors and intelligent controls
4. FEM Model Testing
    a. With Composite Materials
    b. Smart Materials

Stage 2: Advance Modeling and Simulations

5. Mechanical System Simulation
6. Aerodynamic Simulation
7. Noise And Vibration Scenarios

Stage 3: V R Application Development

8. Visualizations with Scenarios
9. Results Documentations
10. Prototype Development

Stage 4:

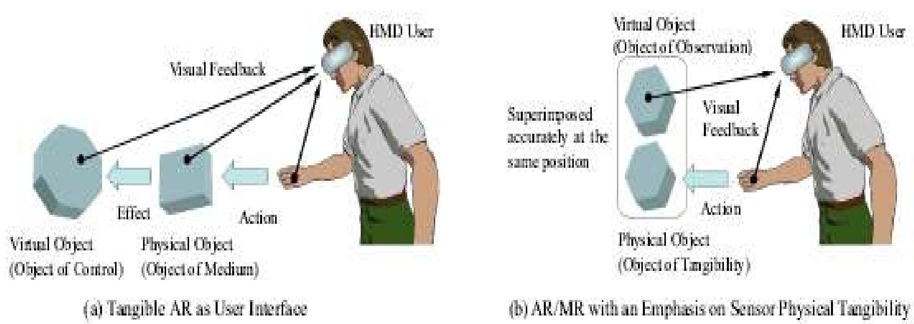

Figure 3 Virtual Product Analysis taken from *MR Systems Laboratory, Canon Inc.* 2-2-1
Nakane, Meguro-ku, Tokyo 152-0031, JAPAN

11. Manufacturing Technology And Automation

Stage 5:

12. Optimum Wind Turbine Installation Simulations using VR Programs
13. Real Installation
14. Various Testing of Real Systems
15. Feedback for Future Blades

4.2 FEM Analysis of Blade

After constructing CAD Model, the blade structure is divided into an equivalent system of smaller part called elements. Apply load s, such as forces or pressure or imposed displacement, specify the elastic material data, identify the boundary condition..

The computer implementation [10] using erstwhile IDEAS software starts with boundry conditions development with environmental constraints. The boundary condition task provides tools to create enforced environmental conditions on a finite element model; the solver predicts how the model will behave with given set of conditions.
To create boundary conditions pick the type of analysis you will perform, such as linear statics. The analysis type icon or command acts as filter, static analysis is default type. Now Pick ther command to create boundary conditions. After this pick the surface on the blade to apply load condition by using traction force.

Meshing is carried as the next step in our objective of FEM analysis. In particular case meshing element size 500 and meching thickness is 4mm. The Preprocessor the FE Modeler includes the entire process of developing CAD Model. The post processor or visualizer utilizing the data generated by the solver to create easilty understandable graphics and visualizations. Here we must say that the using PRO E and Solidworks better for transporting the CAD Model to a MATLAB SIMULINK system than IDEAS application software.

4.3 Analysis and Visualizations

Sophisticated Image Processing[7] computer Programs are created for Engineering Analysis like Fractures and Fatigue, bending and torsion, displayed on virtual level, increases the understanding as well are life and hence reliability of the product**.** The role of VR Technology has been monitored for not only in early stage of product design, simulations and modeling, but also once the product is hand s of humans at the time of installations. Further the product life cycle stage can be assessed. This paper has the following case studies done in favor of this technology.

5. Virtual blade Analysis

The main design objectives of wind turbine blades are:

1. Reliability And Blade Performance
2. Cost-effectiveness

Basically the performance of the Wind turbine blade from aerodynamics geometry can be expressed as the ratio;
It's the ratio between the power Production of the turbine and the cost Ownership of the blade for 20-30 years of operation. The testing of aerodynamics, noise and vibrations apart from sensors and subsystems at the time of blade development and automation of production activities assist in optimizing the design of the turbine blade, Virtual reality simulation becomes integrated part of this blade development processes. Testing is a vital part of the blade Development process and must be Performed on all scales from Nanometer to full blade length

5.1 The Smart Blade

The smart blade [3] could be coupled to a remote monitoring station that would log health information from the wind turbine. An approach has also been outline d to make the intelligent blade autonomous. The PZT nerves are already self-powered, and the

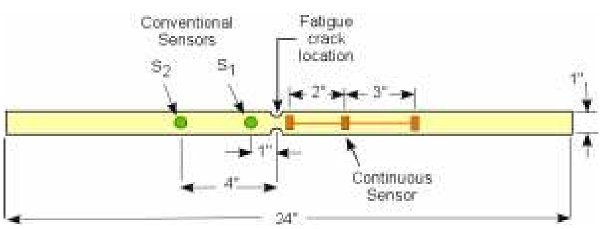

Figure 4 Sensors for Fatigue Detection

AFC material can also be used for micro power generation to power the TBIM for signal processing. Wireless transmission of the reduced health information could simplify the blade health monitoring system. It is estimated that signal processing electronics on each blade might require on the order of 10 watts of power to operate. This could be achieved by harvesting strain energy in the blades produced by the gravity moments and the wind loading. The improved reliability, reduced maintenance, and increased wind capture would make the smart blade cost effective. The concept for the smart blade is shown in Figure 4

5.2 Sensor Subsystem

A dedicated microprocessor is a key component in the Simple Blade Health Monitoring system. Local processor architecture was designed to work with the continuous sensor. This processor, different than the SNS, is designed with a local storage of sensor data and a digital bus to download the data. Development of the software emulator for the local processor was done in this project. Leveraging a grant to North Carolina A&T State University from the Air Force Materials Laboratory funded the emulator work. A semiconductor development company, Triad Semiconductor assisted in the work.
Two different versions of this emulator were successfully tested to monitor fatigue cracks in complex joints in metallic structures. Based on the availability of future funds it is planned to develop the local processor chip based on this architecture. Such a chip can autonomously acquire and analyze AE signals, and to communicate the reduced data over a digital bus. It is possible to embed or surface mounts this local processor chip close to the continuous sensor on the structure being monitored. The development of this chip involves several steps before the processor could be miniaturized to a level where it can be integrated into the structure.

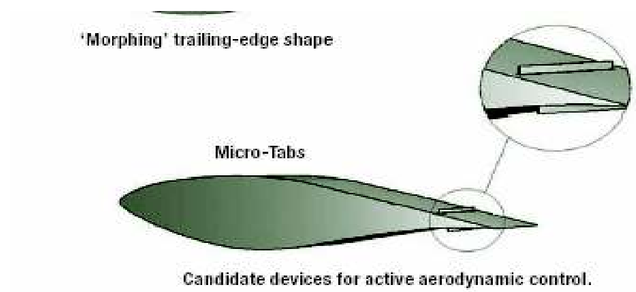

Figure 5 Active Aerodynamics Control

5.3 Structural Health Monitoring System

The objectives of structural health monitoring [6] and a condition based maintenance strategy are to:
• Minimize labor costs for inspection of turbines.
• Prevent replacement of components based on time of use.
• Uncover design weaknesses before failure.
• Improve the availability of power while preventing overload of the turbine.
• Allow repair rather than replacement of blades by detecting damage early.
• Protect the investment in wind power by residential owners, utility companies, and public facilities such as schools that are trying to reduce energy costs.
• Use lighter advanced blades made from fiberglass and graphite that will allow the large turbines to react to wind changes more quickly and thus capture more wind energy.

5.4 Sensor to Monitor Fatigue Damage

The continuous sensor performance was analyzed and validated using simulated AE signals, namely those caused by pencil lead breaks. The advantage of the continuous sensor configuration for monitoring actual AE signals generated by fatigue damage growth in a composite specimen was determined. We used 610-mm-long, 25-mm-wide, and 3-mm-thick fiberglass cloth laminate specimens. The central section of the specimen had two semicircular notches of 0.25-inch radii. The specimen was initially subjected to fatigue until a visible crack appeared at one of the edges. The arrangement of sensors on the specimen is shown in Figure 5.1. This specimen was instrumented with a surface-bonded continuous sensor as shown in Figure 5.1. The first node of the continuous sensor was at a distance of 0.625 inches from the fatigue damage site. In addition, two conventional sensors were also attached to the specimen. The sensors S1 and S2 were 0.25-inch damped ultrasonic sensors with a resonant frequency of 5 MHz. These sensors were chosen for their suitability in terms of wide band non-resonant response needed for quantifying AE signals, based on an earlier study.

5.5 Aerodynamics Control

The pitch actuation for aerodynamic control is vital for the optimum output from the blade. A wide range of other technologies can modify rotor aerodynamics and geometry, and may reduce COE. This study explores two major technologies:

• Devices or methods that can be used to actively alter the local aerodynamic properties of the rotor blade. These devices would typically have response times about the same as or faster than, a full-span, variable-pitch system. Reduced systems loads, increased energy capture, or some combination of these may reduce Cost of Energy.

• An actively controlled variable-diameter rotor. Its primary advantage is increased energy capture; the engineering challenge is to mitigate cost increases caused by increased loading and added mechanical systems.

5.6 Smart Materials

The design of Wind Turbine always involves which type of material is to be utilized for location specific installations ans well as quest towards lighter rotors. Nanotechnology and composites can be tested using advance simulation techniques.

7. Conclusion

Harnessing Wind Energy is a complex activity. In order to reduce cost of energy from wind, designing of blades with advance IT Tools are felt. The blades are to be made self-analyzing intelligent systems so that human intervention is minimal, at the same time increasing the reliability & Performance of the rotor blade and its efficient operating environment. The goals of this project are to:
• Develop detailed performance and loads for active aerodynamic and geometry control parameters at a rating consistent with the current market for utility-scale
Turbines.
• Incorporate the most current technology in controls, materials, and mechanisms.

• Identify technical barriers to achieving Low Wind Speed Technology Project COE targets, and suggest ways to surmount these barriers researchers and turbine designers can use the results with COE models to determine How much such systems could add to the cost of a wind turbine without increasing the COE, and determine how much a proposed approach is likely to reduce the COE.

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