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# Transient Response Analysis by Impulse for Stresses at the Tip of Wind Turbine Blade along Y-Axis over a Time Interval

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**ABSTRACT**: Transient response analysis by impulse for stresses at the tip of Wind Turbine Blade along Y-axis over a time interval has been carried out. This involves the conversion of kinetic energy to electrical power using wind turbine blade. The geometry of this analysis was done using finite element, where the material was changed to Epoxy E-Glass Wet. After the finite element analysis the mesh independence occurred at 800 and 600 element size. The 800 element size was chosen for subsequent transient response analysis. In addition Campbell diagram was analyzed and showed that response vibration occurred at amplitude of 5.5x106Pa with a corresponding frequency of 5Hz. This gave a rotational speed of 262.4x106 rpm. At this point, transient response reached its steady-state at 3.8secs within the considered time interval of 1 to 5 secs, suggesting critically damped transient response with transient damping ratio equal to one. This shows that the impulse force is better applied in wind turbine blade transient analysis at a lower Von Mises stress to attain a quicker damping response steady-state, which favors wind turbine blade analysis.

**KEYWORDS:** Transient Model, Finite Element Analysis, Wind Turbine Blade, Wind Speed

## 1. INTRODUCTION

In a wind turbine system, the blades play a very vital role. Kinetic energy is converted into electric energy when the blades of a wind turbine rotate. The blades are nice looking components of the wind turbine system and were designed by aero dynamical procedure for attaining maximum wind energy. The blade of a wind turbine system comprises of three components: the rotor component that comprises the blades for converting wind energy to low speed rotational energy. The second component is the generator that controls electrical generator and electronics. The third component is the structural support that houses the tower. (Bin and Dongbai 2013). The blade was intended to have low cut-in speed, high power output, and was structurally strong for resilience and buckle. (Loeriesfontein ,2015)

Furthermore, the blades of a wind turbine were projected to generate the maximum power from the wind at a low cost. Basically, the design was driven by the aerodynamic requirements, but economics mean that the shape of the designed blade was a compromise to maintain the cost of construction sensible. In particular, the blade of a wind turbine was thicker than the aerodynamic optimal close to the root, where the stresses ascribable to bending were greatest (Mathew et al., 201). Researchers of engineering extraction created the wind turbine system in order to extract the energy inherent in the wind. Because the energy generated by the wind was converted to electric energy, the machine is sometimes called a wind generator. Locally, wind velocities are significantly affected by obstacles such as trees or buildings (Thumthae & Chitsomboon 2008). A renewable energy source will be ideally suited to comply with these energy needs. The sources of energy available easily are wind, solar, biogas, etc. out of which energy of the wind was studied in length in this project. The blade of a wind turbine system comprises three components: the rotor component which includes the blades for converting wind energy to low-speed rotational energy. The second component is the generator that controls the electrical generator and electronics. The third component is the structural support that houses the tower (Egwuagu al., 2023).

The blades of the wind turbine function by generating lift ascribable to their shape. The side that is most curved generates low air pressure, while high pressure air forces on the other side of the aerofoil. The net result is a lift force perpendicular to the direction of flow of the air. The lift force heightens as the blade turns to show itself at a greater angle to the wind. This phenomenon is referred to as the angle of attack. The blade stalls at very great angles of attack and the lift decreases again. So there is an optimal angle of attack to give the maximal lift. There is, regrettably, also a retarding force on the blade; the drag. The drag is the force analogue to the wind flow, and heightens with angle of attack. When the shape of the aerofoil is beneficial, the lift force is always larger than the drag, but at very prominent angles of attack, particularly when the blade of a wind turbine stalls (Ghasemi & Mohandes 2016).

The restriction on the power available in the wind means that having more blades will result in less power being extracted.

An effect of this is that each of the blades must also be narrower to preserve aerodynamic efficiency. The total area of the blade as a fraction of the total swept disc area is referred to as solidity, and aerodynamically there is an optimal solidity for a given tip speed; the greater the number of blades, the narrower each of the blades must be. In practice the optimal solidity is low which entails that even with three (3) blades; each one of them must be very narrow. To be able to slide through the air easily the wind turbine blades should be slim relative to their width, so the limited solidity also restricts the heaviness of the blades. Moreover, it becomes a difficult challenge to construct the blades firm enough if they are too slim or the price per blade gains greatly as more costly materials will be required (Zhang et al., 2013).

Because of this reason, virtually all big machines have at most three blades. Another factor determining the total number of blades in a wind turbine is aesthetics: broadly speaking, three bladed turbines are less visually troubling than one or two bladed designs (Mo et al., 2015). In particular, a wind turbine blade was thicker than the aerodynamic optimal close to the root, where the stresses ascribable to bending were greatest (Onah. et al., 2023). Researchers of engineering extraction created the wind turbine system to extract the energy inherent in the wind. Because the energy generated by the wind is converted to electric energy, the machine is sometimes called a wind generator. Locally, wind velocities are significantly affected by obstacles such as trees or (Onah. et al., 2023).

The wind turbine blade is better designed at a vertical position to allow better deformation stress at a static position. Conversely, the von Mises stress showed 44.64% and 38.61% at horizontal and vertical positions. This also agrees with static total deformation, since stress is better managed at a lower percentage range (Aka et al., 2024), but did not study the transient wind turbine analysis for investigation of stresses based on finite element model. Hence, the need for transient analysis of wind turbine.

## 2. MATERIALS

Source of components used in this study include the geometry of the blade that was provided in the file "WindTurbineBlade.stp" downloaded from wind turbine design model 2019 work bench file. It was manufactured from a composite material "Epoxy E-Glass Wet", but its material characteristics were found in "Composite Materials" library of ANSYS Workbench "Engineering Data Sources". For the analysis types, the blade deformation was accounted for in the rotating frame of reference Figure 1 based on the coordinate system attached to the blade that is revolving and the blade cross-section attached to the wind turbine hub. This rotating frame of reference was created to have Z-axis coinciding with the blade rotation axis.

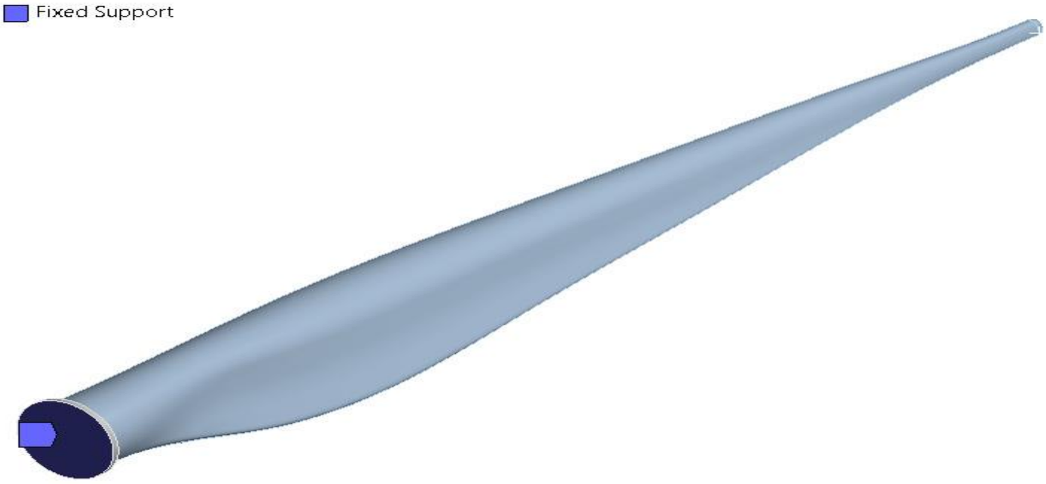

**Figure 1: Displacement constrains for the wind turbine blade[30]**

### 2.2: Procedure

In this study, the following procedure has been adopted to examine Wind turbine blade that converts kinetic energy using wind to electrical power.

### 2.3: The Transient Analysis:

The impulse force 5000N at the blade tip along Y-axis over time interval 0.1s with transient vibrations were accounted for the force application over total interval transient vibration of 5 s, at the stiffness damping coefficient-controlled ratio of 0.02 and the frequency 1.84 Hz.

This followed plotting the variation of displacements at blade tip over time for the whole considered time interval from 0 to 5 s for Y and Z coordinates, as well as the plot of Von Mises stress distribution over the blade at the time instant displacements where the maximum occurred.

### 2.4: Parameters and Conditions

Table 1 shows the parameters and considerations of the analysis in the wind turbine blade

**Table1: Parameters and considerations of the analysis in the wind turbine blade**

| Type of analysis | Parameters and conditions | Values |
|---|---|---|
| Static | Rotation speed | 12rpm |
| | Gravitational acceleration | 9.81m/s$^2$ |
| Modal | First natural frequencies | 6 Hz |
| | Centrifugal forces at the rotation speed | 12 rpm. |
| | Rotation speed range | 0 to 30 rpm |
| Harmonic | Amplitude of acceleration free- fall out. | 9.81m/s$^2$ |
| | Structural damping coefficient value | 0.01. |
| | Frequency response curves | @ X, Y and Z components |
| Transient | Impulse force at the blade tip along Y-axis. | 5000N |
| | Time interval with transient vibrations | 0.1s |
| | Total interval transient vibration | 5 s, |
| | Stiffness damping coefficient controlled ratio and frequency | 0.02 ans 1.8Hz |
| | Time interval | 0 to 5 s for Y and Z coordinates |

### 2.5: Finite Elements and Material Properties

By way of the wind forces, impact forces of birds and other vibrations the blade is manufactured from a composite material "Epoxy E-Glass Wet" that can withstand these impacts. The procedure was done by importing the geometry from **C:\Users\44730\OneDrive-WindTurbineBladeFiniteElements\AnsysProfile\Turbine blade_files\dp0\SYS-1\DM\SYS-1.agdb into Model (D4),** the material was changed to **Epoxy E-Glass Wet.** Its coordinate was followed to mesh. The meshing was done under **Static structural.** The process was from **static structural-analysis** to **setting/sub modeling/fixed support/ standard earth gravity/ rotational speed/ solution.** The resolution then gave **solution information/total deformation/equivalent stress.**

### 2.6: Mesh independence

The number of elements that were chosen for the mesh independence that started from default element size of 2131.94 to 2000, 1800, 1600, 1400, 1200, 1000, 800, 600 and 400, respectively. These finest meshes for the convergences, based the maximal stress and convergence plot were conducted after meshing could not go further.

## 3 RESULTS AND DISCUSSION

After applying an impulse force 5000N at the blade tip along Y-axis over time interval 0.1s and consideration that occurred over time interval 0 to 5 sec, the outcomes of transient for time variation of X & Y displacement for blade tip and deformation at the maximum were shown in figures 2 and 3, while figures 4 and 5 present the transient Von Mises Stress plot for time variation of X & Y displacement for blade tip and Von Mises stress.

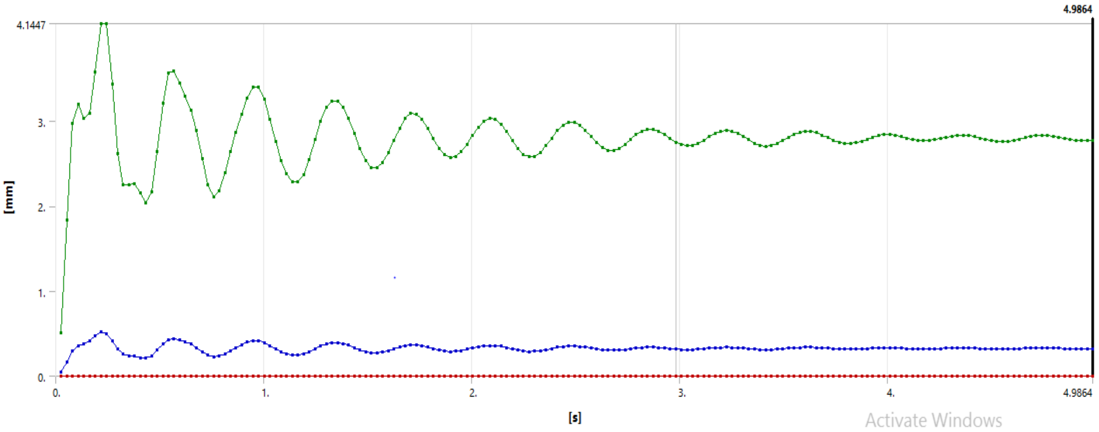

Figure 2: Total transient plot for time variation of X & Y displacement for blade tip

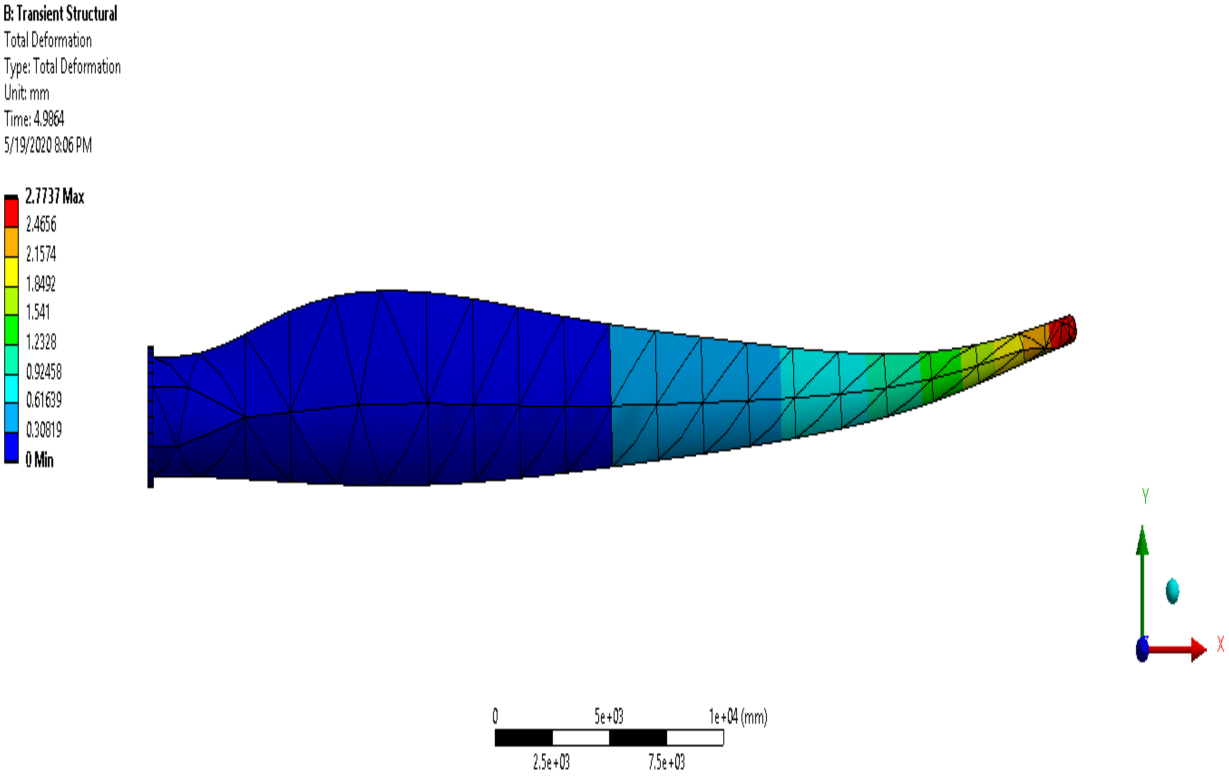

Figure 3: Total transient deformation at the maximum

### 3.1: Findings of transient displacement analysis.

Figure 4 showed a transient response of 4,1447mm on Y-displacement over a time response of 0 to 4, 9864secs, with equivalent stress deformation figure 5 of 2,7737Mpa for 4, 9864sec. The transient response took longer over considered time interval of 1 to 5secs to reach its steady-state. This suggests under damped transient response, since its transient damping ratio is less than one (1).

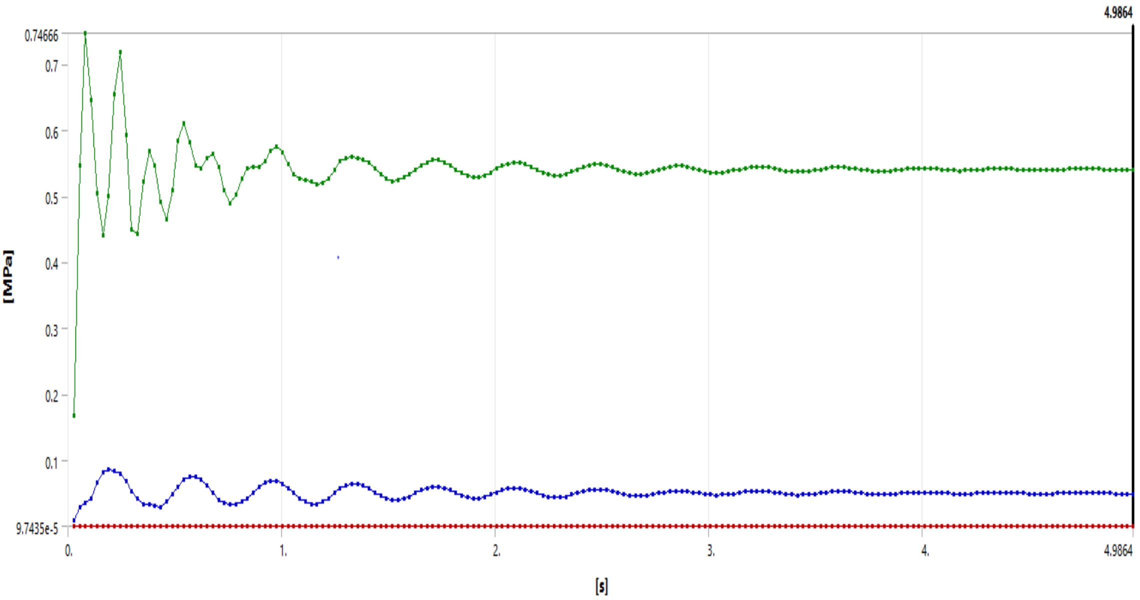

**Figure 4: Total transient Von Mises Stress plot for time variation of X & Y displacement for blade tip**

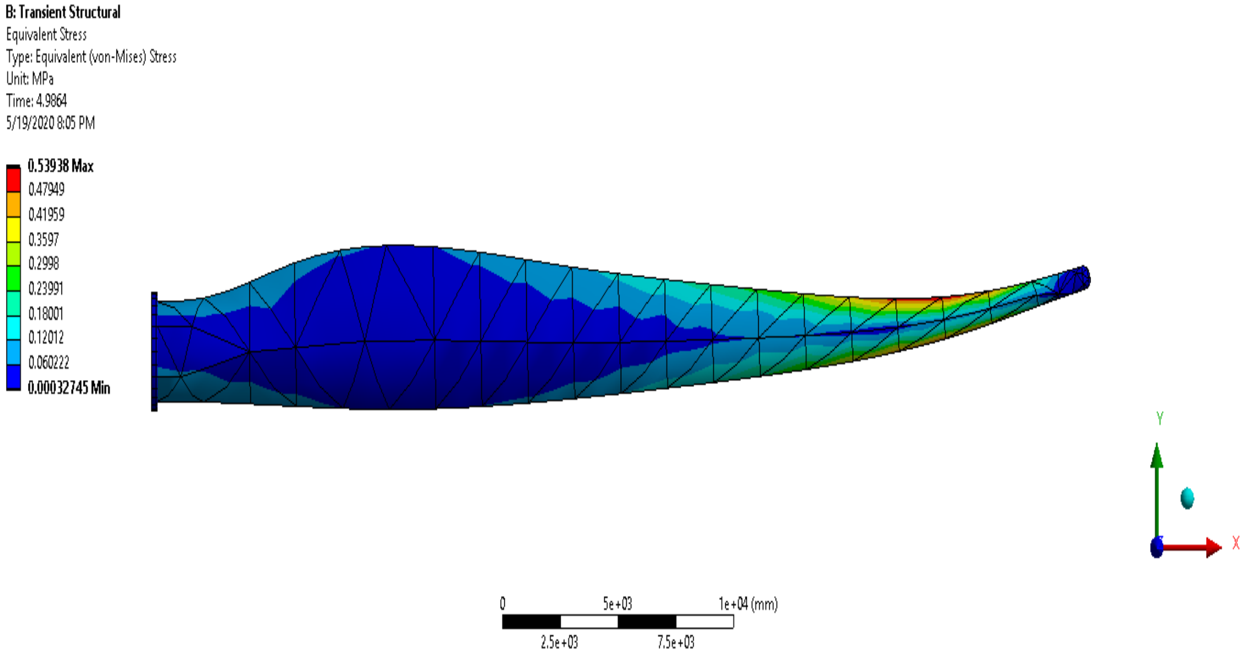

**Fig. 5: Total transient Von Mises Stress at the maximum**

### 3.2: Findings for transient Von Mises Stress at the maximum

Figure 4 showed a transient response of 0.74666mm on Y-displacement over a time response of 0 to 4,9864secs, with Von Mises stress figure 5 of 0.539387Mpa for 4, 9864sec.The transient response reached its steady-state at 3.8secs within over considered time interval of 1 to 5secs. This suggests critically damped transient response, since its transient damping ratio was equal to one (en.wikipedia.org/wiki/Transient_response). It is therefore deduced that impulse force is better enforced in wind turbine blade transient analysis at lower von mises stress to attain quicker damping response steady-state. This will allow the blade to withstand external impulse forces at the tip of the blade.

## 4. DISCUSSION

The transient response reached its steady-state at 3.8secs within over considered time interval of 1 to 5secs. This suggests critically damped transient response, since its transient damping ratio is equal to one (1). It is therefore deduced that impulse force is better applied in wind turbine blade transient analysis at lower von mises stress to attain quicker damping response steady-state. This will allow the blade to withstand external impulse forces occurring at the tip of the blade. Subsequent upon this analysis, the impulse force is better applied in wind turbine blade transient design analysis at lower Von Mises stress to attain quicker damping response steady-state.

## 5. CONCLUSIONS

The geometry of this analysis was done using finite element, where the material was changed to Epoxy E-Glass Wet. After the finite element analysis the mesh independence occurred at 800 and 600 element size. The 800 element size was chosen for subsequent transient response analysis. In addition Campbell diagram was analyzed and showed that response vibration occurred at amplitude of 5.5x106Pa with a corresponding frequency of 5Hz. This gave a rotational speed of 262.4x106 rpm. At this point, transient response reached its steady-state at 3.8secs within the considered time interval of 1 to 5 secs, suggesting critically damped transient response with transient damping ratio equal to one. This shows that the impulse force is better applied in wind turbine blade transient analysis at a lower Von Mises stress to attain a quicker damping response steady-state, which favors wind turbine blade analysis

## 6. FURTHER WORKS

1. The role played by wind turbine blades in the assimilation of energy from the wind cannot be over emphasized.
2. Careful designing of the blade will help in achieving; the greatest efficiency when absorbing vitality from the wind.
3. Too much transient vibration may damage the internal structure of elements of a subject. When it happens to a mechanical structure, it would be much more difficult to manipulate the condition of the structure. Transient vibration cannot vanish only in some cases, vibration can be brought down. It can be developed in future works.

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