LOAD STRESS DISTRIBUTION IN A TYPICAL SMALL WIND TURBINE STRUCTURE IN STATIC CONDITIONS

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Fall 2016
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Capstone Final Report

Approved by the Supervisor

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I. Acknowledgment

First and foremost, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my whole existence, years of study and through the process of completing and writing this report. This accomplishment would not have been possible without them. Thank you.

I would also like to acknowledge Dr. Anas Bentamy from the School of Science and Engineering at Al Akhawayn University in Ifrane, who open-heartedly agreed to be my capstone supervisor. I am grateful to his valuable comments on this project, his precious help and the trust he had put in me and my work.

I would like to thank Mr. Lghoul for constantly helping me through this capstone project thanks to his guidance and support.

I would also like to thank the PhD students, Mr. Tenghiri and Mr. Khalil for their unconditional help, advice, and assistance in this project. Without their passionate participation and input, the capstone could not have been successfully conducted.
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IV. ABSTRACT

During the last decades, many technologies have emerged in the renewable energies market, among which there are wind turbine which have been growing exponentially. Wind turbines offer sustainable opportunities to researchers, and thus making them more interested in this domain than ever before. Economically speaking, the hope of entirely substituting non-renewable resources by this technology has helped its cost to decrease through the years.

Developed countries nowadays have been able to develop energy stations which could cover the needs with capacities’ scale ranging from kilowatts to several megawatts order of electrical energy. Wind turbines are used to provide energy to any kind of usage thanks to the continuous improvement of their efficiencies, reliability and safety.

The long term objective is to practically build up a functional prototype of a typical small wind turbine. This project aims to define the dead load and stress distribution on a small typical wind turbine in static conditions for us to be able afterwards to ensure the safety of our design and model. The scope of this project is to assess the dead loads stresses on our designed wind turbine through conducting a structural analysis of this structure in static conditions, using Finite Element analysis or FEA.

Keywords: Wind Turbine Design, Wind Turbine Tower Load, Finite Element Analysis, Structural Analysis, Stress distribution, Displacement
V. STEEPLE Analysis

5.1. Social

The development of renewable energies is the future for our planet, renewables including wind are meant to produce energy using natural resources which will decrease the price of the power consumption probably since there will be enough resources to accommodate all the demands, which is beneficial for people. As this industry is growing, it will create more job offers and thus help improve the income. It will help improve our R&D and provide our youth with golden opportunities to evolve internationally and merge in the global energy world.

5.2. Technological:

Currently, wind energy is being used by house of grid in order to cover part of the power needed and energy to people. There are other inventions using wind energy such as: motors, generators, Vento mobiles and so on. The emergence of this industry requires an advanced level in technologies, for simulations, design, prototyping and others. This creates a great opportunity for developing our current technologies, and getting aligned with the world’s improvement to a maximum value.

5.3. Economical:

The proliferation in the use of wind energy in Morocco could be the starting point of a new industry related to the different component of wind turbines such as generators, brake systems, blades. Additionally, if the country attains its prospective in terms of renewable energies, it might be able to the export of some energy amounts, and therefore develop its economy. Wind energy is an emerging industry which will create job offers and help in the economic growth of our economic sector in Morocco.

5.4. Environmental:

The use of wind energy in particular, and of renewable energies in general has a positive influence on the environment all over the world, for the simple reason that those energies are known to be environment friendly, to be more explicit the rate of gas emission is very low. They preserve our natural resources and at the same time making very high profit out of them, without getting any damages done on either parts.
5.5. Political

The renewable energies development in Morocco allowed the country to benefit from many international alliances, which will lead to the strengthening of relations between Morocco and other countries.

5.6. Legal:

Our project completely respects the Moroccan law concerning renewable energies. This later gives directives about the integration of any renewable systems in the national electrical grid and also laws about private project that needs approval of authorities before the final on field prototyping.

5.7. Ethical:

At a certain point in the design stage, engineers are required to use some softwares for simulation as an example, or cost analysis, or even for design. Unlicensed software is considered as theft which is ethically unacceptable. Also, being ethical means being in harmony with humanity values, which stands for the preservation of our world, and using its resources properly. This is the main objective of renewable energies use.
Chapter 1: Literature Review on Wind Turbines

I. Introduction to Wind Energy

As Morocco is currently engaged in a wide renewable energies program, and specially wind energy, our project of development of a small typical wind turbine is feasible within this energy strategy framework on several levels. The object of this capstone is the analysis of the dead load and stress exerted by the self-weight of the wind turbine in static conditions. As stated in the specifications, the tower and the nacelle of a wind turbine are mainly designed to ensure the stability of the whole system during its lifetime. In static conditions (wind turbine rotor not spinning), the turbine structure is subject to intrinsic loads (dead load) applied by the self-weight of the components composing the system. In order to improve the system stability, the dead loads must be spread uniformly on the whole structure.

It is important to determine the dead load distribution on the wind turbine in its static phase, for us to further progress in the whole project. We will be using mainly SolidWorks software to build, assemble and analyze the whole structure. This software enables us to precisely describe the dimensions and positions of each component, to get an accurate stress distribution analysis, to finally identify the safest wind turbine layout.
II. WIND ENERGY

Wind power supplies the power consumption steadily throughout the years, but has less consistency in shorter periods and is thus used in parallel with other power generating sources to allow for a reliable supply. The global leader in wind power generation is arguably Denmark as it produces nearly 40% of its domestic needs in electricity. As of 2014, the global wind power production is of 369,553MW. The European Union generates 11.4% of its electricity through wind power. [2]

III. Wind Turbine Topologies

![Common types of wind turbines](image)

*Figure 1: Common types of wind turbines*

3.1. Lattice Tower

The lattice tower is made from trusses or frames that are bolted or welded together as shown in Figure 1. Aesthetically, it is less appealing which is an important factor.

3.2. Tubular Tower
The tubular tower is represented in Figure b. and has a pipe cross-section. Generally, bolts are used to join the sections of the tower and to secure the tower and the foundation. The tubular tower has many advantages over the lattice tower as it provides a protected section to access the structure under some conditions. It provides a certain level of security as it limits the access to the turbine oppositely to the lattice tower. Although the initial material cost may be higher than the lattice tower, it does not rely on many bolted-connections nor on high maintenance cost. Aesthetically, it is more appealing than the lattice tower, hence, European countries have always favored tubular towers for aesthetic reasons.

### 3.3. Hybrid Tower

The hybrid tower combines different configurations of the wind turbine tower. The hybrid tower shown in Figure c is an example the tubular type. It has a major section size limitation of about 4.3 m for larger turbines. This limit results in site welding and fabrication which decreases the quality of the tower. Also, transporting the large diameter sections can be very costly as well.

The wind turbine which has been designed by our team previously is shown in the figure below. Its properties are defined to be:

**Tower:**
- Height : 24 m
- Divided into three parts (of 8m)
- Mass : 1264 Kg
- Material : Structural Steel (S355JR)

**Blades:**
- Length : 3 m
- Material : E-Fiber Glass

**Nacelle:**
- Generator Mass : 300 Kg
- Overall Mass : 567 Kg

*Figure 2: Wind Turbine Model designed*
IV. Wind Turbine Components

The illustration below describes the wind turbine components which will be detailed in the upcoming sections.

![Wind Turbine Components Illustration]

Figure 3: Wind turbine components

4.1. Tower and Foundation:

Very strong foundation, generally cement based, is used in order to guarantee the stability of a wind turbine. The tower is supposed to hold the weight of the nacelle and the rotor blades which can be combined to 576 kg, and absorb the huge static loads caused by the varying power of the wind as well. In general, concrete or steel structures are used.

4.2. Rotor and blades

The rotor is the component which makes the blade rotates and thus converts the kinetic energy in the wind into mechanical energy. The rotor blades are 3 meters long, and are mainly made of E-glass fiber.

4.3. Nacelle

The nacelle holds all the components of the turbine. It is connected to the tower through bearing which rotate the tower in order to follow the direction of the wind. It holds other components such as rotor shaft, transmission, generator, coupling and brake and others.
Our wind turbine model is represented in the figure below. It shows the components mentioned above, adapted to our own specific model. This layout is subject to change upon inspection and different analysis;

![Figure 4: Model components layout](image)

V. From wind to electricity

On top of each turbine, there is a box know as a nacelle. Attached to the nacelle, are three propeller like blades. They connect to a rotor. Also on the nacelle there is an anemometer to measure the wind speed and direction. The wind direction rotates the nacelle to face into the wind. The energy in the wind called kinetic energy turns the blades around the rotor, and creates therefore mechanical energy. The rotor spins the main shaft which turns inside the generator. Here a magnetic rotor rotates inside a copper wire causing the electrons to flow and thus creating electrical energy. A transformer inside the nacelle increases the generation of electricity, which goes down large cables from the nacelle through the tower into underground cables for storage and distribution.
VI. Limit of Betz

In 1919, the German physicist Albert Betz has concluded that no wind turbine is able to convert more than $\frac{16}{27}$ (59.3%) of the kinetic energy in the wind into mechanical energy. This is known as the Betz Limit which is completely dependent on the nature of wind turbine itself. [4]

The following figure represents this concepts in a clearer illustration.

![Diagram of wind energy conversion]

*Figure 5: Conversion from wind to electrical energy*

VII. Loads on Wind Turbines

The mere objective of this project is to conduct a structural analysis in order to assess the effects of dead loads on our wind turbine. This requires a prior understanding of the matter. We are originally interested by the effect of dead loads on the wind turbine. The dead loads are defined to be the intrinsic weight of a structure, excluding the weight of other goods. For instance, if we have a house, as illustrated below, with people and furniture on it, then we can say that the house is subject to two kinds of loads:

- Live load which is the weight of the people and the goods
- Dead load which is the weight of the structure (house in this case) itself.
Dead load can cause stresses, deformations, displacements in the structure. Its effects can be assessed through a structural analysis so we can identify the failures and either redesign the structure or consider it during maintenance and frequent checks. An excess in dead loads or overloading always leads to structural failure. An example of a structural failure is represented in the figure below. This wind turbine collapse happened in Kansas USA, in December 17th, 2014. It was reported to have caused no human damage. However, the loss is still considerable. [8]
A structural analysis on our wind turbine will help us identify the best layout of the turbine and avoid failure. Solidworks offers several options in simulation studies such as static, dynamic, flow simulation and others. For a structural analysis the most suitable one is the static study. Every static analysis has eight major steps, which we will describe in details in the following chapter. It is important to note that to ensure a high accuracy of our results, it is essential to conduct several static study trials to make sure that the results are constant, and match the set of trials.
Chapter 2: Stress Distribution and Analysis using SolidWorks Simulation 2016

I. Static Analysis

As stated before, the objective of this capstone is to study the effects of dead load and the distribution of their equivalent stress in a small wind turbine structure composed of typical components.

II. Steps and methodology

To conduct our structural analysis, we will be using SolidWorks software. It is a tool which will enable us to evaluate the performance and improve the quality of our product and innovation. This software helps in setting up a virtual real-world conditions in order to test the product and their designs before actual manufacture.[12] The tests can be conducted to assess the design and their parameters under many studies such as static, dynamic, fatigue analysis, heat transfer, and flows simulations. The company says. SolidWorks has several tools, add ins and options. We will be using SolidWorks 2014 simulation, for us to test our wind turbine design virtually before manufacturing. The components were already designed by Mr.Lghoul in approximate dimensions. We will conduct our stress distribution analysis based on that design. [1]

The steps to be followed in this static study are as follow:

1. Start a new static study
2. Select material
3. Define the structure fixtures
4. Apply the loads, on surfaces and set magnitudes
5. Define the contact sets and contact components
6. Mesh the model properly
7. Run the study
8. Interpret the results
A detailed description of each step will be presented in this chapter of the report. I have begun with the tower analysis before addressing the whole structure. The following is a description of the tower analysis at first.
Our tower is designed as a 3 parts tower, the bottom, the mid, and the top part. Each part is of 6m tall, which makes our whole tower 24m tall.

The tower has a mass of 1264 kg.

It is essentially subject to five loads which we will define later.

2.1. Material Selection:

Once the static study is open, the first thing we are called to do is to select the model’s material.

During the design of this tower, some the material specifications were set as a result of the analytical studies conducted. SolidWorks offer a range of materials in its library. In addition, it offers us the possibility to create our own specific materials based on its known properties such as yield strength, tensile strength, density, and other properties.

A table of characteristics of this material is represented in the figure below.
Figure 8: Tower Material Properties (S355JR)

For the other components, the materials are represented in the table below:

Table 1: Materials Properties

<table>
<thead>
<tr>
<th>Component</th>
<th>Material Name</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing House</td>
<td>Stainless Steel</td>
<td>Predefined in the SW Library</td>
</tr>
<tr>
<td>Bolts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coupling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blades</td>
<td>E-fiber Glass</td>
<td></td>
</tr>
<tr>
<td>Main Shaft</td>
<td>Medium Carbon Steel</td>
<td>Ultimate tensile stress = 700 MPa</td>
</tr>
<tr>
<td>Hub</td>
<td></td>
<td>Yield Strength = 450 MPa</td>
</tr>
<tr>
<td>Main Frame</td>
<td></td>
<td>Young’s modulus, stiffness = 210 GPa</td>
</tr>
<tr>
<td>Tower</td>
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<td>Non Alloyed Structural Steel S355JR</td>
<td>Predefined under the Structural steel</td>
</tr>
</tbody>
</table>
2.2. **Fixtures Definition:**

For each step, there is a corresponding advisor which can be followed in case of confusion.

Our model needs to be fixed for the simulation to operate properly in order to prevent any failure or unwanted displacements. For our wind turbine tower, the fixture will be of course in the bottom face of the tower, the face in contact with the ground.

The fixture advisor presents many options for fixing, we will go with “Fixed Geometry” as we have no roller/slider, fixed hinge or elastic support. The following figure shows the result of our fixture. We have fixed the face as well as inner and outer edges of the base of the bottom part of the tower for optimal fixture. [1]

Solidworks offers three options when it comes to fixtures. The following figure shows the fixture options.

![Fixtures Definition](image)

*Figure 9: Fixtures Definition*

Our model does not hold any hinge, nor roller or slider, which leaves us with the fixed geometry option. Thus we have to apply a fixed geometry fixture at the bottom face of the bottom tower part. The Procedure is shown in the following figure.
2.3. **Loads Application**

The loads which will be applied on our tower are set by the designer, Mr. Tinghiri. The 5 loads applied on the tower are presented in the figure below. Each of these loads were previously calculated analytically by the designers.

1. The gravity load is a pre-set option in SolidWorks and is essential for any static study.
2. The distributed mass load is a representation of the mainframe with all of its components. Its mass was set to be equal to 576 kg. The application of this mass was on the top face of the top part of the tower.
3. The thrust’s magnitude is 4102 N. It is applied on the top part of the power, on the left edge.
4. The drag force, which is a wind representation is of 21.31 KN, applied at the center of gravity of the tower as a resultant force.
5. The torque is also applied on the top part of the tower with a magnitude of 324 KN.m.
2.4. Connections

This part is quiet challenging as it requires a very precise knowledge of the parts and the way they are all connected to each other. Connectors are mechanisms which define the way in which the components are connected to each other entity or to the ground. Modeling and simulations is simplified thanks to connectors without creating the exact detailed geometry of the connections. It contains three major sub tools.
a. The contact set

In SOLIDWORKS Simulation, the contact settings describe the types of interaction happening between boundaries of the different parts of the model. For accurate description of the different contact settings, SOLIDWORKS Simulation offers several types of contacts, such as:

- Bonded contact conditions to simulate parts or entities such as if they were actually welded.
- Node-to-node or surface-to-surface conditions which are set to avoid interference between different entities, however they allow gaps to form between them.
- Self-contact conditions are set to determine the contact between faces of a body in big deflection studies.
- Shrink Fit is to simulate shrinking fit between two entities.
- Virtual Wall to set the contact between an entity and a virtual wall, this is typically used in setting foundation bolts which are to be done with respect to a virtual wall, usually is the bottom plane of the foundation tower.

b. The component set

This tool enables the user to define the type of contact between faces of the entities. It offer three main options.

- No Penetration: The selected components are not allowed to penetrate each other while running the simulation, no matter how their initial contact conditions are.
- Bonded: Selected components or bodies behave as if they were welded during simulation.
- Allow Penetration: The selected components are allowed to penetrate each other while running.

c. Bolts

Bolts represent a very important feature of SolidWorks simulation as they simulate the real effect and roles in the fixture of the whole structure.

The software enables us to set the type of bolts, dimensions, material used, strength and physical properties depending on their use.

Bolts: Defines a bolt connector between two components or between a component and the ground. There are several bolt types namely Counterbore with nut, countersink with nut, counterbore screw, countersink screw and foundation bolts. We have only used two in simulating our model’s connections.
Foundation bolts, as an example, are set with reference to the bottom plane on which the tower foundation faces the ground. Their properties are as follows. The head and nut diameter was set to be 36mm, whereas the shank diameter is 24 mm. For the strength data, as we do not the tensile stress area, and our foundation bolts have no threads, we just specify the material (alloy steel), the software has set the strength to be 620.422 Mpa. The safety factor of 2 is specified by us, so that we can compare our bolts and see if they have passed the safety factor, in this case it means they are good. Otherwise, if they fail to pass the safety factor, we need to do some modifications. For the pre-load, the axial force was found to be 960N. We have retrieved this value from a program which, given the diameters of the bolt, it outputs the axial force magnitude.[11]
2.5. **Meshing (solid, shell, beam, control, incompatible)**

Meshing is an essential step in every simulation, and is equally challenging. It is based on a Finite Element Analysis technique which provides a reliable numerical technique for analyzing engineering designs. At first, a geometric model is created; then the model is divided into small pieces of simple shapes (elements) connected at common points (nodes). The model then is treated as a network of discrete interconnected elements through the FEA. It predicts the behavior of the model by combining the information obtained from all elements making up the model. [6]

The small pieces into which our model is to be divided are called elements, which are are connected into points called nodes. The elements generate the stresses and strains calculations, whereas deformation and displacement are calculated at the nodes. The following picture illustrates the difference in geometry between Solid and Shell meshing.
There are several differences between these two types of meshing, namely the degrees of freedom. Solid elements have three degrees of freedom which are the three translation along x,y, and Z axis. Shell elements have six degrees of freedom which are the three translations, in addition to the three rotations along x,y, and Z axis.

Meshing quality is also divided into two types:

- **Draft Quality**: Uses Linear elements in meshing. Triangular for shells and tetrahedral for solid.
- **High Quality**: uses parabolic elements which is higher in terms of accuracy. It also provides greater mathematical approximation. The only drawback of this option is the high computational resources it requires, namely time and memory.

The meshing component in the software generates a mesh based on a global element size or local mesh control specifications. Mesh control lets you specify different sizes of elements for components, faces, edges, and vertices, bolts areas. It is a very useful parameter which helps overcoming some meshing errors. It enables the program to generate a finer mesh in the specific areas.

The software gives an estimation of a global element size for the model. It is essential that it takes into consideration its volume, surface area, and other geometric details. The size of the generated mesh which is the number of nodes and number of elements is highly dependent on the geometry and the different dimensions of the model. For a more accurate solution, a smaller element size may be required.
Meshing generates solid elements through 3D tetrahedral elements, and 2D triangular elements for shells, and finally 1D elements for beam structures. A mesh consists of one type of elements unless the mixed mesh type is specified. Solid elements are basically conventionally used in models which are more or less bulky. Shell elements are naturally suitable for modeling thin parts (sheet metals), and beams and trusses are suitable for modeling structural members. It is also important to mention the DOF, or Degrees of Freedom when talking about meshing. In our model, we have used the solid meshing, because our model does not have thin parts, additionally we have no beams nor trusses in our model. This leaves us with the alternative of solid meshing.

Despite the fact that the automatically created work is, most of the time, appropriate, issues with small or little, yet critical, geometrical and physical components can lead to a great degree of high number of cells. Thus, the computer is compromised by its relatively small memory. In such cases Flow Simulation alternatives authorize us to physically change the computational work to the tackled issue's components to determine them better. The geometry then can fittingly be managed. However, in the case of mesh generation by zooming in a thin area, we notice that the issue is still running. Therefore, we will utilize the Local Initial Mesh to determine these areas suitably. The local initial mesh enables us to locate an initial mesh in its local area of a computational domain, which leads us to a better Geometry optimization as well as flow peculiarities in that same region. The local section can be characterized by a segment of the assembly, incapacitated in the Component Control dialog box, or indicated by selecting a face, edge or vertex of the model. Besides, Local mesh settings are connected to all cells converged by a part, face, edge, or a cell encasing the chosen vertex. The local mesh settings don't impact the fundamental work. However it is essential work delicate: all refinement levels are established as for the fundamental work cell. To upgrade the mesh in a particular area and prevent extreme splitting of the mesh cells in different parts of the model, we apply a local initial mesh across the segment enclosing this district. The element is made particularly to indicate the local initial mesh. The sets on the Narrow Channels tab control the mesh improvement in the model's stream entries. Trademark number of cells over a restricted channel box determines the quantity of starting lattice cells that Flow Simulation will attempt to set over the model's stream sections in the bearing ordinary to solid/fluid interface. If feasible, the number of cells crosswise over thin channels will be equivalent to the predefined characteristic number. Else, it will be near the typical number. If this circumstance is not fulfilled, the cells lying in this bearing direction will be part to fulfill the condition. [15]
For our model, we have used a mixed meshing: solid meshing for all the components, except for the Blades for which we have employed shell meshing as the structure is very thin and requires precise meshing. The meshing of the blades is illustrated in the figure below:

![Figure 18: Blades meshed by Shell meshing](image)

Meshing is a very challenging step in any structural analysis or simulation using any other simulation software (ANSYS, Abaqus, Catia...). Throughout this study, we have faced several errors and issues related to meshing which can be solved by:

- Mesh control is an option which allows the user to further refine the mesh size in specific areas. We had to use this option to be able to mesh the sections around the bolts so it can be more accurate. The following figure shows the mesh control applied at the bolt area of the top tower, around the tower link.
- Incompatible mesh: in an incompatible mesh, there is no a node-to-node connection between the mesh of each touching entity. Each entity is independently meshed.
2.6. Solvers and their uses.

Any rigid body, unconstrained in space has six degrees of freedom which are the three translational and the three rotational. It can move along its X, Y, and Z axes and also rotate about its X, Y, and Z axes. Knowing the number of degrees of Freedom in our model is essential for meshing and solving purposes. In finite element analysis, every problem is represented by a set of algebraic equations that must be solved simultaneously. Solution methods are either direct or iterative. [10]

Direct methods solve the equations using exact numerical techniques, whereas Iterative methods solve the equations techniques where in each iteration, a solution is assumed and the errors are evaluated. The iterations continue until the errors become acceptable.

SolidWorks Simulation offers four different options in solvers. The following describes each one briefly.
a) **FFEPlus**

FFEPlus is an iterative solver that uses implicit integration method. It assumes each iteration and evaluates each error assumed and errors are evaluated. Iteration continues until errors are small enough. Thus, in general, if the study contains more than 100,000 Degrees Of Freedom. It is more efficient and more accurate to use FFEPlus.

b) **Direct Sparse**

Produces a direct solution using exact numerical techniques. “Sparse” refers to the zeroes in the matrices that it uses to find a solution. It is faster when more memory is available, and is generally used in small and medium sized problems, if FFEPlus produces less accurate results.

c) **Large Problem Direct Sparse**

The LPDS Solver is the Direct Sparse solver which can calculate using multiple cores. The LPDS solver is used if the Direct Sparse solver is required and there is a lack of RAM. LPDS is only used as a last resort.

d) **Auto**

The automatic option uses FFEPlus until certain conditions are seen in the study.

### III. Results plotting and interpretation:

3.1. **Von Mises Stress:**

Before getting to results analysis, it is essential to know what is von Mises stress and why is it used in structural analysis to prevent failure.

The von Mises stress is used to determine if a material will yield when it is subjected to a specific loading. The von Mises stress is computed and then compared to the material's yield stress. This is called the von Mises Yield Criterion. [5]

It is an empirical process which has to be verified through the different observation and experiences rather than an imposed theory or reasoning. [16]
3.2. Our Results Plots:

To get the stress distribution in our structure, the structure simulation was divided into parts as a start.

The tower which is made up of three sub parts all bolted together is the first step. The result plot shows a yield strength of $2.75 \times 10^8 \text{ N/m}^2$. The stress distribution on the tower gives us a good insight about the structure base, as the region is all in blue, which means that it will hold the loads applied to it which were previously set as boundary conditions. Our tower, with its defined material, specific bolts set and parameters, loads applied, and geometric fixture is a safe structure. [13]

Based on the Von Mises criterion, or what is called distortion energy, the tower up to now, is structurally safe. The maximum and minimum Von Mises stress for the tower and main frame assembly, are $1.289 \times 1^{11} \text{ N/m}^2$, and $3.565 \times 10^2 \text{ N/m}^2$ respectively. The result is acceptable because the yield strength value of $2.75 \times 10^8$ is actually present in the range of $[\text{minVMStress}, \text{maxVMStress}]$. [7]

$$3.565 \times 10^2 \text{ N/m}^2 < \text{yield strength} = 2.75 \times 10^8 \text{ N/m}^2 < 1.289 \times 1^{11} \text{ N/m}^2$$
In the following illustration, the results of the simulation of the tower, main frame, bearing and shaft are shown. The von Mises stress plot shows a red spot in the link between the bottom tower and the mid tower, in between two bolts. The stress in that area goes up to \(1.289 \times 10^{11}\) N/m\(^2\). That is a potential failure area of the structure due to its dead loads.
The previous stress deformation is clearly stated in the following figure. It shows two red spots, with higher stress values in the regions between two bolts connecting the bottom part of the tower with the mid part of the tower.

In this simulation, getting a yield strength is not possible in this case, simply because the material used for the different components of this study is not the same. It is not possible to get a unique value of the yield strength which could be a sort of representation of the overall assembly. Joe Galliera, who is a solidworks simulation specialist, says in a forum about the matter:” That marker [of the yield strength] only shows up for part analysis (and only when the stresses go beyond the yield strength specified in the material property).” [14]
In the same structure, we can see the deformation in a more obvious way in this static displacement plot. The maximum displacement in this assembly is set to be $1.018 \times 10^{11}$ mm.
3.3. **Principal Stress:**

As Von Mises stresses will not lead us to accurate interpretations, we have generated the 1\textsuperscript{st} and 2\textsuperscript{nd} principal stresses of the model.

The Software tutorial provides a definition of the principal stress concept:

The normal and shear stress components define the stresses at a point, in reference to an orthogonal coordinate system XYZ. In general, if the coordinate system is rotated, then the values of the stress components change as well.

At a certain orientation (X′Y′Z′), all shear stresses eliminate and the state of stresses is then defined by three normal stress components, which referred to as principal stresses (where the axes (X′Y′Z′) are referred to as principal axes.) This is illustrated in the figure below:

![Figure 1](image)
![Figure 2](image)

*Figure 24: Principal Stress*

The principal stresses usually are represented by an ellipsoid. The 3 radii of the ellipsoid are the 3 principal stresses’ magnitudes accordingly. The arrows represent the direction of the stress, to tell whether it is tension or compression.

SolidWorks gives the option of plotting the 1\textsuperscript{st} and 2\textsuperscript{nd} principal stresses. The plots are shown in the figure below. It is important to note that the values of the two plots are not really different form each other.
Based on the first principal stress plot, we can conclude that it shows an overall tension varying between (1.7 GPa and 7.57 GPa) and two negative stress values referring to compression on the flange of the bottom - mid tower part, one is of magnitude 33.4 GPa, the other is of 10 GPa. The yield strength of the material used in the tower which shows this failure is 275 MPa. The compression obtained is in GPa, whereas we have the yield strength in MPa; this means that our structure will not withstand the dead load simulated in the software. These values of stress are very high compared to the yield strength of the material which has failed. The simulation software has given these values which are found to be way higher than normal.

This shows the failure of these two areas within the tower. Other results or different colors may exist, however cannot be seen due the dispatching of the nacelle components as it is illustrated in the principal stress shown in the figure above.
It is approximately the same thing for the second principal stress shown in the figure below.

*Figure 26: 2nd Principal stress*
3.4. Displacement

The displacement plot below, shows that the tower will not hold in its place, and the slewing bearing will be displaced due to the loads applied and due to the weakness of the connections, namely the bolts.

Figure 27: Deformed Shape Displacement

The figure above shows the displacement of the tower in form its initial position which is supposed to be centered within the tower. The dead loads of the structure will cause the tower to fail and not hold in its place. The original position of the model is shown in the figure below. It is clearly noticeable that the tower link has indeed been displaced.
IV. Future Work

The structural analysis of this wind turbine can be further detailed and be a stronger basis of the rest of the research. The need present now is that of a complete and entire structural analysis with the precise dimensions of every component and every load to be bearded by the tower in static conditions. The structural analysis will enable us to even improve its design. Once the design is finalized, it is appropriate now to begin a dynamic study, during normal operations and extreme conditions, followed by fatigue analysis and flow simulations.

Simulation is a very essential aspect of every research as it provides guidance to the designer and is an important decision making point. It should be implemented with good care and attention.
V. Conclusion

The main objective of this study was to assess the effect of dead loads on a small typical wind turbine under static conditions. The assessment was done through a structural analysis via SolidWorks static simulation tool. The methodology of how to conduct a static study was presented in details which enables people who would like to carry on this study to do so in a smooth manner.

Analytical study and research have been carried on earlier and form a good starting point to conduct our static study. However, our structural analysis has presented some results and conclusions which make the research done before to reconsider some of the outputs of this study, and redo the wind turbine design accordingly.

The results we have obtained of the static study were under application of the following loads: gravity with a mass of 1264 Kg, distributed mass, thrust of 4.102 KN, torque of 321 KN.m, a drag force of 21.31 KN.

We have obtained the von Mises stress plot, displacement and deformation of the wind turbine, in parts and as a whole. It has shown that our wind turbine design need to be rectified at certain points to avoid the structural failures we may face.
VI. References


VII. Appendix

Figure 29: Bolts parameters