Project Wind Turbine

Solution Engineering Report

Hanzehogeschool Groningen – Mechanical Engineering –
Group 9 – Semester 4-6 – Fortis Montana Wind Turbine

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Preface

The final report resulting from the project wind turbine. This report is written to show how this project was prosecuted and what the final results are from the researches that have been done.

This project was worked on from the 9th of February till the 14th of June to come up with this eventual report. This project has been elaborated by project group 9 existing of: Sibbe Bakker, Matthijs Rinsma, Nikki Boer, Julian Manhro, Harold Streekstra, Tahsin Islam and Joran Borger. Thank you all for the pleasant cooperation on this project.

This project has been commissioned by Hanze University of Applied Sciences, EnTranCe & Energycampus Leeuwarden. During this project we have been guided by our tutor Mr Arjen de Ruijter. We would like to thank him for all of the help he provided us with. We would also like to thank Mr Eric Jahn, Mr Laurens Mengerink and Mr Christiaan Dirksen for all of the help they have provided us.

Groningen, 14-06-2021

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Summary

A second-hand 5 Kw wind turbine has been donated to Hanze University of Applied Sciences. This wind turbine has some broken parts and has no tower and is missing a part of the foundation. The pivoting shaft is broken and there are some electrical cables missing. The wind turbine is located at EnTranCe and wants to collaborate with Energycampus Leeuwarden to eventually put the wind turbine on their location. The goal of the project is to choose the best location to put the wind turbine, to fix the turbine so it works again and to choose the right tower and foundation. The main question of the project is therefore: ''What is the best location for the wind turbine, and what is needed to make the wind turbine work again?''

To determine where the wind turbine is going to stand, a destination plan has been made. The outcome of that destination plan is that the wind turbines best location is on the old garbage dump. Here the tower can be a maximum of 13 meters because of the height of the dump and the restricting permits. Later this turned out not to be possible because the tower must be at least 15 meters tall. The ground is also not good enough for a wind turbine to stand on. The place where the companies will be located is now the best. There are 3 places in this area where the wind turbine can be placed. After a new trade-off matrix, it appears that the wind turbine will be located on the south of the site. This is where the most wind is, the companies are not affected by it and it is reasonably close to an electrical connection.

The mounting point of the tail is broken because one of the ends is bend. The tail of the turbine has to be attached to the frame via the mounting point. Luckily this couldn't have happened when the turbine was running because the forces on this piece come from the horizontal axis. So the part does not need to be reinforced because it probably happened during assembling or breaking the wind turbine apart. Because this part is broken a new one will be ordered. There can't be any improvements to this part because that will mess with the balance of the turbine. For the tower a choice can be made between 4 towers that are suitable. Two of these towers are used by Fortis, the tube tower and the guyed tower. Because the wind turbine was scheduled to be built on the garbage dump at first, the foundation would not be allowed to go that far into the ground. Calculations have been made for this to see what the best tower would be so it would not fall down with heavy wind. Now that the wind turbine will be located on the company site, this is no longer the case and the calculations are no longer necessary because the soil here permits the worst case pressure of 100 KN.m^2. The single tube tower is chosen to use because it occupies little space.

For the electrical system, everything seems to be complete. Parts still need to be tested to see if everything still works properly. All wiring must be replaced. This is 20 meters wire from the generator to the ground and 10 meters for everything between the components. A stop button could be installed for extra safety as well.

A step-by-step plan has been drawn out for the installation of the wind turbine. The foundation is first placed in the ground. Only then will the tower and the wind turbine be assembled. Then everything is lifted up by a tractor. Then the battery is placed and finally all the cables are going to be connected. The wind turbine doesn't need any mandatory maintenance, but it is still wise to check the wind turbine on malfunctions. The advise it to do this once a year.

Nowadays it is important to look at the lifespan for a product. That's why a sustainability plan was made. The most important outcome of the plan is that when welding to use the technique that emits the least amount of CO_2, when milling or drilling try and do this in an efficient way. When the wind turbine needs to be transported this has to be done at an green way like hydrogen. The blades can be coated so the lifespan of the blades are longer. The total cost of the project is €9554,40. This include the broken parts, the electrical parts, the installation of the wind turbine and the tower and foundation. There needs to be extra attention for the legal parts and the technical calculation because of a risk analyses the outcome is that this has the most change of going wrong.

1. Introduction

EnTranCe in cooperation with Hanze University of Applied Sciences received a damaged 5 Kw wind turbine which got delivered disassembled in boxes. It has been donated to the University with the intention for it to be a more practical project which ensures that the students can learn from it with more insight to realism. Due to having a physical object that needs to be repaired and installed. The disassembled wind turbine is immediately noticeably incomplete, with a missing a mast and a foundation. More missing parts are to be discovered in further research. The scope of this project is for the turbine to be repaired and installed ate the energy campus in Leeuwarden. The location on this campus is to be determined too which requires a destination plan. Consequently, the main question addressed in this report is therefore, ''What is the best location for the wind turbine, and what is needed to make the wind turbine work again?''

To determine a location for the turbine many factors must be taken into consideration such as, the mast must be at least 15 meters in height (requirement by Fortis) and with minimal surrounding obstructions to have a strong continuous uninterrupted air flow to rotate the blades of the turbine. Also, factors such as accessibility for maintenance and installment must be taken into consideration. Besides the location it is crucial to find replacements for the missing parts. A market and design research must be done consequently to ensure the healthy working of the turbine. Furthermore, the pivoting shaft of the tail is broken, and a solution must be found for this. For example, ether a repair is needed, a new component must be designed and fabricated or the component must be purchased. The electricals is an important topic too, to see whether it works or action is needed to make it work. Finally, an installation plan will showcase how it can be installed optimally.

This report has 10 chapters that contain the following. In chapter 2 there is a destination plan which decides where the turbine will be placed. In chapter 3 all of the missing and broken parts are listed and there is an explanation on how to fix this. In chapter 4 the electrical parts of the turbine are explained and what still to do with them. In chapter 5 an installation plan is explained. In chapter 6 a sustainability plan has been worked out to take a look at how the turbine can be as sustainable as possible. In chapter 7 the maintenance plan is explained to maintain the turbine after the installation. In chapter 8 a risk analysis is worked out to explain what could go wrong. In chapter 9 the costs of the entire project are projected. And finally in chapter 10 recommendations are given for the upcoming project group that will take on this project afterwards.

2. Destination plan

2.1 Results of the first destination plan

In the first destination plan (9, 2021)the choice of the designated location for the turbine was either on the Dyke, company experimental area or the plug and play park (Shown in figure respectively as location 1, 2 and 3). With a trade-off matrix points were given to each location based on the favourability of each location. The result was that (location 3) the plug and play park was the most favourable due to not having obstructions around, being cheaper to install, having a shorter mast making it cheaper and more accessible.

Figure 2.1 possible locations first destination plan

2.2 Results from the design report

From the previous *solution design report,* it was concluded that the optimal location for the turbine was location ''1'' on the experimental location of the industrial zone. This was based on the argument that the plug and play park has both an excessively unstable soil for the foundation and a very low height limit, which makes it prone for turbulences caused by the altitude difference (12m) of the plug and play park. Location 1 on the industrial zone has a building free area from the angle where the wind is more likely to come from (south-west). Even in the case of the wind coming from another area the surrounding building is approximately 12m which is still 3m below the lowest height of the turbine blade tip.

Figure 2.2 location decided in design report

2.3 Results after meeting with clients

After meeting with all the involved parties, the designated location has been discussed and altered towards the new wishes of the clients. The plug and play park indeed continues to be a non-suitable location due to the reasons stated in in the solution design report. Although location 1 was a suitable place it was argued that a new area for the turbine was possible. Previously it was unknown that the area aside of the main road was an option due to not being stated in the ''rules'' documents of the energy campus Leeuwarden. With this area now being an option further reasoning must be done to determine if this might be a potential new optimal location for the turbine. Also, it was argued that the buildings surrounding location 1 aren't in fact 12m but instead 25m in height. This makes location 1 less desirable and rises the potential of the new area.

By observing the new area, it immediately indicates to be a much more sensible place for the turbine than the previous location 1.This is due to various reasons. For example, if located in the new area the turbine won't occupy any of the company's experimental locations giving more revenue possibilities to the Energy campus. Also, the cable connection to the ''grid'' is a shorter and more direct connection, resulting in cheaper installation costs. There are three locations on this area that have some potential. These locations are shown in figure 2.3 as location 4, 5 and 6; With location 4 standing out as the most promising one due to favourability of the wind.

Figure 2.3 possible locations actual destination plan

Just like in the destination plan a trade-off matrix for the new situation is made to determine which of the 3 locations is more favourable.

Factors	Location 4	Location 5	Location 6
1. Maximum Height = 20 meters			
Surrounding Heights (x2)	4	1	3
NAP Height (x3)	2	2	2
Permitted Height (x2)	4	4	4
2. Noise			
Loudness depending on Height (x2)	4	3	4
Nuisance (x2)	3	2	3
3. Soil Conditions			
Soil Type (x2)	3	3	3
4. Safety			
Distance of Blades to Surroundings (x2)	2	1	2
Turbine Malfunctions (x1)	2	1	2
Installation Risks (x3)	2	1	2
5. Site Accessibility			
Accessibility for Students (x3)	5	5	5
Accessibility for Maintenance (x3)	5	5	5
Carrying the Turbine on the Site (x3)	5	5	5
6. Wind			
Access to Wind Flow (x3)	5	2	2
7. Extras/Miscellaneous			
Public Amusement by Interaction (x1)	1	1	1
Total Points (without x)	47	36	43
Total Points (with x)	115	90	104

Table 2.1 trade-off matrix

As previously anticipated, table 2.1 “trade-off matrix” confirms location 4 to be the optimal location for the turbine. Scoring above location 6 with 11 points.

3. Missing and broken parts

3.1 Introduction

The wind turbine that has been received by EnTranCe is a second-hand turbine and therefore it is crucial to determine if there are parts that are missing and/or broken. This chapter includes a small research on these parts, giving an ultimate repair or replace solution for each part to make sure the turbine is complete and functioning again.

3.2 Parts List

To have a comprehensive overview of what is already in our possession, a parts list has been created. This is important for the understanding of what parts are missing and/or broken.

Tail

- Tail vane
- Tail frame

Nacelle

- 5 kwh generator (needs to be tested)
- Nosecone
- 3x blades
- Rotor
- Electricity cable (needs to be tested)
- Pivoting shaft

Electrical components

- 2x 3.1 kw inverter Sunprofi (see chapter 4.3 components) Needs to be tested
- Dump load (see chapter 4.3 components)
- Junction box (see chapter 4.3 components) needs to be tested
- 2x kwh meters (see chapter 4.3 components) needs replacement, glass is broken

Broken/ missing

- Electricity cables (missing).
- Pivoting shaft (broken) (figures 3.2.1)
- Tower (missing) (figure 3.2.3)
- Main axle (missing) (figure 3.2.2)

Figure 3.2.1 Pivoting shaft

Figure 3.2.2 Main axle

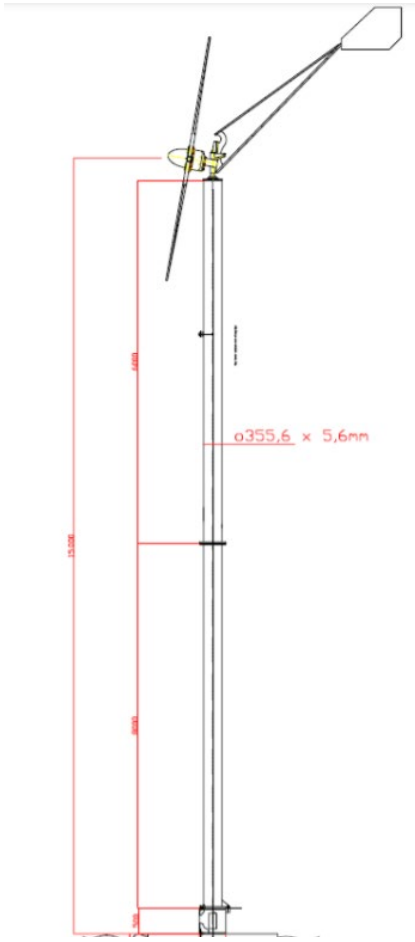


Figure 3.2.3 Tower

3.3 Analysis of the tail

The fortis Montana turbine shows to have a broken mounting point for the tail. This chapter will show what's wrong in detail and explain how to fix it.

3.3.1 How does the tail function?

The tail is located behind the generator, it yaws the blades into the wind. The tail is fitted with a pin that can rotate; the pin is mounted between two holes see "figure 3.3.1: the tail". The tail can rotate a little bit before it starts moving the whole turbine, this is to prevent small wind direction changes making an impact on the yaw of the turbine.

Figure 3.3.1 the tail

3.3.2 The current situation

At first glance it looked like the tail was broken, but after further investigation the tail seemed to be fine (see “figure 3.3.2: the backside of the tail at entrance”). The tail only needs to be reassembled with (new) screws. However, it is the mounting points of the tail that are bent (see “figure 3.3.3: attachment of tail to the turbine” & “figure 3.3.4: broken part of the tail”). In the current position the rolling pin cannot fit in the mounting holes. This type of damaging cannot be caused by normal operation, since the mounting hole is bended upwards. By normal operation this part only receives force in the horizontal axis. So, the damaged must have occurred during assembly or disassembly of the wind turbine.

Figure 3.3.2 the backside of the tail at entrance

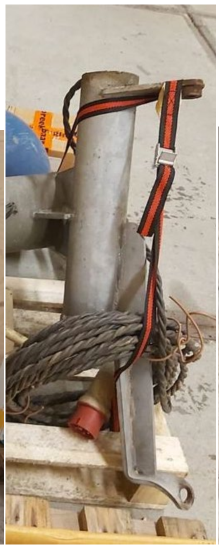


Figure 3.3.3 attachment of tail to the turbine

Figure 3.3.4 broken part of the tail

3.3.3 Fixes

There are a few possible ways to fix the broken mounting point.

- The first and cheapest one is to try to bend it back into the correct position with a press.
- The second option is to cut of the bended section and weld on a new mounting hole (see “figure 3.5: new part”).
- The third option is to buy a new piece (see “figure 3.3.6 & 3.3.7: new part of the tail”) and weld that on the pole the same way as the factory did.
- The final option is to buy an entirely new “tail connection on frame” (see figure 3.3.8). This would solve the broken part of the tail and the missing main axle.

All the repairs can be done in the engineering workshop at Hanze university with normal construction steel.

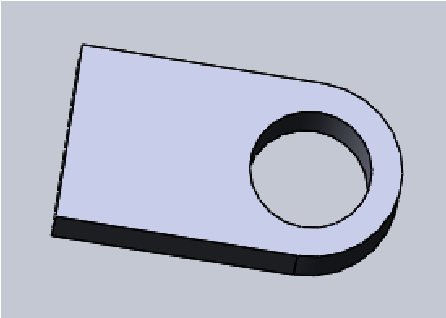


Figure 3.3.5 new part

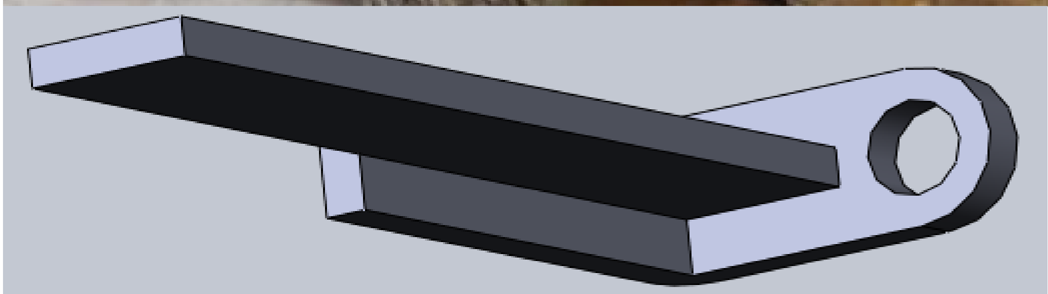


Figure 3.3.6 & 3.3.7 new part of the tail

Figure 3.3.8 tail connection on frame

3.3.4 Conclusion

The tail will not be improved because it’s a well-balanced piece and a lot of research has been done to make it this way. If it is made lighter or smaller by changing it to different material, the wind turbine would become out of balance and it would not work properly anymore. The tail also needs some inertia to rotate the turbine when it’s not heavy enough the wind turbine will not rotate itself. Due to this reason no significant improvements can be done without completely redesigning the whole wind turbine. To fix the broken part and the missing main axle the best solution would be to buy a new “tail connection on frame” from Fortis wind energy (Fortis, sd). This new part will cost €300,- (Jahn).

3.4 Analysis of the tower & foundation

3.4.1 Introduction

The tower is a crucial part of the wind turbine, making sure that the turbine is secured in the desired location and height withstanding all forces applied by the wind. There are various tower construction types, being the most used type the steel tubular tower as it is simple, cheap, and easy to install. Although this sounds as an attractive solution, the decision must be based on an analysis of the surrounding conditions.

3.4.2 If on the Plug and play park

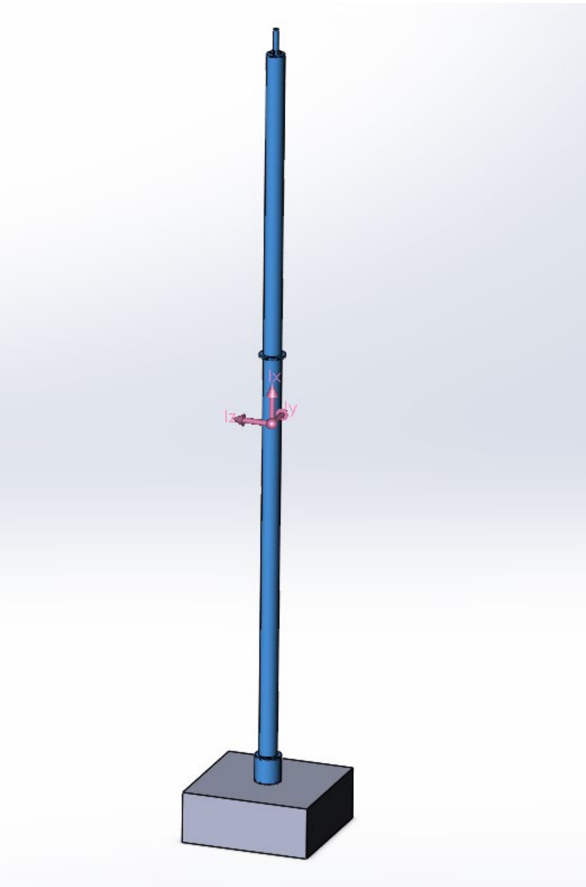
With the minimum height of the tower being 18m and the location being on top of a waste dump, it is crucial for the tower to be as light as possible with its weight distributed over a large area. Immediately there are four types of towers that come to mind, a lattice tower (jacket), a three-legged tower, a tubular steel tower and a guy-wired pole tower. Considering the soil conditions which only permit a foundation depth of 1m and a maximum load of 25KN/m^2 (Information provided by *Oosterhof-Holman)*, the towers must be analysed. The towers offered by Fortis are the preferred towers due to being easy, cheap, and accessible. These towers will be analysed for possible use further in the next chapters. The other towers such as the lattice tower and the three-legged tower are set aside due to being a heavier and more expensive construction. If the accessible towers from fortis are not suitable for installation, then a review on the remaining towers will be made.

3.4.2.1 Tower analysis

To be sure the towers and foundations don't exceed the soil limitations the following calculations have been made with the non-guyed and guyed single tube masts made by Fortis. Being located on top of a waste dump, the soil condition needs to be considered with care. The main restriction here is the ground pressure which may not exceed 25kN/m^2 (Information provided by *Oosterhof-Holman)*

To calculate the ground pressure that the masts put on the soil, a SolidWorks model has been made to accurately define the mass of the towers. The tube mast and the guyed mast are both made by Fortis, therefore can their measurements be taken from the Fortis site. (Fortis, sd) *Note: the exact measurements of some parts are not known and are therefore estimated on scale of drawings and photos.*

Tube mast



Mass properties of Tube_Mast_18m
Configuration: Default
Coordinate system: -- default --

Mass = 999331.02 grams

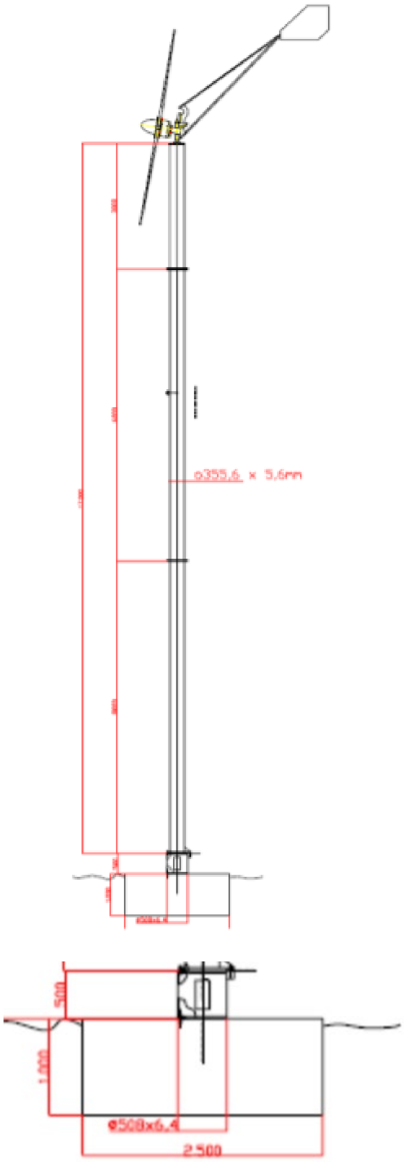


Figure 3.4.1 18-meter tube mast, the in SolidWorks calculated weight and the fortis drawings (Fortis, 2021)

The mast is made of plain carbon steel, which has a density of 7800 kg/m^3 and has a mass of 999331,02 grams or 999,3 Kg. This is only the mass of the mast and not the mass of the concrete block. To calculate the mass of the concrete block, the volume of the concrete block (2,5m x 2,5m x 1m)[*1] (Fortis, 2021) has been calculated and then multiplied by the density of concrete (2400kg/m^3).

$$\rho_{concrete} := 2400 \frac{kg}{m^3} \quad V_{concreteTube} := 2.5m \cdot 2.5m \cdot 1m = 6.25 \cdot m^3$$

$$m_{concreteTube} := \rho_{concrete} \cdot V_{concreteTube} = 1.5 \times 10^4 \, kg$$

Equation 3.4.1 Calculating the mass of the concrete block:

$\rho_{concrete}$	= the density of concrete	[kg/$_{m\wedge 3}$]
$V_{concrete}$	= the volume of the concrete block	[m^3]
$m_{concrete}$	= the mass of the concrete block	[kg]

The weight of the concrete block has been calculated to be 15000 kg. Now that the weight of the mast, the turbine and the concrete block is known, the ground pressure can be calculated:

$$m_{mastTube} := 999.3kg \quad m_{turbine} := 200kg$$

$$m_{concreteTube} := \rho_{concrete} \cdot V_{concreteTube} = 1.5 \times 10^4 \, kg$$

$$A_{concreteTube} := 2.5m \cdot 2.5m = 6.25 \, m^2$$

$$m_{totalTube} := m_{mastTube} + m_{turbine} + m_{concreteTube} = 1.62 \times 10^4 \, kg$$

$$F_{mastTube} := m_{totalTube} \cdot g = 1.589 \times 10^5 \, N$$

$$p_{groundTube} := \frac{F_{mastTube}}{A_{concreteTube}} = 25.418 \cdot kPa$$

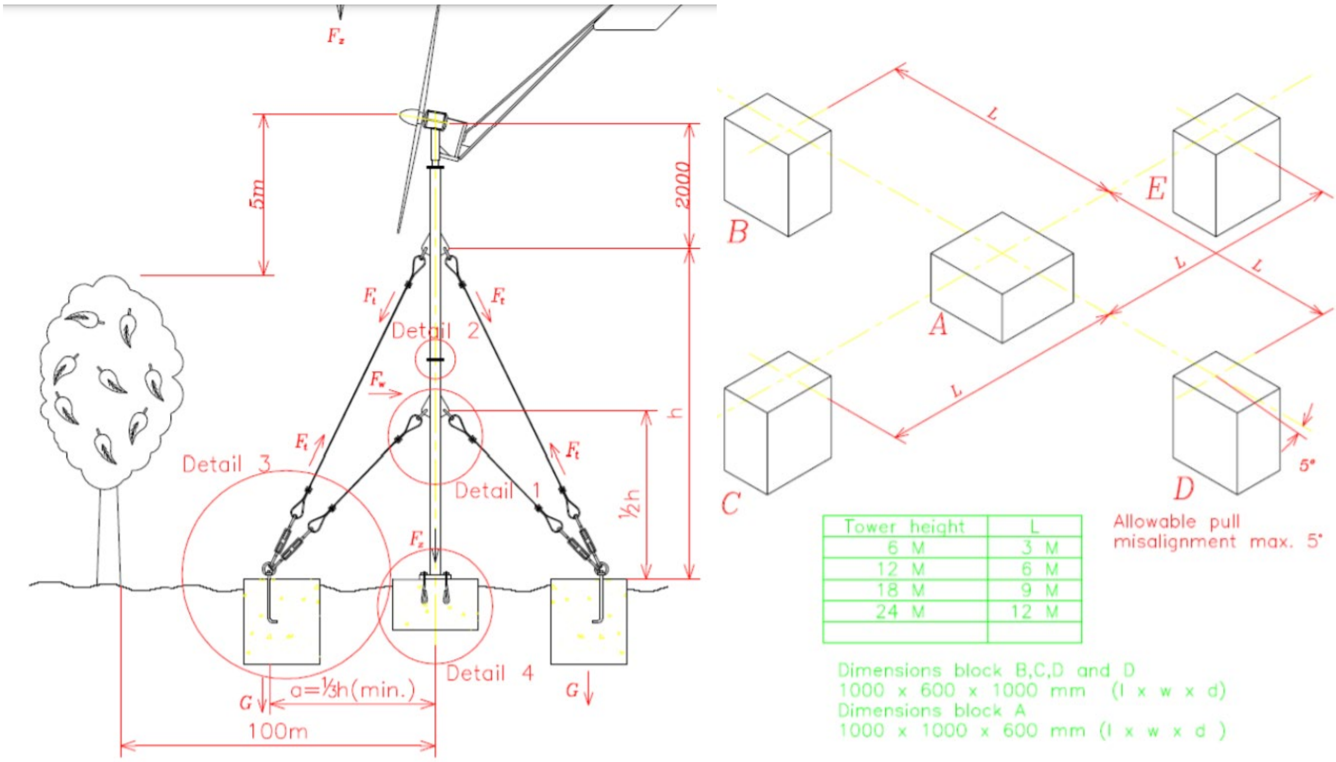
Equation 3.4.2 Calculating the ground pressure

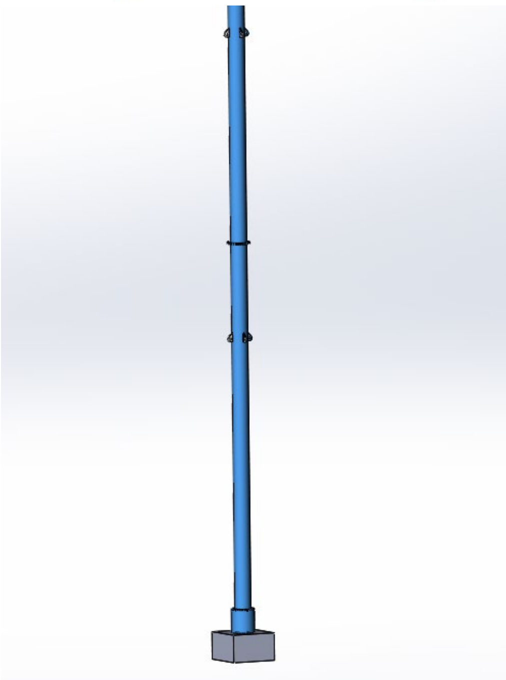
$m_{concreteTube}$	= the mass of the concrete block	[kg]
$m_{turbine}$	= the mass of the turbine	[kg]
$A_{concreteTube}$	= the surface area of the concrete block	[m^2]
$F_{mastTube}$	= the ground force of the wind turbine	[N]
$p_{groundTube}$	= the ground pressure of the total turbine	[kPa] or [kN/m^2]

The ground pressure of the tube mast (25,418 kN/m^2), exceeds the maximum ground pressure of 25kN/m^2 therefore it is not possible to install the wind turbine on the tube mast on the hill as it currently is. Modifications to the surface area of the concrete slab will have to be made, such as either making surface area of the concrete block larger and the height smaller (which is not recommended as the dimensions determined by Fortis are confidentially secure and safe) or by using the guyed tower system where the concrete block is smaller due to being held in place by smaller blocks spread around the mast. The second option is the more realistic option and therefore calculations for this system have also been made:

*Note *1: the dimensions of the concrete or the mast will not be changed, as these are carefully calculated and designed by Fortis, and changes to this may result in unwanted outcomes*

Guyed mast





Mass properties of Guyed_Mast18m
Configuration: Default
Coordinate system: -- default --

Mass = 1016953.12 grams

Figure 3.4.2 guyed mast Fortis Montana (Fortis, 2021)

Figure 3.4.3 Guyed mast and the in SolidWorks calculated weight

The weight of the mast itself has increased a bit, because of added brackets for the guyed wires. Now the mast has a weight of 1026953,12 grams or 1026,95 Kg. The volume of the concrete block directly underneath the guyed mast (1m x 1m x 0,6 m), (Fortis, 2021) is smaller in volume than the concrete block underneath the tube mast. It has to be calculated again.

$$V_{concreteGuyed} := 1m \cdot 1m \cdot 0.6m = 0.6 \cdot m^3$$

$$m_{concreteGuyed} := \rho_{concrete} \cdot V_{concreteGuyed} = 1.44 \times 10^3 \, kg$$

Equation 3.4.3 calculation for the concrete block, guyed mast

$V_{concreteGuyed}$	= the volume of the concrete block guyed mast	$[m^3]$
$\rho_{concrete}$	= the density of concrete	$[kg/m^3]$
$m_{concreteGuyed}$	= the mass of the concrete block guyed mast	[kg]

$$m_{mastGuyed} := 1026.95kg$$

$$m_{concreteGuyed} := \rho_{concrete} \cdot V_{concreteGuyed} = 1.44 \times 10^3 \, kg$$

$$m_{totalGuyed} := m_{mastGuyed} + m_{turbine} + m_{concreteGuyed} = 2.667 \times 10^3 \, kg$$

$$F_{mastGuyed} := m_{totalGuyed} \cdot g = 2.615 \times 10^4 \, N$$

$$p_{groundGuyed} := \frac{F_{mastGuyed}}{A_{concreteGuyed}} = 26.154 \cdot kPa$$

Equation 3.4.4 The calculated ground pressure of the guyed mast

$m_{mastGuyed}$	*= the mass of the mast*	*[kg]*
$m_{concreteGuyed}$	*= the mass of the concrete block*	*[kg]*
$m_{turbine}$	*= the mass of the turbine*	*[kg]*
$A_{concreteGuyed}$	*= the surface area of the concrete block ($1m^2$)*	*$[m^2]$*
$F_{mastTube}$	*= the ground force of the wind turbine*	*[N]*
$p_{groundTube}$	*= the ground pressure of the total turbine*	*[kPa] or $[kN/m^2]$*

As shown above, also the guyed tower exceeds the ground pressure restriction of $25kN/m^2$. And is not feasible to put on top of the waste dump either. Although the extra separate concrete blocks to which the cables are connected do not exceed the ground pressure restriction of $25kN/m^2$. As shown in equation 4.3.6:

$$V_{ConcreteCable} := 1m \cdot 0.6m \cdot 1m = 0.6 \cdot m^3 \quad A_{ConcreteCable} := 0.6m^2$$

$$m_{ConcreteCable} := V_{ConcreteCable} \cdot \rho_{concrete} = 1.44 \times 10^3 kg$$

$$F_{ConcreteCable} := m_{ConcreteCable} \cdot g = 1.412 \times 10^4 N$$

$$p_{groundCable} := \frac{F_{ConcreteCable}}{A_{ConcreteCable}} = 23.536 \cdot kPa$$

Equation 3.4.5 Calculation of the ground pressure of the extra concrete blocks

$V_{concreteCable}$	= the volume of the concrete cable block	[m^3]
$A_{concreteCable}$	= the surface area of the concrete cable block	[m^3]
$\rho_{concrete}$	= the density of concrete	[kg/m^3]
$m_{concreteCable}$	= the mass of the concrete cable block	[kg]
$F_{concreteCable}$	= the force of the concrete cable block	[N]
$p_{concreteCable}$	= the ground pressure of the cable block	[kPa] or [kN/m^2]

3.4.2.2 Wind forces applied to the tower

The wind is also an important factor to look at when installing wind turbines. If the wind speeds are too great and the wind turbine can't handle those forces the results could be catastrophic. To make sure that the turbine mast can handle the high wind speeds, some calculations have been made to determine the force of a worst-case scenario.

First the wind pressure on the surface of the blades will be calculated, using the following formula:

$$\rho_{wind} := 1.3\,\frac{kg}{m^3} \qquad v_{wind} := 32.6\,\frac{m}{s} \qquad C_d := 0.04$$

$$p_{wind} := \frac{1}{2}\cdot\rho_{wind}\cdot v_{wind}^{\,2}\cdot C_d = 27.632\,Pa$$

Equation 3.4.6 Wind pressure on a surface

Using the density of air at 1bar atmospheric pressure, the wind speeds during a hurricane (KNMI, 2021) and the C_d of 0,04 because the rotors of a wind turbine are streamlined the C_d value of 0,04 has been chosen

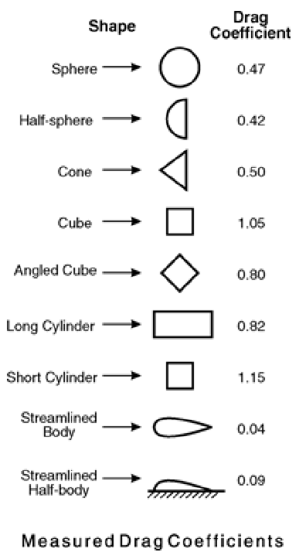


Figure 3.4.3 drag coefficients

Now that the pressure is known, it can be multiplied by the surface area of the rotors to calculate the force that is being applied on the turbine's mast:

$$r_{rotor} := 2.5m$$

$$A_{rotor} := \pi\cdot r_{rotor}^{\,2} = 19.635\,m^2$$

$$p_{wind}\cdot A_{rotor} = 542.548\,N$$

Equation 3.4.7 Force on the mast

In conclusion, in the worst-case scenario the mast will have to endure a force of 542,548N.

Next, the stress on the tower is determined with a Solidworks CAD simulation. By applying the calculated force of 542N (814N using 1,5 factor) on the top of the mast (where the turbine is located), and a fixture at the bottom of the mast. The stress on the connection between the tower and concrete foundation can be simulated.

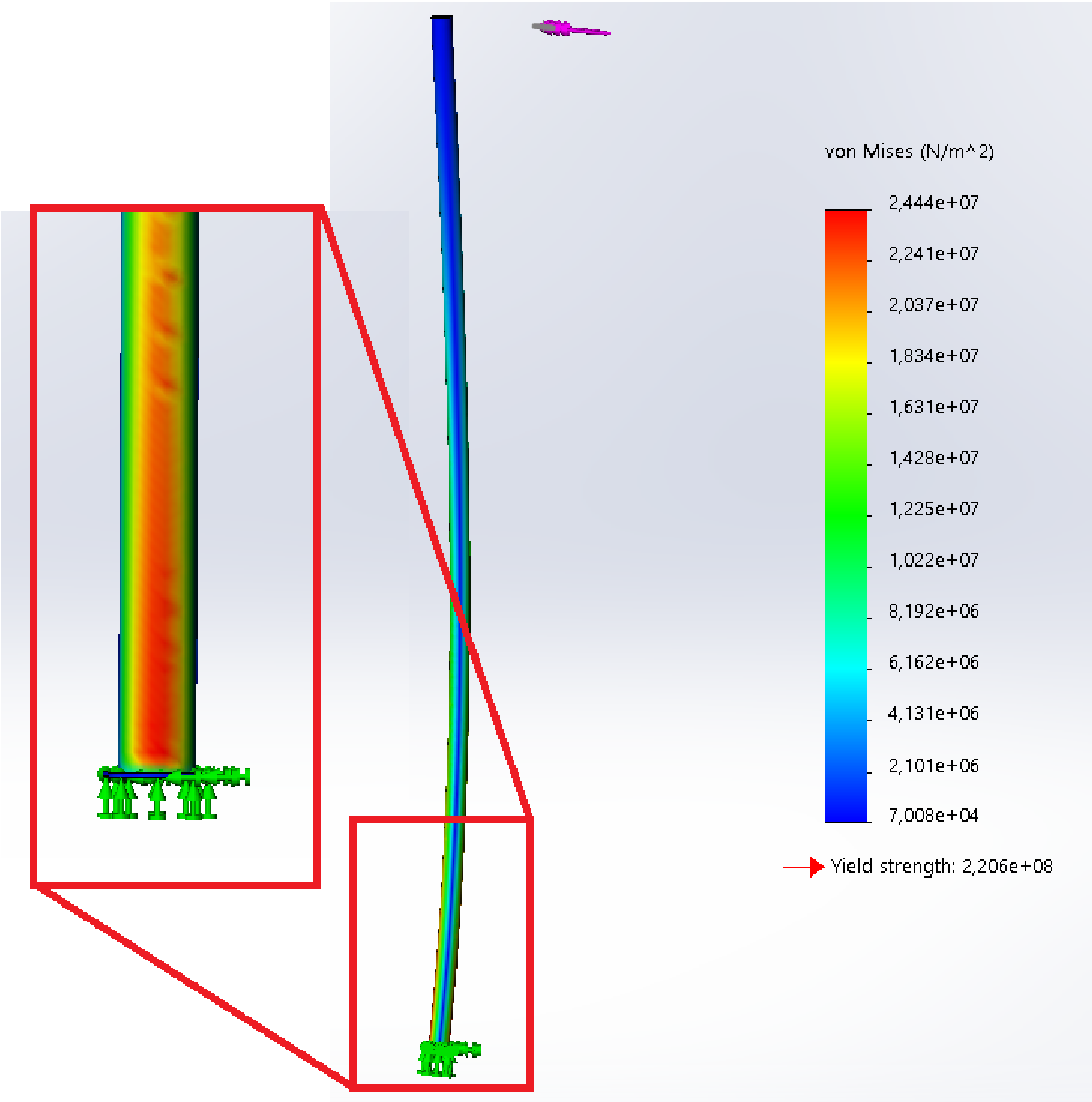


Figure 3.4.4 von Mises stress of the turbine's mast

By analysing the simulations, it can be observed that most of the stress in tower is at the bottom of the tower. Do take in mind that these stresses are at the worst case and hurricanes have never happened in the Netherlands. But the remains of hurricanes can and sometimes will pass over the Netherlands which is why the worst case has been calculated. (Klaassen, 2020)

Plain carbon steel has a yield strength of $2{,}206*10^8$ N/m^2 but the highest von Mises stress is $2{,}444*10^7$ N/m$^{\wedge 2}$ (keep in mind that the safety factor of 1.5 has already been applied) It is well below the yield strength of steel.

3.4.2.3 Result of wind forces on the tower to the concrete block

The forces that the wind puts on the mast are known, and show that the mast can handle these forces, but nothing is known about the concrete block yet. But that is easy to find out with a few small calculations.

Firstly, a schematic drawing has been made to explain the situation better.

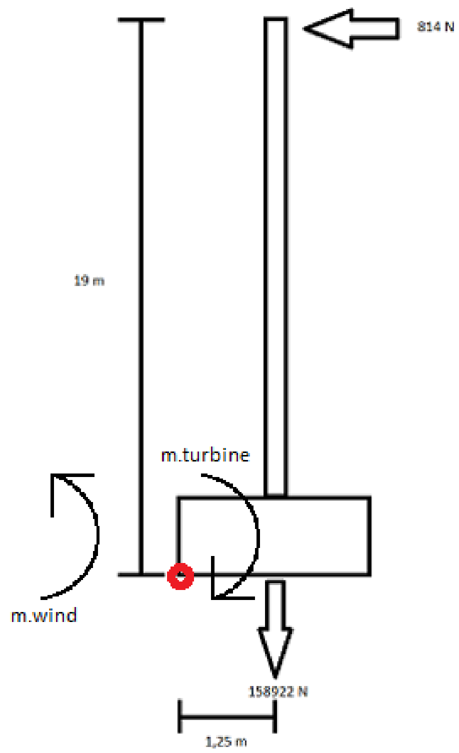


Figure 3.4.5 schematic drawing of the mast

The force of the wind is known, which is 814N. The downward force of turbine can be calculated using the weight of the complete turbine, which is 16200 kg, by multiplying this by 'g' (9,81m/s^2) gives: 158922N

In the following calculation it shows that the force/weight of the turbine is greater than the force of the wind.

$$moment.block > moment.wind$$

$$158922N * 1{,}25m > 814N * 18m$$

$$198652{,}5Nm > 14652Nm$$

Even when the safety factor of 1,5 is applied, the wind generates 21978N of force. This force continues to be lower than the weight of the complete turbine. Also keep in mind that the soil surrounding the concrete block hasn't been taken in consideration, so the actual supporting force is even greater.

3.4.2.2 Conclusion tower and foundation type on the plug and play park

With reasoning to set aside the most expensive towers, more time has been put into assessing if the more accessible towers from Fortis are a possibility. To assess their suitability, the wind stress on the tower and the soil pressure have been calculated and simulated. It can be observed that the single tower mast is too heavy for the soil pressure limit at the ''Plug and play park'' due to the load being all on one single foundation block. Changing this block would not be wise as Fortis has previously calculated the perfect dimensions for this specific tower. In this case the guyed tower from Fortis would have been the second option but this tower too exceeds the maximum ground pressure. This reaffirms that the plug and play park is not an option for the wind turbine.

3.4.3 At Location 4 (aside the road)

At location 4 (aside the road) the minimum tower height of 15m continues. This is not a problem on the industrial zone as the only restriction is that the tip height of the wind turbine cannot exceed 25 meters. Meaning that the tower can have a height of 22,5 meters (although it will become 18m due to this being the highest mast by Fortis, given the restrictions). So, a more defining aspect would be the soil restrictions. The 'normal' soil located on the rest of the campus is currently unknown, but this is possible to find out:

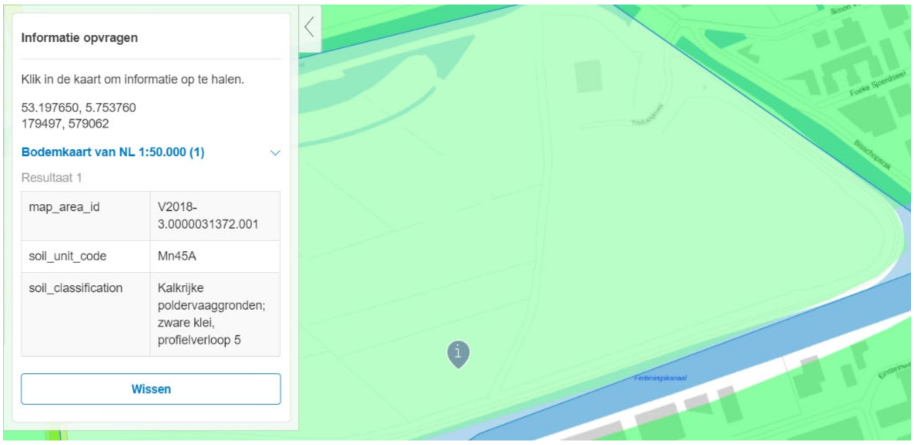


Figure 3.4.6 soil at energy campus (Kaarten, 2021)

From the (Kaarten, 2021) it can be taken that the soil at Energy campus is consisted of heavy clay (zware klei). Knowing the ground type, the maximum ground pressure can be determined.

Indicatie toelaatbare druk σd op bouwgrond in N/mm²	
Grondsoort	σd N/mm²
Ingewaterd zand van grondverbetering naar gelang van de dikte van de zandlaag en de draagkracht van de ondergrond	0,05 - 0,1
Vaste zandbodem, nabij riviermonden en zeearmen	0,15 - 0,3
Vaste zandbodem, op draagkrachtige onderlagen	0,2 - 0,4
Zeer vast zand op grote diepte onder maaiveld	0,3 - 0,6
Leemhoudende gronden	0,08 - 0,16
Kleilaag, op draagkrachtige onderlagen	0,1 - 0,2
Mergel	0,3 - 0,8
Zachte krijtlaag	0,1 - 0,2
Grindlaag, op draagkrachtige onderlagen	0,3 - 0,8
Niet-verweerde rotsgrond	0,5 - 2,5

Table 3.4.1 different acceptable ground pressures with different soil types (Toelaatbare gronddrukken, 2021)

Clay like soil has a maximum acceptable ground pressure of 0,1-0,2 N/mm^2 (100-200 kN/m^2).

3.4.3.1 Conclusion of tower and foundation type at location 4 (aside the road)

The tower choice in this case is much easier due to the soil conditions being able to endure a lot more pressure than on top of the plug and play park. Therefore, all the tower load calculations can be left out. The tower choice on these grounds is only between the two given towers by Fortis, the tube tower, and the guyed tower. As the soil on the industrial zone permits the worst case pressure of 100 KN/m^2, which is far above the pressure the tower creates, the choice for a single tube tower is the most obvious choice as it occupies less space in the already cramped area aside the road.

3.5 Conclusion of the missing and broken parts

A lot of parts of the wind turbine seem to be present but arguably the most important parts seem to be missing or broken. This includes the mast, the main axle and a lot of electrical parts. The list below shows all the parts that are missing or are broken.

The missing/broken parts are:

- Electricity cables (missing).
- Pivoting shaft (broken) (figures 3.3.1 & 3.1.2)
- Tower (missing) (figure 3.1.3)
- Main axle (missing) (figure 3.1.4)

The electricity cables that are missing and broken will be further discussed in “chapter 4. electrical”. The pivoting shaft, the mast and the main axle will have to be replaced or newly acquired. The best place for this is of course Fortis as they produce these parts. The costs for these parts are further discussed in *“chapter 9 Costs”.*

Concerning the mast a few more things have been taken in to consideration as it is not a simple matter of just replacing the mast. One of these matters is: if it is possible to put the mast on top of the plug and play park, an old waste dump. A few calculations have been made in *“chapter 3.4 analysis of the tower & foundation”* to see if this is possible. This is not possible and the mast will be placed on ‘normal’ soil conditions. Also wind force was taken in to consideration and have been applied to the 18 meter tube mast. It seems that the mast can withstand these forces. So a ‘regular’ 18 meter tube mast has been chosen as the best choice for installation.

The solution for the missing electricity cables is worked out in *“chapter 4 Electrical”.* And the broken pivoting shaft and the missing main axle will be replaced by an entirely new component.

The costs of all these parts will be discussed further in *“chapter 9 Costs”*

4. Electrical

4.1 Introduction

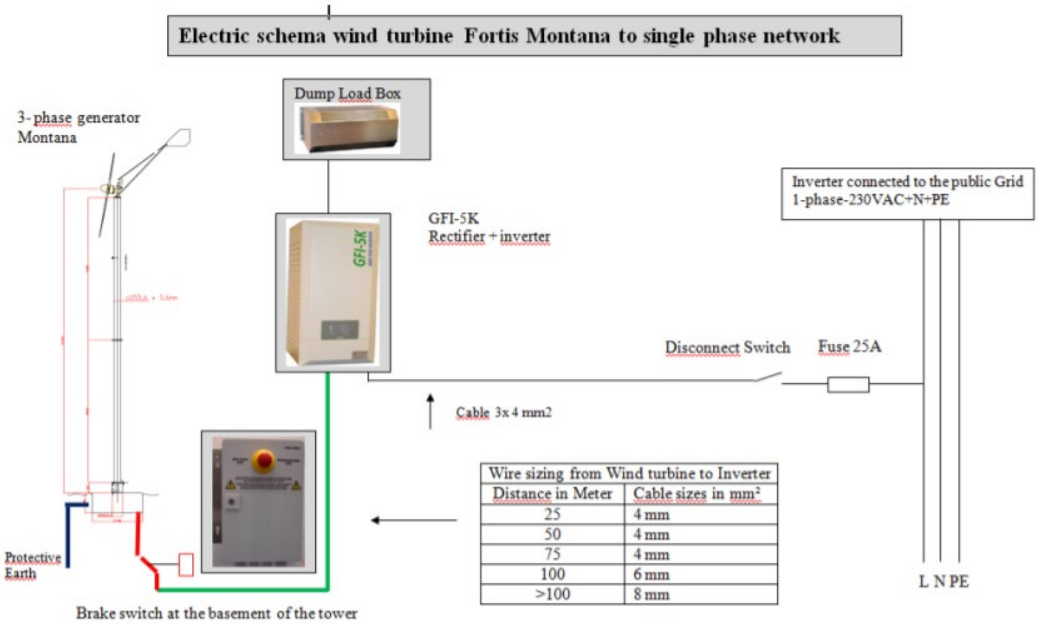
When looking at a wind turbine the electrical system is arguably the most important part of the puzzle. That is why it is of utmost importance that the system works properly, safely and is easy to maintain and repair. At the moment this isn't the case and this needs to be sorted before the turbine can be taken into use. Therefore, the following subjects will be discussed:

The electrical system will be examined, and the components will be reviewed to once again, determine what is missing and what needs to be tested, repaired and/or replaced. In sub-chapter 4.1 a small analysis will be done concerning the existing diagram of the Fortis Montana and based on pictures taken of the parts a new diagram will be developed. In 4.2 the system will be examined, worked out and compared to an existing system. In 4.3 the components will be evaluated, and in 4.4 extra components will be added if need be.

4.2 current situation

Concerning the turbine located at Entrance, most if not all, electrical parts seem to be present. Of course, it is not known if these parts are functioning, this will be discussed in the following subchapter. It appears that the installation of the turbine has been taken apart hurriedly, as a lot of cables have been cut. Because of this a diagram would be helpful to see if everything is there and how the components would have been connected to each other in the past.

When looking at the wiring diagram of the Fortis website it shows how the global wiring looks like. From this and the pictures of the components located at Entrance a sketch of the wiring diagram can be made.



Wire sizing from Wind turbine to Inverter	
Distance in Meter	Cable sizes in mm²
25	4 mm
50	4 mm
75	4 mm
100	6 mm
>100	8 mm

Figure 4.1 wiring diagram of the fortis montana

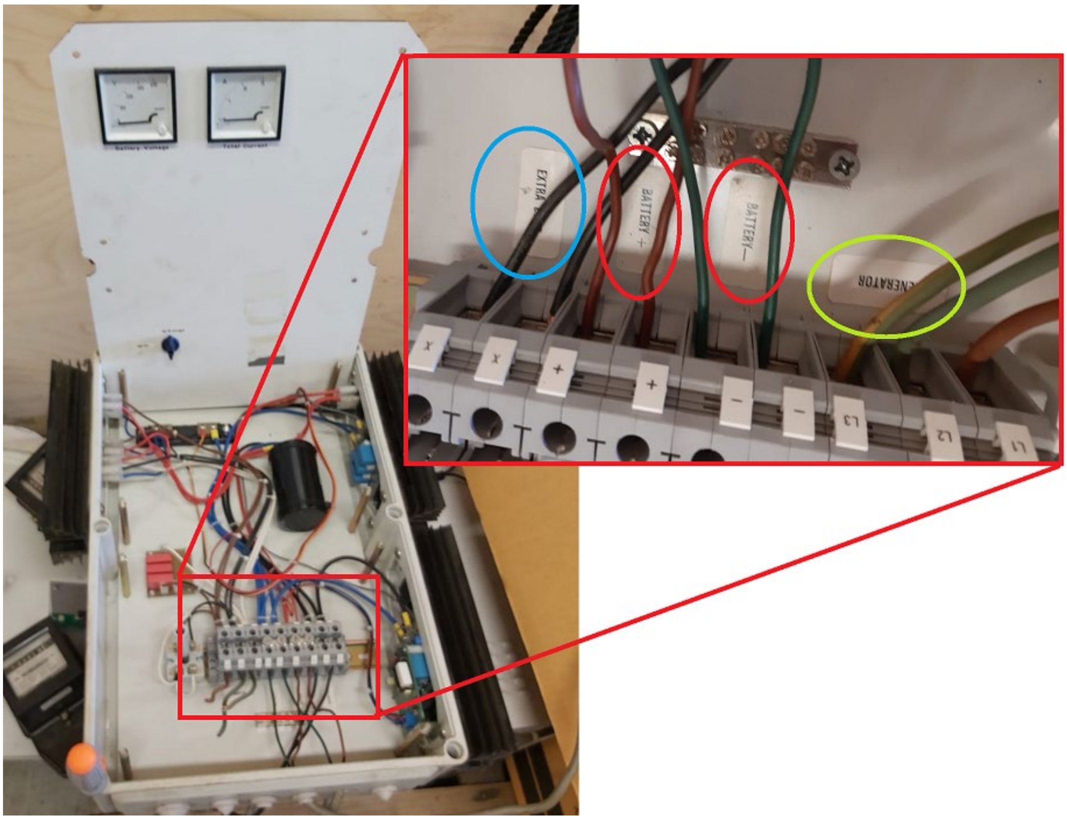


Figure 4.2 inside of the main control box

In the picture above an inside look is taken at the main control box, multiple wires run inside and to the outside of the unit, these are labelled: Generator (encircled in green), battery +&- [*1](encircled in red), and extra load[*2] (encircled in blue). Now it is known that the three wires from the turbine run directly to the main box. And from here the wires run to the inverters (red circles) and to the dump load (blue circle). With this the wiring diagram can be made.

*[*1]battery = inverters*
*[*2]extra load = load dump*

Following the pictures taken of the electrical components and looking at the marks on the cables and the wire colours the wiring diagram has been made:

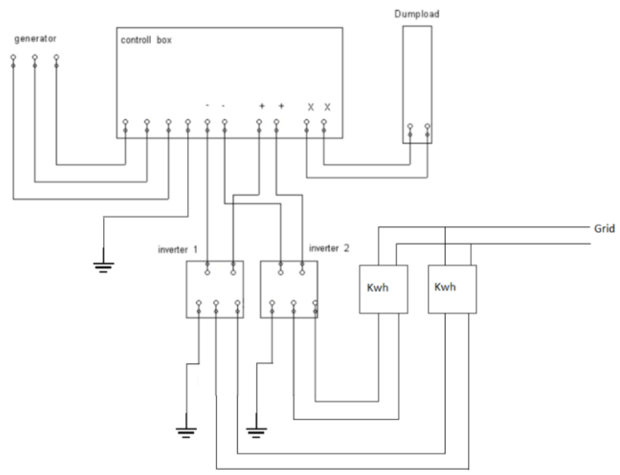


Figure 4.3 Wiring diagram with existing components

4.3 Components

Following is a list of all the main electrical components that need to be checked and/or repaired before installation.

- Generator/turbine
- Control box
- Inverters
- Dump load
- Electricity meters
- Wiring

At first glance the turbine appears to be functional, it spins freely and doesn´t make any abnormal sounds (which could indicate worn bearings) but it is advisable to get the turbine be tested by experts. A company in Groningen called *BTD* is specialised in this sort of work.

The control box, the inverters and the dump load are all components that need to be tested before installation. Mr. Laurens Mengerink offered to test these components. This is done by letting a voltage run through the components to see if any parts inside are broken by not letting a voltage go through the system. Concerning the electricity meters, it would be wisest to purchase new ones as these parts are relatively cheap and this guarantees that it will work. All wiring between the turbine and the control box; between the control box and the inverters and from the inverters to the Kwh meters has been cut. Therefore, it is recommended to buy all new wiring instead of connecting the cut off pieces, to guarantee a long-lasting working system. The mast is 18 meters, so a cable of 20 meters is needed to connect the turbine to the cut-off switch. And for the miscellaneous cables (between the components) a meter will be taken as length, so 10 meter in total.

4.4 Extra components

Everything seems to be complete, however there are some things that could be added to make the wind turbine more reliable and safer.

The first safety feature to add is an extra stop button located on/near the wind turbine. So, when something happens to the cable from the wind turbine to the control box the turbine can still be stopped before a dangerous or catastrophic outcome.

When the stop switch is pressed the stator windings are short-circuited, so the energy the wind turbine generates is used to create an opposing magnetic field. The magnetic field slows down the rotors by creating an opposing force to the spin direction. A higher torque is needed to spin the wind turbine when the switch is pressed, when it suddenly becomes windier the wind turbine can spin faster, but when it spins faster it generates more energy and that energy creates a stronger magnetic field.

To implement this a switch that looks something like *Figure 4.3 example of a stop switch* is connected parallel on the 3-fase wire that runs from the generator to the control box. The type of switch that is shown on *Figure 4.3 example of a stop switch* that has 3 positions. The left position is the braking position, here the energy that is generated goes directly back to the stator windings. The middle position is how the wind turbine should operate; no short circuit is created here. And the right position is the same as left but then for reverse. The fortis at entrance only needs the first 2 positions.

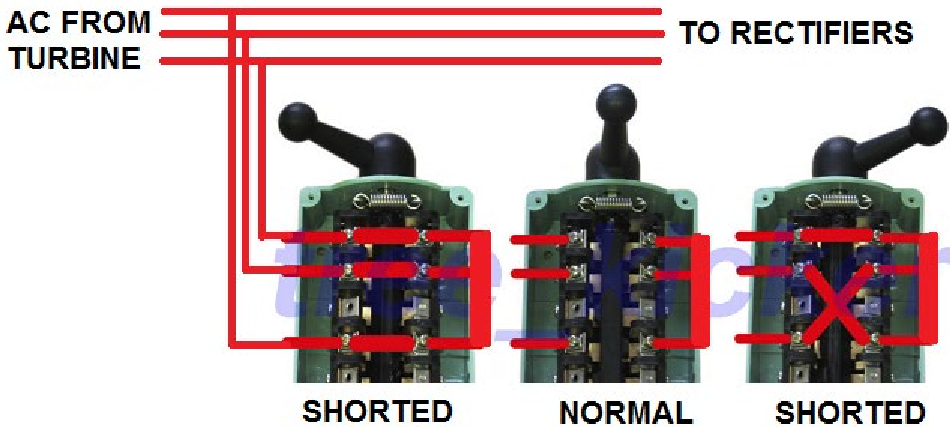


Figure 4.4 example of a stop switch (fieldlines, sd)

4.5 Costs

In *table 4.1* The price of the missing/broken electrical components are shown.

Description	Price	Price in €
The brake switch (Futureenergy, sd)	£74,70	€86,76
Cable clips (Kabelshop, sd)	€1,50	€1,50
4 pole connector male (Vekto, sd)	€3,82	€3,82
4 pole connector female (Vekto, sd)	€5,24	€5,24
3 fase wire 20 meter (Neopreen, sd)	€32,60	€32,60
10 meter 2 veined (kabelshop, sd)	€27,50	€27,50
Kwh meter 2 x (allekabels, sd)	€16,99 x2	€33,98
total		**€191,40**

Table 4.1 costs

4.6 Conclusion

For the turbine the existing components and wiring diagram will be used as shown in *Figure 4.3 'Wiring diagram with existing components'.* The turbine still must be tested and the rest of the electrical components will be tested by Laurens Mengerink. If any of these components are broken, they need to be replaced. All wiring of the turbine will need to be replaced as well, as these are all cut up. The Kwh meters will also be replaced to be sure they work. This all comes down to an investment cost of around €200.

5. Installation

5.1 Introduction

Installing the wind turbine on the selected location is the last required step for it to go online. It is crucial that the guidelines for the installation are followed properly & the effort put into installing the turbine is adequate enough. The installation of the turbine can be done only once in its lifetime. Hence, the high emphasis to ensure a secure operation. It would be too expensive & inefficient to extract the turbine out from the foundation and do it all over again if the installation doesn't happen smoothly on the first attempt.

Keeping everything mentioned in mind, chapter 5.2 manifests a detailed guideline which explains the step by step process of the whole installation. All the steps must be completed in the order they are listed in and none of them can be skipped. Chapter 5.3 concludes the Installation part of the turbine by taking a look at the total cost of the installation broken down into steps with their respective expenses.

5.2 Analysis

Step 1 – Installation Location

Choosing the correct location to install the wind turbine is crucial to ensure safe & efficient operation. Higher average wind speeds will enable the system to generate more power. A 10% increment in wind speed, may increase the wind power by 37%. Unstable wind is not good for the safe operation of wind generator and will reduce power that generated by the system. Trees & buildings that will shadow the turbine should be avoided because they can cause turbulence. Finally, it's necessary to consider the distance between the generator and the pile as less cable length results in less energy waste during the transmission. This exact location will be worked out in "chapter 3, Destination plan".

Step 2 – Foundation

The position of tower base and fastened anchor is shown in the following diagram. Three important points must be kept in mind:

I. The base should be on the line between one anchor and its direct opposite counterpart.
II. The line between the two anchors should be parallel to the line between the two holes on the grounding feet.
III. On the grounding feet, the side with three screws should near the frontal anchor.

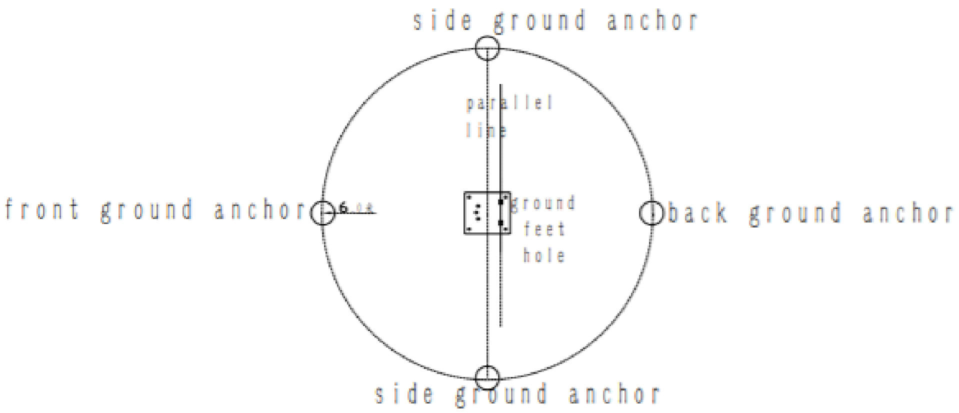


Figure 5.2.1 placement of anchors

Ensuring these 3 points will guarantee the balanced tensile force produced among fastened tightwire and easy for final adjustment, which is closely related with the successful erecting of tower. Besides, the height of anchor and the tower base should be consistent.

Next, the holes must be dug according to the mentioned layout (0.8 × 0.8 × 1.6 meters for central base and 0.8 x 0.8 x 1.0 meters for 4 anchors). C25 concrete is a suitable type to concrete the entire foundation. Four anchor bolts will be installed according to the holes on the base and four annular anchors need to be deposited 60° - 80°along the base direction. Finally, the distance between the four hooks of the anchors and the centre of the base (6 meters) must be checked and the four anchors should be horizontal.

The tower base must be fixed up on the prepared concrete seat by bolts.

Step 3 – Assembly of Tower & Wind Turbine

- **I.** Place the infrastructure of the tower in the base, insert the axes to the base holes and lock it.
- II. Connect the middle part and top part in turn; place it on the sawbuck when assembled.
- **III.** Rip the cable of generator and dogvane into the tower and draw it out on the exit near the grounding feet.
- **IV.** Secure the gyro flange and the tower flange with bolts and sling it with chain blocks. A very important thing is to remember that the axletree should be placed upside to set the leaves on it.
- **V.** Install the wind leaves, cover the press board and screw the bolts but care to not screw them too tightly. Then, cover the dome itself.
- **VI.** Infix the above aviation connector plugs to the jack under the dogvane and set the dogvane up.
- **VII.** Fasten the tightwire on the tower. For the left and right side tightwires, connect them with side anchor directly by turnbuckles. While for the back one, fix it up with the anchor behind along the same length. Be sure that the tightwires won't be entangled together and the frontal tightwire should be installed later.
- **VIII.** Connect two assistant poles. Select two thinner tightwires (about 9 meters) and fix them on the two ears of pole. Drill the frontal tightwire through the ears and put it in the up pulley and fix it up.
- **IX.** Infix the assistant poles to the tower by 5 to 6 people. Fix the tightwire through the ears on the two sides' anchors and fix them up.
- **X.** Secure the pulley below to the frontal anchor. Fix one end of tightwire (length 30 meters, width 5 millimetres) to the pulley on the assistant pole. Drill the other end to the pulley below and then through both pulleys and finally fix it up on the retractor (tractor or chain blocks).

Figure 5.2.2 foundation wind turbine

Step 4 – Erecting the Tower

- I. Operate the tractor or chain blocks slowly.
- II. To guarantee the safety, all staff should be away from the working spot (at least 20 meters away).

III. Drive the tractor slowly and the tower will stand up along the moving wire. Stop at each rising 15°and examine the tightwire's tensile force on both sides. Any over tight or loose wire should be regulated by putting down the tower slowly and adjusting the length of tightwire.
IV. Go on pulling the wire until the tower stands upright. Put the rest wires through its anchor and fix it up.
V. Inspect and adjust the tension on each fixed tightwire. Over tight force may bend the tower while over loose force may cause the tower unstable and shakeable. The perfect force is neither too loose nor too tight and can be adjusted through circumrotating the bolt. The appreciably flabby strain would be much safer than the over tight force.

Figure 5.2.3 erection of wind turbine

Step 5 – Collocation, Placement and Connection of Storage Battery

I. Storage battery should be emplaced in dry buildings with invariable room temperature. The surrounding environment should open and ventilated. Confirm the total number of series-wound batteries and then design the shelf to store the batteries, controllers and invertors.
II. 20 sets of 200 AH storage batteries would be recommended to match a 5000-kilowatt wind turbine.
III. Put the storage batteries in series. Connect the anode of first battery with the cathode of second one.
IV. Coat all connection parts with grease or other antiseptic material. Fuse should be set on the anode of the battery to avoid electromagnetic disturbance. The connecting leading wire between the storage batteries and controllers should be less than 3 meters.

Step 6 - Connecting Controllers, Anemoscopes and Invertors

I. On the controllers, the anode of terminals marked "connect storage batteries" must be connected with the anode of last battery while the cathode must be connected with the first one's cathode end.
II. There are two cables leading out from the head of the generator. One is to test the wind direction signals, in which the aviation plug sticks into the matched socket directly. The other cable, which contains five wires, is to export the electricity and control the signals. 3 thicker wires mark the output of generator and 2 thinner wires mark the export of

controlled signals. All anodes and cathodes would be connected in the corresponding terminals behind the controllers.

III. Anemoscope should be deposited on the roof or other exposed area and should be vertical to the ground.
IV. For the matched cable of anemoscope, one end could be inserted to the socket below the anemoscope and other end should be sticked into the relevant socket in the controllers.
V. When connecting the invertors, it should be noticed that the import voltage of inverters should be equal to the value of series-wound voltage.
VI. The detailed parameters of inverters can be seen on the instruction manual.

5.3 Installation plan

For the installation of the wind turbine all aspects must be considered, such as the required installation equipment and personnel with their respective hourly rates to determine an approximate quotation.

Following are the generic steps for the instalment a 5kw wind turbine:

1. A trench must be dug from the turbine location to the electrical connection point. The connection point is located at the roundabout as this is where the main power supply cable for the companies lie. This can be done with a JCB digger (specifications).
2. This same JCB can continuously dig the foundation hole too.
3. The cable can be put into the trench by an average of three people.
4. Simultaneously the foundation can be prepared for filling.
5. A cement truck will fill the foundation.
6. After the concrete has dried, the base must be placed horizontally on the ground and connected to the bolts of the foundation.
7. The turbine can be prepared and put into position for erection.
8. Turbine erection is done by a tractor.
9. Electrical wiring must be done by a turbine electrician.

An excel document has been made for the financial calculation of the machines and personnel.

	Equipment	Description	Hour rate	Hours	Total cost	Bibliography
Cable installation	JCB (digger)	Dig cable trench	145	5	725	https://www.chaseplanthire.com/pr
	3 workers	Laying cable in trench	90	3	270	
	JCB (digger)	Fill cable trench	145	3	435	
Foundation installation	JCB (digger)	Dig foundation hole	145	2	290	
	Cement truck	Foundation filling with cement	-	-	1300	https://homeguide.com/costs/conc prices
Turbine installation	Turbine parts transportation	From Hanze to leeuwarden	-	-	130	https://borent.nl/auto-huren/product/toyota-dyna-pick-up
	tractor and operator	Turbine erection	52	2	104	
	electrical installation	Turbine wiring	70	6	420	
				Total	€ 3674	

6. Sustainability plan

6.1 Introduction

In this day and age, it is important to make sure a product is sustainable and environmentally friendly. The LiDS wheel is a handy tool to use to look at different points on which the product can be made as sustainable as possible (Zeiler, 2014). In this chapter each of these points are worked out on which items we can implement to make the wind turbine as sustainable as possible.

The 8 points:

- Choose low impact materials
- Reduce material usage
- Select environmentally friendly production techniques
- Select environmentally efficient distribution methods
- Reduce environmental load of user phase
- Optimize lifespan
- Optimise end-lifespan system
- Optimize function fulfilment

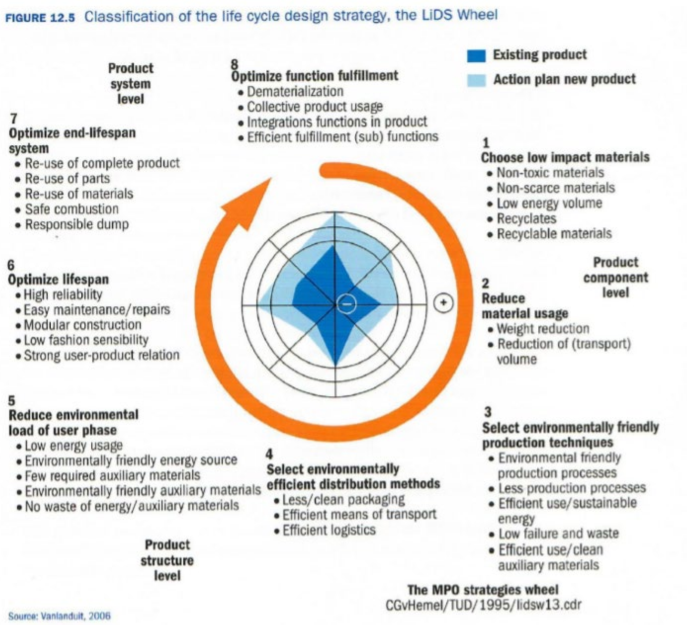


Figure 6.1 LiDS wheel

6.2 Low impact materials:

For the design of the wind turbine, it is important to look at the materials and make sure they are as environmentally friendly as possible. Toxic and scarce materials must be avoided, and it has to be easily recyclable.

- The rotor blades are currently made of a composite sandwich composed of fiberglass, sheets of balsa wood and a chemical called an epoxy thermoset resin. The material itself isn't specifically bad for the environment because it isn't toxic or scarce, nor is the production method polluting. The problem arises after 30 years (the desired lifespan) when the rotor blades will decay and will have to be replaced. The material you're left with is a material that as of right now, is difficult to recycle. There is an ongoing investigation on how to recycle this type of composite and use it for example: for pedestrian bridges, playground equipment, public benches and roofing materials. This recycling method isn't completely worked out yet and for the future it might be better to redesign the blades instead of recycling them every time. But for the already existing blades this is of course a good solution. Right now, there are researchers working on a new type of blade called the NREL blade. This blade uses most of these components, but bonds them together with a thermoplastic resin called Elium that can harden and sets the blade's shape at room temperature (Fialka, 2020). It can also be reclaimed at the end of its life by heating it into a liquid resin that can then be reused to make new blades. The research is yet to be finished and the biggest difficulty right now is to find out if the rotor blades will last the full 30 years of its desired lifespan. But these new blades might be a good replacement for the current blades.

- The mast and foundation weren't delivered with the wind turbine so it must be designed and made or purchased from Fortis. The best solution is to make the mast out of steel because it's easily recyclable and it's strong enough to hold the construction. For the original foundation of the fortis Montana concrete blocks are used to stabilize the wind turbine. Concrete has a long lifecycle and high resilience, but the production of concrete is not environmentally friendly because it uses a lot of water and has high CO2 emission.

- Some cement substitutes are (greenspec, 2021):
    - Pulverised Fuel Ash (PFA), aka 'Fly ash'
    - Ground Granulated Blast-furnace Slag (GGBS)
    - Silica fume
    - Limestone fines

6.3 Reduce Material Usage:

For all the components it’s necessary to make sure the material usage is minimalized and as light as possible.

- All of the components of the wind turbine are quite heavy and could be made lighter by making them out of aluminium or wood for example. After discussing with an Eric Jahn of Fortis it became clear that each component was made so that the entire wind turbine is in balance. If any of the components change (different material or different design) the turbine will be out of balance and will not work anymore. As there isn’t enough time to figure out how much has to be changed to make the turbine lighter or out of a different material and still be in balance the reduction of materials for these components is not possible.

- For transport it is smart to take the entire wind turbine apart so it can be more easily distributed to its destination.

- The mast will have to be as optimized as possible by using as little of material as possible so it will be light and no material will be wasted.

6.4 Environmentally friendly production techniques:

When producing your components, a lot of things happen which have a negative effect on the environment. Using production techniques which have a lot of CO_2 emission like welding or wasting material by milling or drilling. This has to be taken in consideration when making the components and have to be avoided if possible.

- When creating the mast and repairing the tail there are components that have to be welded together. When welding it is important to use a welding technique that emits the least amount of CO_2.

- When creating the mast some parts have to be milled and/or drilled in. These processes have to be limited and used efficiently.

6.5 Environmentally efficient distribution methods:

To be environmentally friendly the distribution and packaging has to be clean as well. The trucks that transport the components emit CO_2 and parts often get wrapped up in plastic. This isn’t good for the environment and has to be evaded if possible.

- When transporting the components of the wind turbine an electrical- or hydrogen driven truck should be used to cleanly transport the wind turbine.

- Some components have to be packaged before transport. By using carton to package the components an environmentally friendly material will be used.

6.6 Reduce environmental load of user phase:

When powering the machine its best if it's powered by clean energy and no energy gets wasted. The wind turbine produces clean energy itself and does not consume any energy so this strategy does not apply to our project.

6.7 Optimize Lifespan:

As time goes by materials and electrical components decay and need to be replaced. Some of these can be recycled and given a new life but sometimes a component cannot be recycled, and it will become waist. To optimize the lifespan and prevent components from becoming waist it is important to choose good materials and keep good maintenance. The product can also become irrelevant over time which causes its lifespan to be shorter as well.

- When designing the foundation, it is important to use sustainable materials with a large lifespan. If not done already the blades can be coated to prevent corrosion from the wind and the bearings have to be properly oiled. This coating for surface protection can either be a gelcoat or a paint and can be made of (Storm, 2013):
    - Polyester
    - Epoxy
    - Polyutherane
    - Acrylic

- A mechanism to easily lower the wind turbine can be implemented in the design so maintenance can be easily performed to constantly add coating and oil to increase the lifespan. This mechanism can also be used to easily repair components when they are damaged or replace them entirely.

6.8 Optimize end lifespan-system:

When the wind turbine eventually comes to the end of its lifespan the components must be taken apart and if possible recycled. To do this as environmentally friendly as possible the components must be easy to dismantle. It is also important to use as much clean material as possible instead of composite material which are more difficult to recycle.

- As mentioned in “1. Low impact materials” the rotor blades are made out of a composite material and for now are difficult to recycle and can be replaced with a material that is more easily recyclable.

- The wind turbine is a relatively easy mechanism and is easy to dismantle after its lifespan so the compartments can be recycled or used again in another machine.

- After this project the wind turbine will belong to Oosterhof Holman and the Energycampus Leeuwarden and they are invested in environmentally friendly products so they will be motivated to actually properly recycle everything after its lifecycle.

6.9 Optimize Function Fulfilment:

When creating a product, it is important to use every possible function of the product so nothing will go to waste. The sole purpose of the wind turbine is to generate electrical energy and that is also the only function that the wind turbine has so every function is already used.

- The Energycampus will also be used to educate different people on sustainability and the wind turbine can be used for that.

- The wind turbine is second hand so it’s function fulfilment is already being optimized by reusing it.

7. Maintenance plan

7.1 Introduction

All equipment needs different levels of maintenance (even the human). The term maintenance-free has been coined from the equipment having a technical service life, and that maintenance is not necessary over this period. But the fact remains that equipment is affected over its life by its particular environment and how it is “handled” during operation and maintenance. Many of the failures may originate from handling errors or incorrectly applied maintenance methods. It is therefore important that the machine is run and maintained properly at determined intervals to avoid serious and costly breakdowns.

7.2 Wind turbine maintenance

In principle, FORTIS wind turbines do not require any maintenance at all. On the other hand, it would be unwise not to check the wind turbine occasionally. FORTIS advises to check the wind turbine at least ones a year.

The following points should be checked:

- Check noises: the noise level should not have increased and should sound normal
- Check nuts and bolts; as far as possible. They might have worked themselves loose
- Check the electrical wires that are hanging through the inside of the mast; the tension must not be too high; this can occur if the wires have been wound too far and there is no slip ring used
- Check the leading edge of the blades from the tower basement on a wind less day. Small damages can be caused by small objects carried by the wind; such damages will speed up the process of wear and tear and should be repaired
- Check if the turbine, tail or tower is shaking more than usual. If this shaking occurs only at a specific low speed this means own frequency. If it becomes stronger with higher wind speed, stop wind turbine and contact your dealer or agent or contact Fortis direct
- Check the tension of the guy wires, if you have a guyed tower, in the first 6 months regular

8. Risk analysis

8.1 Risk register

This chapter looks at a risk analysis. This involves looking at what has the greatest chance of going wrong. By doing this, more focus can be put on this as you don't want it to go wrong. The risk analysis includes the political aspects, the legal aspects, the technical aspects, whether it is and can be organized, the location where the wind turbine will be installed and the social aspect. Furthermore, the chance of it happening has been looked at. And how bad the consequences are when you look at how bad the delay is going to be. How much more it will cost, the quality of the product, whether it is still a safe product and whether the environment will be affected.

Project	**Wind turbine**	T	: Time		
Project number	1	G	: Money	(green)	Risk acceptable (score 0-10)
Version	: 0.1	K	: Quality	(yellow)	Risk extra attention (score 11-20)
Date	7-4-2021	V	: Safety	(red)	Risk not acceptable (score > 20)
		O	: Surroundings		

Risk analysis					**Initieel risico**												**Beheersmaatregelen**
Nr.	**Angle of approach**	**Risk** *(it can happen that.........)*	**Cause** *(Because.........)*	**Consquince** *(Causing........)*	**Chance**	**Consequence**					**Consequences**					**Sum**	**Uit te voeren beheersmaatregelen**
						T	**G**	**K**	**V**	**O**	**T**	**G**	**K**	**V**	**O**		
Political/ administrative											0	0	0	0	0	**0**	
		the municipality is not allowing it.	lasw apply.	he may not be placed.	1	3	3	0	0	0	3	3	0	0	0	**6**	
		the companies disagree.	it makes too much noise.	it must be placed further away or not at all.	1	3	3	0	0	2	3	3	0	0	2	**8**	
Legal											0	0	0	0	0	**0**	
		the wind turbine may not be high enough.	this is necessary to catch enough wind.	the wind turbine is not producing enough.	3	2	0	4	0	0	6	0	12	0	0	**18**	
		the wind turbine ruined the view	people in the area don't like it.	the wind turbine has to be moved and is not in the ideal location.	2	2	0	4	0	2	4	0	8	0	4	**16**	
Technical											0	0	0	0	0	**0**	
		the wind turbine falls over.	it is not strong enough.	it to break.	2	0	2	4	4	0	0	4	8	8	0	**20**	
		the wind turbine is not going to turn.	he has too much resistance.	it not to work.	1	0	2	2	0	0	0	2	2	0	0	**4**	
		breakdown of the electrical circuit	it has been overused or an error in production	no more resistance for the motor and the blades fly around so fast that they fly off	2	0	2	4	4	0	0	2	8	8	0	**18**	
Organizational											0	0	0	0	0	**0**	
		the repairs are not well planned.	it is not well organized.	the wind turbine is not maintained enough and it can break down.	2	0	0	2	3	0	0	0	4	6	0	**10**	
		the wind turbine is not properly transported.	it is not well organized and planned in advance.	damage to the wind turbine.	2	0	3	3	2	0	0	6	6	4	0	**16**	
Geographically / spatial											0	0	0	0	0	**0**	
		the wind turbine cannot be reached.	there is no good path that can lead to it.	maintenance is going to be more difficult and students cannot work well with it.	1	0	0	3	3	1	0	0	3	3	1	**7**	
Social											0	0	0	0	0	**0**	
		people find the shade unpleasant.	there is a shadow moving all the time.	people can protest against the wind turbine.	1	0	0	2	0	2	0	0	2	0	2	**4**	
		the wind turbine breaks down and falls on someone's head.	the wind turbine is not strong enough.	people can be injured.	1	0	0	3	4	0	0	0	3	4	0	**7**	
											0	0	0	0	0	**0**	

Figure 8.1 risk register

Score	Chance (K)
1	0 - 5% (rarely or never occurs)
2	5 - 10% (chance exists, not great)
3	10 - 25% (there is a real chance)
4	> 25% (high probability)

Score	Consequence time (T)
0	no time effect
1	<1 month overrun
2	1 - 2 months overrun
3	2 - 3 months overrun
4	> 3 months overrun

Score	Consequence money (G)
0	no costs
1	0 - 0.5% **contract sum** €
2	0,5% – 2 % **contract sum** €
3	2 % – 5 % **contract sum** €
4	> 5 % **contract sum** €

Score	Consequence Environment / Image (O)
0	No environmental consequences
1	Experience disruption. Local nuisance for a limited duration
2	Weeks of inconvenience. Light damage
3	Night / evening nuisance. Extensive damage. Nuisance health.
4	Damage with side effects. Evacuation 103 days. Loss of turnover 1-3 months

Score	The consequence of quality (Q)
0	No consequence for quality.
1	Deviation from end product requirement, fully repairable without additional maintenance during life cycle
2	Deviation not fully repairable additional maintenance required during life-cycle
3	Permanent deviation with reduced performance with regard to the requirement from the Agreement
4	Permanent deviation, system failure

Score	Consequence safety (V)
0	No consequence for safety
1	Slightly injured, in need of medical assistance
2	Injured, no permanent injury
3	Badly injured, permanent injury
4	Deadly ending

Figure 8.2 points range explained

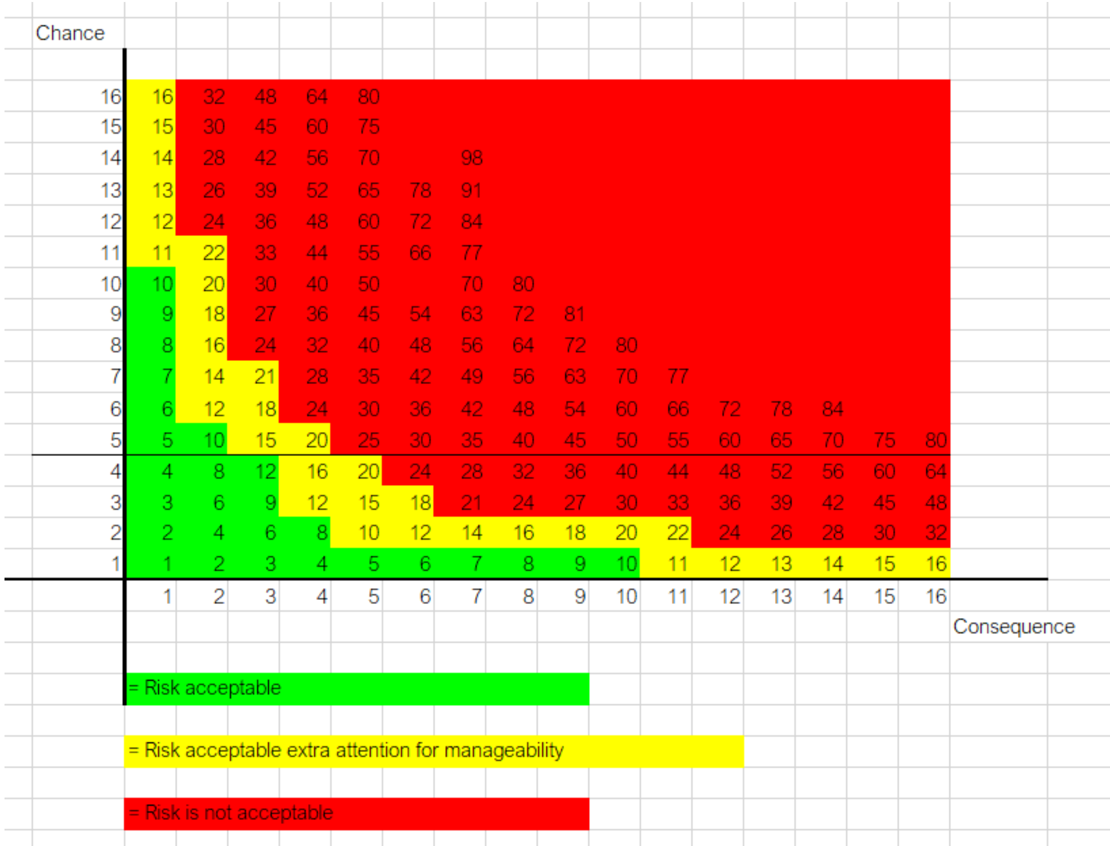


Figure 8.3 acceptable and non-acceptable risk range

The outcome of the risk analysis is that extra attention must be paid to the legal parts of a wind turbine and the technical calculations. There is a higher chance of not getting a permit so that's why there is a high chance of not getting the right permit, and not be able to place the wind turbine. It's good to start early to request permits so that it is clear if it's possible to place the wind turbine on certain places or there has to be chosen a different location. The reason why the technical calculations are important to pay attention to is mainly because the safety of the people is endangered if this goes wrong. And in addition, the wind turbine will probably break down and can no longer be repaired. Organizing the transport of the wind turbine is also important to consider. Here, especially money and quality would deteriorate should this go wrong.

8.2 FMECA chart

The Failure Mode, Effects & Criticality Analysis (FMECA) chart is a risk identification method for preventing failure which involves quantitative failure analysis. The FMECA involves creating a series of linkages between potential failures (Failure Modes), the impact on the mission (Effects) and the causes of the failure (Causes and Mechanisms). This method was developed by the US army in the late 1940s to anticipate failures & prevent them.

To implement this technique into the project, the first step is to identify the components of the wind turbine which face the highest chances of failure. 4 such components have been targeted and a risk analysis is done on them through the chart. The corresponding functions, potential failures, & the causes of potential failures of all the components are defined in the next step. After that, the probability of failure & effect of the failure are also acknowledged. And finally, the overall risk is derived by multiplying the probability with the effect which gives the final risk verdict of the component. The final two columns in the table are regarding how to prevent the failures. Firstly, ways are suggested in the ''Measure in design/process'' column on how to reduce the chances the failure by implementing those suggested ideas during the manufacturing stage of the component. And finally, the type of required maintenance for each component to reduce failure is labelled out when they are in operation.

The FMECA chart is a completely practical approach to the risk analysis idea when compared to other ways. It is a “anticipate failure and prevent it” way instead of the traditional “find failure and fix it” method. That's why it's a more technical piece of information which is extremely useful to prevent failures as much as possible and thus getting the maximum yield of the components.

Component	Description of component	1. DEFINE the FUNCTIONS and the desired PERFORMANCE STANDARDS at the component level	2. Define FUNCTIONAL FAILURES at component level where performance standards are not or partially achieved	3. Define the CAUSES of FAILURE and CONDITIONS at component level	4. PROBABILITY of the causes of failure	4. EFFECT of the causes of failure	P	E	P x E	Measure in design/proces	Type of maintenance (time-based, condition-based, reactive)
Rotor Blades	Most important parts of a wind turbine in terms of performance & cost of a wind power system	Generates kinteic energy when being moved by wind flow	Rotor blade arc is too large	Defect blade length	Incidental	Serious	Incidental	Serious	High	The blades have to be kept safe from lighting strikes, material or power regulator failure, & damage from foreign objects	Reactive Maintenance, it is advised to do this maintenance by trained personnel
Generator	The generator is the component that converts the mechanical energy of the rotor, harnessed from wind to electrical energy. A generator has the same structure as an electrical motor	Creates electricity by converting mechanical energy into electrical energy	Overload, no excitation, environmental effects, misalignment, fatigue, mechanical failure, loss of drivetrain control	Defect operating conditions	Incidental	Moderate	Incidental	Moderate	Low	Comprehensive maintenance and repair program will improve the reliability and longevity of the generator	Time based, it is advised to do this maintenance by trained personnel.
Gearbox	A mechanical part located in front of the generator whose purpose is to enhance the RPM of the turbine. The gearbox is 13 percent of the overall cost of the turbine and is an expensive component to replace	Increase rotational speed from a low-speed rotor to a higher speed electrical generator	Contaminated lubrication, Improper Settings, Temperature fluctuations, Fatigue loads underestimated; Exceeding design load; improper material	Defect operating conditions	Incidental	Serious	Incidental	Serious	High		Reactive Maintenance, during replacement, the turbine will be taken offline for as little as a few days, or it could be up to a couple of months based on the availability of parts
Main Shaft	The main shaft is a critical component in the wind power station, which carries variable forces transmitted by the system.	Transmit large amounts of torque	Fatigue loads underestimated, Operation of WTG at off-design conditions; Material properties below specs	Defect shaft design	Rarely	Moderate	Rarely	Moderate	Negligible	Enhancements to the bearings or a redesign to replace SRBs with TRBs, which can accept much greater thrust loads.	Based on condition, it is advised to do this maintenance by trained personnel

Figure 8.4 FMECA chart

9. Costs

9.1 Introduction

The wind turbine that EnTranCe has received is second-hand and not entirely up to shape nor complete. For the broken and missing parts new components have to be bought and these of course cost money. The wind turbine has to be installed and this will cost money as well.

9.2 Costs broken/missing parts

The only part that is broken is the pivoting shaft and is part of the “tail connection on frame” from which the main axle is missing. This entire “tail connection on frame will replaced by a new one bought from fortis and will cost €300,- (Jahn).

In chapter 4 “electrical” a research has been done to figure out which electrical parts have to be newly bought, these parts are:

- Brake switch €86,76
- Cable clips €1,50
- 4 Pole connector male €3,82
- 4 Pole connector female €5,24
- 20m 3 fase wire €32,60
- 10m 2 veined cable €27,50
- Kwh meter 2x €33,98

The total cost of these electrical parts amount to: €191,40

The last missing part is the mast. In chapter 3.4 “foundation” it’s concluded that the mast that will be used is the 18m tall mast that will be bought from Fortis wind energy (Fortis, sd). The mast itself will cost +/- €1200,- (Jahn). The mast of course has to be transported, installed, weld and put together, the estimate cost of this is +/- €2950,- (Jahn).

For the wind turbine to properly stand and stay in place a concrete block has to be put in the ground in which the wind turbine can be placed. A total amount of 6 m^3 concrete has to be used to hold the wind turbine (Jahn). The cost of concrete is between €165-€248 per m^3(hipages2). So it will cost a total of 6*((165+248))/2=€1239,-

9.3 Costs installation

When the turbine has been repaired and completed it has to be installed at Energycampus Leeuwarden. The installation of the wind turbine costs money and in chapter 5.3 “installation plan” this has been worked out to see what has to happen to install it and an estimate has been made on how much this will cost. The total cost of this comes to a total of €3674,-.

9.4 Total costs

The total costs of this project are:

- Tail connection on frame €300,-
- Electrical parts €191,40
- 18m mast €1200,-
- Installation of the mast €2950,-
- Concrete block €1239,-
- Installation turbine €3674,- +
- Total cost €9554,40

10. Recommendations for the following project group

10.1 Introduction

At the start of next school year a minor wind energy will take place. The people doing that minor will pick up this project to try and finish it. This chapter shows all of our recommendations for the next project group. First we listed all of our recommendations and then we explain them. We believe that all these steps need to be done before the wind turbine can be installed.

10.2 The recommendations

The list down below show all the recommendations that needs to be done before the wind turbine can be installed.

- The generator needs to be tested
- Build a setup table for the generator to be tested on
- Electrical components need to be tested (in collaboration with Laurens Mengerink)
- Rotor blades need to be inspected to see if they are still viable
- Determine what type of cable will be used to connect the base to the mast when installing the turbine.
- Prepare the installation in full detail

10.2.1 Testing the generator

The generator needs to be checked before installing. Eric Jahn looked at pictures from the parts at entrance and stated that the generator probably needs a rebuild with new bearings and checking the windings from the stator. This will cost around 750 euro. Or Eric Jahn knows a company that can check this and rebuild the generator, we don’t have a price indication for this option .

10.2.2 Build a setup to test the generator

Build and design a construction that can hold the turbine to see if it still generates enough electricity. Make sure that you use something like a lathe to spin the generator.

10.2.3 Testing the electrical components

Al the components of the electrical system needs to be tested, Laurens Mengerink from the company right connection can test all the electrical components. If some components are broken they need to be replaced or repaired, This can also be done by Right Connection.

10.2.4 Inspecting the rotor blades

The rotor blades need to be inspected/ tested to see if they are still smooth enough to prevent too much friction and look if the blades aren’t bend or broken. If the blades aren’t good enough or broken try to recoat/ repair them or replace them.

10.2.5 connect the turbine to the grid

The turbine still needs a cable that connects the turbine to the grid, this cable is mentioned in chapter 5 “installation” but the exact kind of cable has not been worked out. So it has to be found out which cable is suited for this.

10.2.6 Prepare the installation in full detail

We have already made an installation plan but not in full detail, because a lot of thing are still not certain enough to make a detailed plan. So make a plan that shows things like safety measurements.

Conclusion

During this project, a team of Mechanical Engineering students from Hanze University of Applied Sciences worked to repair a broken second-hand wind turbine which was donated by EnTranCe to the university and later, to have this same turbine erected on the grounds of Energy Campus in Leeuwarden. The main question of the project was, " What is the best location for the wind turbine, and what is needed to make the wind turbine work again? ''

A Destination Plan which involved thorough consultation with the client yielded a suitable spot (Location 4) to install the turbine. A few possible ways of repairing the broken tail were suggested, however it was decided not to improve the tail as an expert from Fortis had advised against it. After that, a thorough analysis was done with calculations on the tower mast and foundation which gave a basic design. Research into the electrical components resulted in wiring diagrams for the turbine but also concluded that the components will still need to be tested by an electric engineer with an estimated investment cost of €200. The installation part of the turbine was explained in a step-by-step format and was determined to have an investment cost close to €3700.

A Sustainability Plan was then made up to ensure a long and environmentally-friendly operational life of the turbine which was followed up by a Maintenance Plan. Continuing in the life-cycle theme, a Risk Analysis was carried out with a Risk Register & an FMECA chart to prevent failure of the turbine as much as possible. Finally, a handful of recommendations have been made for the next project group who'll be taking over.

The total cost of the whole project is projected to be just over €9500. This consists of the tail connection on frame (€300), electrical parts (€191), 18-meter mast (€1200), Installation of the mast (€2950), Concrete Block (€1239), & Installation of the turbine (€3674).

The best location to erect the turbine is aside the road (Location 4). The detailed analyses of all other aspects of the wind turbine that have been done explain how to get it operational again once it is installed. It is advised that the next project group follow these detailed explanations & work on solving the recommendations made for them.

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