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# Static Strength Analysis of a Full-scale 850 kW wind Turbine Steel Tower

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***ABSTRACT--- In this present paper, selected results concerning the static strength behavior of a three-dimensional (3-D) steel tower for a 850 kW horizontal-axis wind turbine are presented. The tower structure is 55 m height and consists of thin-wall cylindrical and three conical sections with variable wall thicknesses and variable cross-section axially along its height. The static response of the structure was investigated under gravity loads (nacelle, rotor and tower), rotor force and extreme wind loads with the aid of finite element (FE) software SOLIDWORKS Simulation. Based on simulation results, the tower structure satisfy the design requirements of static strength according to maximum von Mises stresses, maximum displacements, strains and minumim factors of safety.***

***Keywords: Wind turbine steel tower, Static strength analysis, Gamesa G52/850, Wind loads***

## I. INTRODUCTION

Wind energy continues to be the most essential source of new energy added to the energy production portfolio. The Renewable Energy Policy Network for the 21st Century (REN21) declares that more than 52 GW new wind power capacity was brought online in 2017 (REN21, 2017). Among the most economical forms of modern power generation is the Horizontal-Axis Wind Turbine (HAWT) due to have several benefits: they reduce harmful gas emissions, High efficiency and support a sustainable electrical power infrastructure for posterity (Tong, 2010).

Wind turbine (WT) systems mainly consist of the wind rotor, nacelle, and tower…etc. WT tower carries the wind rotor and the nacelle to the required height. As well, it constitutes about 20-30% of the total cost of the typical WT project. Therefore, the reliability of the structural design of WT tower is still very important and necessary to ensure the safety, the functionality, reasonable cost and serviceability during the service-life (Ferroudji et al., 2016; Hu et al., 2014). The most common tower structure for WT is tubular steel type due to the simple structural system of cantilever beam, their cost-effectiveness, the rapid construction and their section properties can be calculated very easy (Way et al., 2015).

WT tower structures are subject vulnerable to several dynamic loads (aerodynamic loads, gravitational forces vary with time as the rotor rotates) and the identification of their actual dynamic properties is an essential step in understanding its static and dynamic behavior (Khelifi, al. 2016).

The site of Adrar in the south-west Algeria is one of the most the windiest regions in the country (significant winds of about 6.3 m/s), it is for this reason the electricity and gas national society SONELGAZ has installed in Kabertene in 2014 a wind farm of about 10MW (See Fig.1) (Nedjari et al., 2018; CDER, 2017).

In the current study, a 3-D structural static modeling on 850-kW WT steel tower is performed by the FEA using SolidWorks software (SolidWorks, 2016). In this analysis, the maximum von Mises stresses, the maximum displacements, strains, and security factors were carried out for tower structure under gravity loads (nacelle, rotor and tower), rotor force and the extreme wind loads. Finally, the structural safety was confirmed through the analysis results.

**Figure 1. Wind farm G52/850, 10.2MW in Kabertene site (CDER, 2017)**

## II. STRUCTURE OF WIND TURBINE TOWER

The main structure of the tower of a typical 850 kW shown in Figure 1, that is in the first wind farm (10.2 MW) was installed in 2014 at Kabertene (72 north of Adrar) in Adrar, Algeria at an altitude of 263 m above the sea mar. The steel tower has a total height of 55 m and consists of

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thin-wall cylindrical and three conical sections, of variable wall thicknesses and variable cross-section axially along its height. The shell thickness at the base is 18 mm and at the top is 10 mm. The tower is pre-assembled into two sections which are bolted together by means of heavy circular end-flanges. The tower also includes an opening of the door at the base. The door section covers 1/6 of circumference of the tower and is approximately twice as thick as the rest of the wall at that height in the tower. It is important to include these details, as they may affect the response of the tower. The key properties of the wind turbine are given in Table 1 (Wind Power , 2017).

## III. FINITE ELEMENT STATIC OF TOWER

The numerical computations for static strength analysis of the tower structure were carried out using commercial FEA software SolidWorks Simulation (SolidWorks, 2016).

A 3D FE model for the studied tower structure was developed using second-order tetrahedral elements, with 10 degrees-of-freedom (DOF) for each. The mesh for the tower (see Figure 3) was refined along its height using well-proportioned FEs for avoiding numerical problems. The final FE model was divided into 95,320 elements, 189,612 nodes and had 566,706 DOF.

For towers of WTs the used steel materials have to satisfy requirements concerning strength, roughness, be recyclable and easy to fabricate (Khelifi, 2016; Tong, 2010). The tower and flanges were made from Steel (AINS 1020 Steel, cold rolled), the properties of the material are given as input to the SolidWorks Simulation which are: : $E = 2.05 \times 10^5\ \mathrm{N/mm^2}$ Young's modulus, $\nu = 0.29$

**Table 1. Gross Properties of the GAMESA G52/850 Reference Model**

| Item | Sub item | Value |
|---|---|---|
| Tower | Height | 55 |
| Rotor (blades + hub) | Number of blades | 3 |
| | Rotor diameter [m] | 52 |
| | Swept area [m²] | 2,124 |
| | Blade length [m] | 25.3 |
| Weights | Nacelle [ton] | 23 |
| | Tower [ton] | 57 |
| | Rotor + hub [ton] | 10 |
| | Total [ton] | 90 |

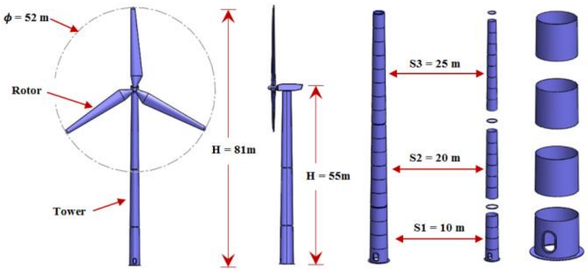

**Figure 2. CAD Model Gamesa G52/850kW**

Poisson's ratio, ρ=7870 kg/m^3 mass density and $S_y = 350\ \mathrm{N/mm^2}$ yield. The adopted boundary conditions for the tower structure that was fully constrained tower base plate in all the translational and rotational DOFs at its base (fixed).

In the structural model, the weight of the tower itself is estimated directly (SolidWorks Simulation). A concentrated load at the top of the tower representing the weight of the nacelle and the rotor with hub will occur a vertical force on the top of the WT tower, which are 230 kN and 100 kN, respectively. In addition, there is a horizontal wind loads (wind thrust) applied on the rotor (rotating blades). This horizontal force eventually transmitted to the tower on the top, which is 76.5 kN (Khelifi et al., 2016). The third component contains a distributed wind which is acting along the height of the tower. According to (IEC 61400-1, 2005), the design wind velocity $V_{e50}(z)$ is distributed along the tower, is obtained from:

$$V_{e50}(z) = 1.4.\, V_{ref}\left(\frac{z}{z_{hub}}\right)^{0.11} \tag{1}$$

Where $V_{ref}$ is the reference wind velocity, in which for the site Adrar, Algeria (Wind Zone II) Algeria $v_{ref} = 28\ \mathrm{m/s}$ (CNERIB, 1999), z and $z_{hub}$ are the height above ground level and hub height, respectively. The resultant pressure from the variation in design wind velocity is determined from:

$$P_x = \frac{1}{2}\rho V_{e50}^2 \tag{2}$$

## IV. RESULTS AND DISCUSSION

The stress–strain state of the tower structure is determined as a result of the static strength analysis. The diagrams of maximum stress distribution (MPa), maximum displacement distribution (mm), strain distribution and safety factor (FOS) of the structure are respectively shown in Figures 4, 5, 6 and 7. The most significant parameter in the static analysis of the structure is the maximum stresses and critical values. The stress values (normal and shear) are calculated initially and then are analyzed based on the Von Mises criterion (von Mises-Hencky theory) and represented by the Eq. 3 (Ferroudji et al., 2014):

$$\sigma_{vonMises} = \{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2/2\}^{1/2} \tag{3}$$

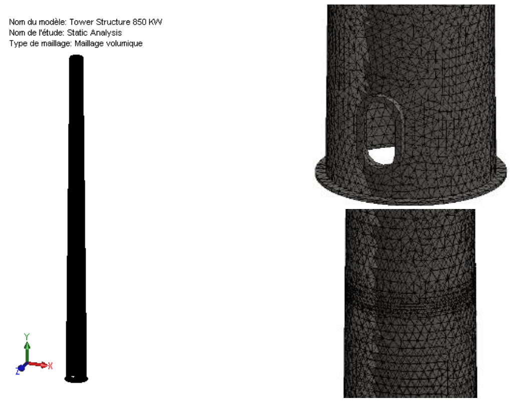

**Figure 3. Mesh generation model of tower structure**

The FOS at a location is calculated from:

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$$\text{FOS} = \sigma_{\text{Stress limit}}/\sigma_{\text{vonMises}} \qquad (4)$$

It can be seen from the Figure 4 that the critical von Mises stress value is only 82.1 MPa which appears in close proximity to side of the door-opening near the tower base. This value is still below the material yield limit of 205 MPa. The rest of the tower structure has very low stress value, less than 50 MPa.

The displacement (Figure 5) is increased with the increase of height of WT tower, the maximum horizontal displacement appears at the top of the tower. Due to the pressure applied on the structure by the extreme wind load and rotor thrust force and the tower bottom is set up fully-constrained, so the displacement of base is almost 0. The maximum displacement value is 195.6 mm. According to Code for Design of high-rising structures, the maximum displacement is limited to $L/100$ (Ma et al., 2014).

The maximum strain (Figure 6) occurs in close proximity to side of the door-opening near the tower base and the largest strain is 3.45e-04. this value is quite small (negligible) and indicates that the tower structure did not suffer permanent plastic deformation.

The safety factor (Figure 7) shows that the tower dangerous place is the door-opening. The minimum value is 4.26 which is larger than the prescribed value of 1.35 (IEC 61400-1, 2005).

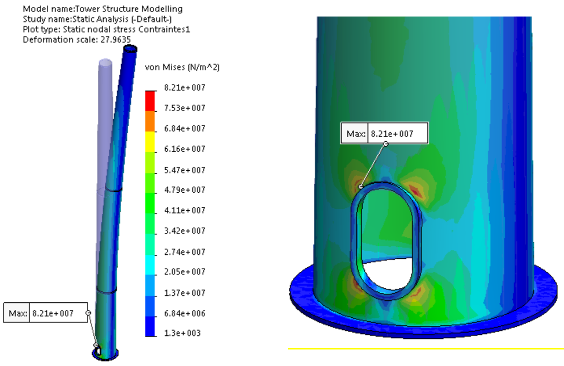

Figure 4. von Mises stress of the WT tower structure

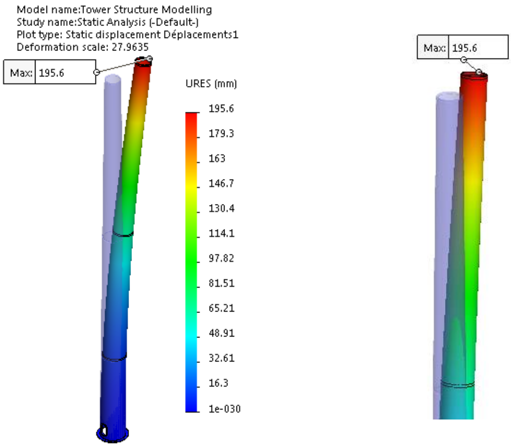

Figure 5. Displacements of the WT tower structure

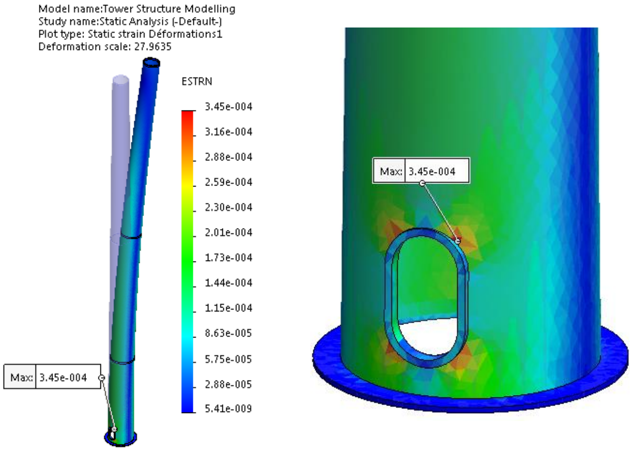

Figure 6. Strains of the WT tower structure

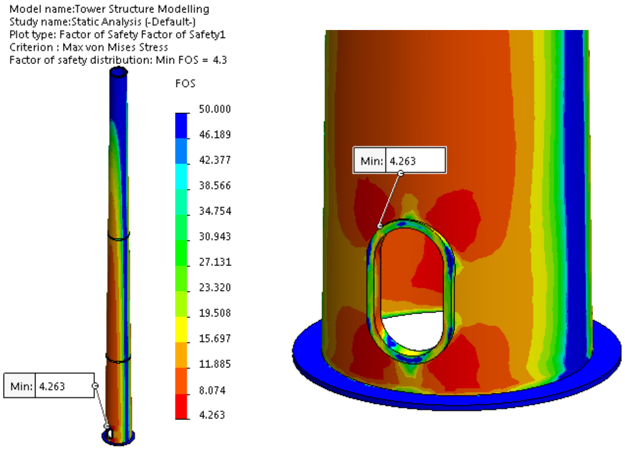

Figure 7. safety factors of the WT tower structure

## V. CONCLUSION

The present research concerns the investigation of the static strength behavior of wind turbine tower under gravity loads, rotor force and wind loads using FE analysis. This analysis has shown that the maximum value of von Mises stress is 82.1 MPa and maximum displacement is 195.6 mm. These values are acceptable as compared to the yield strength of the tower material (205 MPa) and the tolerance allowed for the high-rising structures (L/100). The static local and global stability of the WT tower structure is confirmed since the minimum safety factor of material obtained is 4.26. This value is greater than the value recommended by the IEC61400-1.

## REFERENCES

1. Ren21, "Renewables 2017," global status report, 2017. ISBN 978-3-9818107-6-9, www.ren21.net
2. Tong, W., Wind power generation and wind turbine design. Southampton Boston: WIT Press, 2010.
3. Ferroudji, F. Khelifi, C. Meguellati, F., 2016. Modal analysis of a small H-darrieus wind turbine based on 3D CAD, FEA. International Journal of Renewable Energy Research. 6(2): 637-643.
4. Hu, Y. Baniotopoulos, C. Yang, J., 2014. Effect of internal stiffening rings and wall thickness on the structural response of steel wind turbine towers. Engineering Structures. 81: 148-161.

5. Way, A.C. Van Zijl, G., 2015. A study on the design and material costs of tall wind turbine towers in South Africa. Journal of the South African Institution of Civil Engineering. 57(4): 45-54.
6. Khelifi C. Ferroudji, F., 2016. Stress and fatigue analyses under wind loading of the dual axis sun tracking system via finite element analysis," Journal of Mechanical Engineering and Sciences. 10(2): 2008-2015.
7. Nedjari, HD. Haddouche, SK. Balehouane, A. Guerri, O., 2018. Optimal windy sites in Algeria: Potential and perspectives. Energy. doi: 10.1016/j.energy.2017.12.046.
8. http://portail.cder.dz, Renewable Energy Development Center.
9. SolidWorks 2016, SolidWorks Corporation, 300 Baker Avenue, Concord, MA 01742. Available from: http://www.solidworks.com/.
10. http://www.thewindpower.net accessed Dec. 20, 2017.
11. Khelifi, C. Ouali, M. Ferroudji, F. Adjlout, L., 2016. Modal Analysis of a Small Savonius Aerogenerator by using SolidWorks Simulation. Applied Mechanics and Materials. 806: 214-221.
12. IEC 61400-1, 2005. International Standard, Wind Turbines – Part I: Design requirements, 3rd edition, Geneva: International Electro Technical Commission.
13. Règlement neige et vent "R.N.V. 1999", Document Technique Réglementaire (D.T.R. C 2-4.7). ISBN : 9961-845-03-X.
14. Ferroudji, F. Outtas, T. Khelifi, C., 2014. Design, modeling and finite element static analysis of a new two axis solar tracker using SolidWorks/COSMOSWorks. Applied Mechanics and Materials 446-447: 738-743.
15. Ma, HW. Meng, R., 2014 Optimization design of prestressed concrete wind-turbine tower," Sci China Tech Sci. 57: 414-422.