Severity of Cracks Growths on Static Design of a Three Bladed Savonius Wind Turbine Using SolidWorks Simulation

Cherif Khelifi[1,2*], Mohammed Ouali[2], Fateh Ferroudji[1] and Lhouari Adjlout[3]
[1]Unité de Recherche en Energie Renouvelable en Milieu Saharien, URERMS, Adrar, Centre de Développement des Energies Renouvelables, CDER, ALGERIA,
[2]Laboratoire Dynamique des Structures, Université Saad Dahlab, Blida, ALGERIA, E-mail : [3]Laboratoire d'Aéro. Hydrodynamique Naval, LAHN, Département de Génie Maritime, Faculté de Génie Mécanique, U.S.T. Oran, (Algérie).
E-mail : khelifiam@yahoo.fr

***Abstract*— Modern vertical axis wind turbine is a promising technology, appropriate for small scale applications in urban areas and isolates sites for different uses. Including pumping water, producing electrical power, passive starting others turbines and purposes. The Savonius wind turbine is a robust and reliable mechanical device, easy to build, produces less noise. The formation and growths of cracks in this system reduces its stiffness and yield strength, which lead to a poor performance and system failure. The system works under the wind flow dynamic loading. Then, it is subject to mechanical and aerodynamical cyclic stresses to be inducing the fatigue and shortening the system lifetime. The diagnosis of the system by using nondestructive techniques based on magnetic particle, dye penetrant and ultrasonic are costly. The use of natural frequencies shift measured between uncracked and cracked structure is very small regardless the varying of crack depth and location, undetectable in the practice. The application of analysis and simulation tools based on (CAD) permits to evaluate the system design early in the design process. This technique allowed determining the causes of premature failures, quickly explored designs changes in the aim to reduce cost as well as weight, and estimated the safety factor of product. Present paper investigated the influence of weight and centrifuge force on the static design of a three-bladed Savonius wind turbine cracked under various wind speeds from 5 to 15 m/s. The transverse crack is formed and growth normally to the low speed shaft and to end side of blades. From simulation results, the reliability of wind turbine is strongly influenced by the increasing of wind speed since the security factor was decreased from 14.6 to 1.39. However, the influence of crack on mechanical proprieties of the system, stress, strain and displacement is very small, for all study cases, depth variation from 0 to 50% of the shaft diameter and at different settings. The effect is undetectable in the practice for in online monitoring of the wind turbine.**

***Index Term*— Renewable energy, Savonius wind turbine, transverse open crack, centrifuge loading, static FEA, SolidWorks simulation.**

I. INTRODUCTION

The most common incipient losses of the structural integrity in mechanical structures are the formation and growths of cracks during development process or due to the environmental effects such as corrosion and wear. Accurate inspections revealed that cracks had already propagated up to a depth of almost 50% of the diameter in many shafts, which is obviously a very critical situation. These defects created a plastic zone with concentrate stresses and induced excitation forces that instigate excessive vibrations in the structure. These issues increase the fatigue of the elements damaged during operational conditions until the structure fails. The defect growth reduced the local stiffness, which weakness and destabilizes the structure despite [1].

Current markets demand cheaper systems, reliable, and more productive. This exigency involves the industrial and economical companies to use all the means available for lowering product development costs via research in structures dynamic and remaining successful. Nowadays, the Computer-Aided-Design (CAD) becomes a powerful technology tool enables researchers to simulate design performances, identify and address critical design problems before the investment in prototyping with various shapes. Particularly, the Finite Element Analysis FEA turn into one of the most important techniques that remedies to a design issues at the development design stage and offers a great advantage over the competitors. The universal SolidWorks simulation software develops-into one of the most important tools. Since it aids easily, and rapidly to ensure that these considerations to be addressed early in the product development process. This code permits manufacturers to accelerate time to market and reduce the improvement costs while producing higher quality products with fewer warranty problems. The reference [2] gave an easy description of professional simulation using this software. The authors [3, 4] presented interest reviews on the universal software of modeling and simulation of objects and phenomena which obey to the partial differential, integro-differential, and integral equations. Besides, these authors analyzed the results of comparing a number of commercial codes against a set of user-defined criteria. The study [5], performed an estimated procedure for detecting multiple edge open cracks in slender Euler-Bernoulli beam, based on changes in natural frequencies measurements.

They concluded that for two simultaneous cracks of size more than 10% of rotor section depth, the error between the real and predicted crack locations and sizes is lower than 10% and 15% respectively. The paper [6] carried out free and forced vibration analysis of a multiple cracked cantilever beam. The study results advocate that the free vibration analysis provides suitable informations for the identification of single and two cracks, but the forced vibration can detects only the single crack condition. This author affirms that the forced dynamic response better describes the changes in crack depth and location than the free vibration. However, the difference between natural frequencies due to the shift in crack depth and location has a minor effect. Therefore, the natural frequencies changes due to the sizes, depths and locations of cracks in rotoring shafts or other parts of the system is very slight, undetectable in the practice for controlling the structure healthy in real time. One of the major reasons is that the natural frequencies f are proportional to the square root of the stiffness K according to the classic relation of structure vibration:

$$f = \sqrt{K/M} \quad (1)$$

Thus, if the complete structure rigidity varies of 1%, the natural frequency shifts only of 0.5%. However, the static deflection is proportional to the inverse of the stiffness when the load applied is constant. A change of 1% of the structure stiffness induces a shift of the deflection of 1%. Therefore, the higher accuracy in crack detection in practice may be expected from deflection measurements rather than from natural frequencies testing. Present paper carry out a static design reliability of a small three-bladed Savonius wind turbine based on FEA under SolidWorks simulation. The system is subject to its free weight and to the static critical centrifuge loading. The study includes both the influence of wind speed intensity from 5 to 15 m/s, as well as the variation of depth and location of crack from 0 to 50% of the shaft diameter for various positions. The influence of these parameters are presented and analyzed through mechanicals characteristics of the system, stresses, strains, displacements as well as appreciated using the security factor criterion.

II. Static Design Generation

A) Prototype Generation

Savonius wind turbine shown seen in Figure 1, is a power extracting device based on drag force. It is built in general by four principal components: the blades fixed to the rotoring shaft, the driven train, the electrical generator and the mast for sustaining the structure. This machine is designed to transform the kinetic energy of the wind flow into rotational energy by using three bi-cylindrical blades fixed to the rotoring shaft. The mechanic energy captured is transformed into electric energy by means an appropriate generator coupled to the rotor through a planetary speeds multiplier within a gain ratio equal to 10. The wind turbine is designed to capture wind power at nominal Tip Speed Ratio equal to the unity:

$$TSR = \frac{\omega R}{V} = 1 \quad (2)$$

Where ω, V, and $R = 0.36m$ are the angular speed of the rotor, the tip speed and the radius of the rotor respectively. The aspect ratio and the overlap of the wind turbine are chosen 1.5 and 0.14 respectively regardless the CFD considerations. In the prototype, the parts that are more concern are the blades fixed to the rotoring shaft, due to the weight and centrifuge cyclic forces applied at the rotor. Then, all other parts of the aerogenerator are ignored for simplifying the problem and lowering the simulation computing time. The geometry of the wind turbine is generated and assembled as well as the interference between their parts is checked and the material proprieties are selected by using SolidWorks code. The material of the turbine is selected in galvanized steel, characterized by the elasticity modulus $E = 200GPa$, the yield strength $\sigma_e = 203.95MPa$, the Poisson's ratio $\mu = 0.29$ and the density $\rho = 7870kg/m^3$. This material has a good machinability and weldability as well as a high hardness and availability.

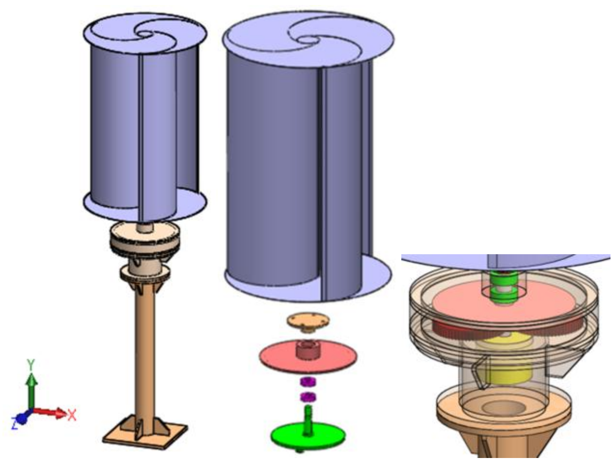


Fig. 1. SolidWorks model of the aerogenerator

B) Finite Elements Analysis

The static design of the system is simulated by using SolidWorks Simulation/Cosmos module based on FEA. The global system meshing Figure 2 was generated by using 3-D tetrahedral elements of 21.57 to 107.86 mm. The structure was discredited in 84922 elements, connected to 142423 nodes with 426873 DoF. The system is fixed at the bottom and at the revolute join (hinge) level. The linear static equilibrium equation for whole the elastic structure is obtained by assembling all equilibrium equations of its finite elements without and with cracks by using finite elements method given in [7] as the form:

$$[K]\{u\}=\{F\} \quad (3)$$

[K], {u} and {F} are the stiffness matrix, displacement and external force vectors respectively. The stresses vector {σ} in the material is related to the strains vector {ε} by using the Hook's law:

$$\{\sigma\} = [E]\{\varepsilon\} \quad (4)$$

The safety factor was introduced into the design process to compensate the uncertainties due to the accidental overloading also for possible inaccuracies in design and unknown variables. This factor is given by the ratio:

$$S_f = \sigma_e/\sigma_{V\,M} \quad (5)$$

σ_e is the yield strength. $\sigma_{V\,M}$ is the equivalent VonMises stress given in function to the principal material stresses σ_I, σ_{II} and σ_{III} as the following manner :

$$\sigma_{VM} = \sqrt{0.5[(\sigma_I - \sigma_{II})^2 + (\sigma_{II} - \sigma_{III})^2 + (\sigma_{III} - \sigma_I)^2]} \quad (6)$$

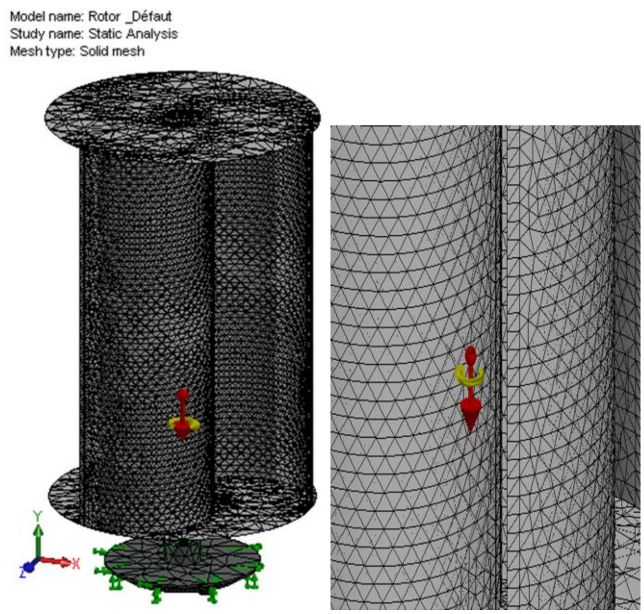


Fig. 2. 3-D Structure meshing and boundary conditions

C) Cracks Issues

The crack growth is a major issue in the prediction and maintenance of turbo-machinery structures. Cracks are located generally at the geometrical discontinuity or at a metallurgical defect in a normal plane to the rotoring shaft axis, when the axial bending stresses are prevailing in X and Z directions seen in Figure 3. This effect is also in correspondence with the sharp changes of the diameter or geometry of the shaft due to the presence of holes, corners, slots for keys, threads and soon in regions of high stress concentration.

The transverse crack in the shaft of the wind turbine may be described by the reducing inertial quadratic moment of the area ΔI using Rayleigh method given in reference [8].

$$\frac{\Delta I/I_0}{1+\Delta I/I_0} = \frac{R}{L}[1-\nu^2]\, f\left(\frac{a}{R}\right) \quad (7)$$

Where, I_0, R, L, ν, a and f(a/R) are the quadratic moment of the shaft area without cracks, the shaft radius, the section shaft length, the Poisson's ratio, the crack depth and the compliance function respectively.

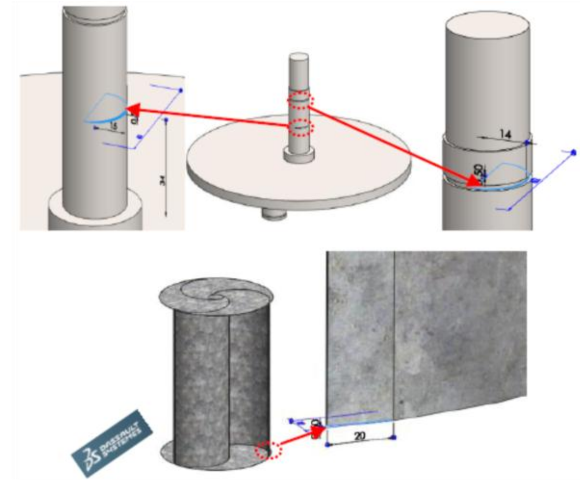


Fig. 3. Cracks growths settings

III. Results

From FEA simulation results of the original and cracked aerogenerator structure for various regimes and conditions, where the nominal situation was shown in Figure 4, the following conclusions are tired:

- The shifts in static stress, strain and displacement Table 1 due to the crack growths are very small for all the cases studied, including the varying of crack depths from 0 to 50% of rotor diameter and for various positions in the rotor shaft and blades. It is clear that the physical effect of these parameters changes is undetectable in the practice. The reason is that the FEA is based on the average values of deformations and stresses calculation. This is not the case for the concentrate stresses and strains at specific local points appeared in the metal such as cracks. In addition, the static stresses analysis requires only the knowledge of the total stress field, but, the high-localized stresses being redistributed by the local deformations according to the linearity principle.

- The mechanical characteristics of the wind turbine Table 2 are strongly influenced by the variation of the angular rotation of the rotor shaft due to the varying of the wind speed. The increasing of this parameter from 5 to 15 m/s reduced the critical VonMises stresses from 856.94% to 827.48% and augmented the displacements from 810.58% to 883.77% also the strains from 826.77 to 876.30 %, but the security factor variation remains approximately constant near 89%.

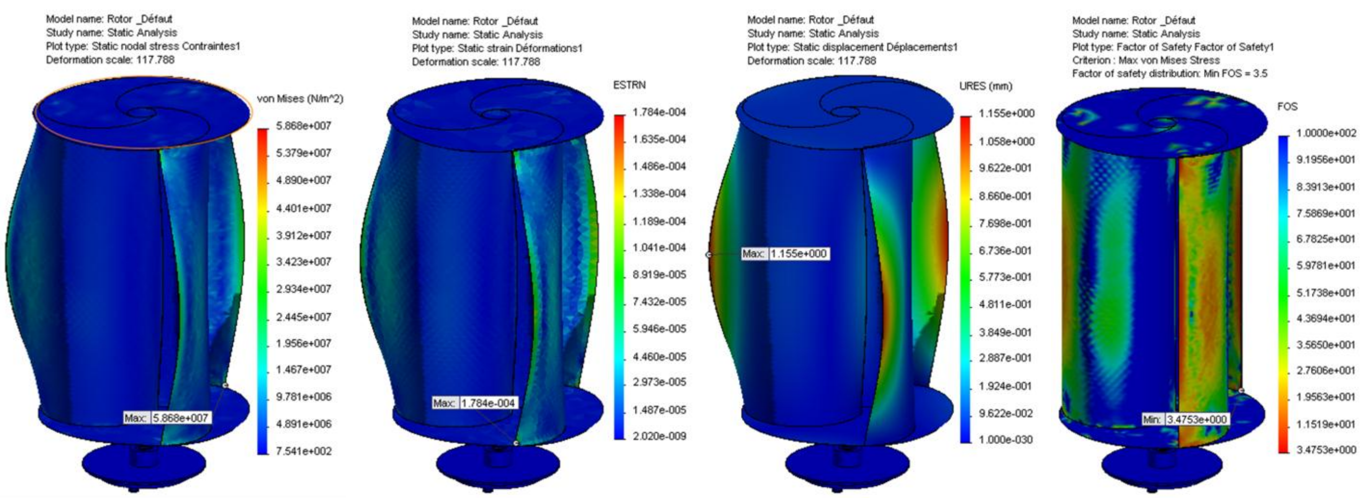
- The cracks propagate in rotoring shaft of wind turbine engenders a local inelastic and plastic deformations, should be treated by using nonlinear considerations.

TABLE I
INFLUENCE OF CENTRIFUGE LOADING AND CRACKS GROWTHS ON THE STATIC PERFORMANCES OF THE WIND TURBINE

Crack settings	V (m/s)	σ_{VM} (MPa)	u (mm)	ε	S_f
Rotor (a/R=0)	05	13.94	0.2863	0.00437	14.635
	10	58.68	1.155	0.01780	3.4750
	15	133.4	2.607	0.04050	1.5280
Rotor (a/R =0.5)	05	13.98	0.2862	0.004353	14.589
	10	59.20	1.155	0.01763	3.4440
	15	133.6	2.609	0.04052	1.5260
Rotor (a/R =1)	05	13.97	0.286	0.004356	14..601
	10	58.92	1.157	0.01784	3.4610
	15	133.3	2.604	0.04044	1.5300
Charp change (a/R=1)	05	14.00	0.2835	0.004304	14.569
	10	58.89	1.235	0.01846	3.4630
	15	133.9	2.789	0.04202	1.5220
End side of the blade (a= 0-2 cm)	05	15.72	0.2572	0.004564	12.973
	10	64.28	1.061	0.01686	3.1720
	15	145.8	2.395	0.03747	1.3980

TABLE II
MECHANICAL PERFORMANCE CHANGES IN % WITHIN THE VARIATION OF WIND SPEED FROM 5 TO 15 M/S

Crack settings	σ_{VM}	u	ε	S_f
a/R=0	856.94	810.58	826.77	89.55
a/R =0.5	855.65	811.60	830.85	89.54
a/R =1	854.18	810.48	828.37	89.52
a/R=1	856.42	883.77	876.30	89.55
a= 0-2 cm	827.48	831.18	720.99	89.22



(a) Stress (b) Strain (c) Displacement (d) Security facto

Fig. 4. Static mechanical characteristic of the wind turbine without crack at nominal working (V=10m/s)

IV. CONCLUSIONS

Based on static mechanical characteristics results obtained from present simulation and analysis, we can conclude that the stresses, strains and displacements are within the permissible limits since the security factor of the weakest material is greater than 1.2 for wind speed lower than 15m/s and for crack propagate until 50% in the shaft diameter section at various settings. The wind turbine cannot lose its stability, due to extremely high critical stresses. Therefore, the material selected for manufacture of the wind turbine and fittings, has satisfactory mechanical proprieties from the point of view of weight and centrifuge loading analyzed. However, the information about the crack growth effect on the mechanical characteristic are not sufficient for controlling the structure healthy during the working conditions. A bad design is not only the one that fails, but also too conservative, too heavy and too expensive.

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