Aeroelastic Simulation of Small Wind Turbine using HAWC2

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Abstract: Horizontal axis wind turbines are subjected to various static and dynamic loads under different load situations. Aeroelastic modelling is used in wind turbines to couple the aerodynamic and structural loads acting on the turbine and to analyse the aeroelastic response. The small wind turbine Nimbus 1.6 KW has been modelled in the Aeroelastic code HAWC2 which uses Multibody dynamics for the structural modelling and BEM theory for the aerodynamic part. The natural frequency and different modes of the turbine has been calculated after the complete modelling in HAWC2.

Keywords: HAWT, Aeroelastic modelling, Multibody dynamics, HAWC2, BECAS.

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Contents

2 Introduction

Aeroelasticity of wind turbines is the most important characteristic under research concerning wind turbines. The combination of aerodynamic, elastic and inertial forces acting on the wind turbine is very important in determining the efficiency and safety of wind turbines. Aeroelastic simulation is tool which helps to investigate the static and dynamic response of a wind turbine under various forces of excitation from different wind conditions. A clear understanding about the aerodynamics, structural dynamics and the interaction between these two enable the development engineers to design light weight highly efficient wind turbines. International Electro technical commission (IEC) has structured rules and standards which should be used to design and certify small and large wind turbines. IEC has also recognized Aeroelastic simulation as a tool which can be used to evaluate the forces acting on the turbine. This reduces the economic and time resources required for evaluation through experimental testing of wind turbines considerably.

According to IEC 61400-2, small wind turbines can be modeled either using a simplified model or with aeroelastic simulation model. The safety factor used in the simplified model is 3.3, which accounts for the turbine to be modeled for 3.3 times the maximum load acting in the worst case scenario. With a suitable aeroelastic model the safety factor can be as small as 1.1. This can highly influence the size and costs per kilowatt energy produced by the wind turbine which make the wind energy cheaper and affordable. The scope of the thesis is to set up a full aeroelastic model of the wind turbine and to do the natural frequency analysis. The aeroelastic simulation model is further used in aerodynamic analysis and load calculation studies of the same wind turbine.

The research in the field of Aeroelasticity in the field of wind turbines started in Europe with Friedmann who derived a set of equations for wind turbine coupled flag-lag torsional equations of motion [1]. These equations are written for single wind turbine blade to investigate the aeroelastic stability.

Risø-DTU is the leading research institute in the field of developing aeroelastic codes in Europe. The software HAWC2 is one of the most advanced softwares for analyzing both offshore and onshore wind turbines. HAWC2 uses Blade Element Momentum (BEM) method for the aerodynamic model, Multibody dynamics is used in the Structural dynamic model and wind simulation is done with the help of Wasp engineering. Matlab or Python is used for the post processing of the data [2].

FAST from National Renewable Energy Laboratory, USA is a free aeroelastic software which is based on Multibody dynamics. It's used extensively by wind turbine manufacturers and researchers in USA for aeroelastic research. Fast is based in the software interface Pearl, which uses BEM as the Aerodynamic model and a Model approach is used in determining the structural dynamics approaches of the wind turbine [3].

Bladed GH is an industry leading aeroelastic tool software from Garrad Hassan which is certified by Germanischer Lloyd for the certification and design of wind turbines. The tool is quite accurate with a simple Graphical user interface which uses BEM method for the aerodynamic model and Multibody dynamics for the structural dynamic model. Bladed is commercial software from Garrad Hassan which is used by various wind turbine manufacturers around the globe for the design and optimization of wind turbines. The software comes with various modules which provide complete modeling of offshore and onshore wind turbines. The modules include options for Static analysis, analysis of loads and energy capture and interaction with the electrical network [4].

The other similar aeroelastic codes dealing with wind energy are ADAMS/WT which is a Fortran based software using MSc Adams for the multibody dynamics part. The software is developed as a contract for NREL. YawDyn has been developed in University of Utah in association with NREL which focuses on the stabilization of yaw using the Adams for the structural dynamics parts and classical BEM theory for the aerodynamics part [5]. HAWC is an earlier version of HAWC2 from Danish Technical University using Finite element method instead of multibody dynamics. VIDYN is the aeroelastic code developed by Teknikgruppen AB in Sweden which uses BEM for aerodynamic model and Model analysis for the evaluation of structural stability. PHATAS is an aeroelastic code from ECN which uses frequency domain calculations for integrated pitch and yaw control.

The aeroelastic research in wind turbines a new and gradually evolving field. National Renewable Energy Laboratory, USA and Danish wind energy institute are the top two research institutes working on the aeroelasticity of wind turbines. The other major players in this field include ECN, Netherlands and Garrad Hassan UK. The published papers on aeroelasticity in different countries around the world retrieved from the engineering index are shown in the figure 1.1 [6].

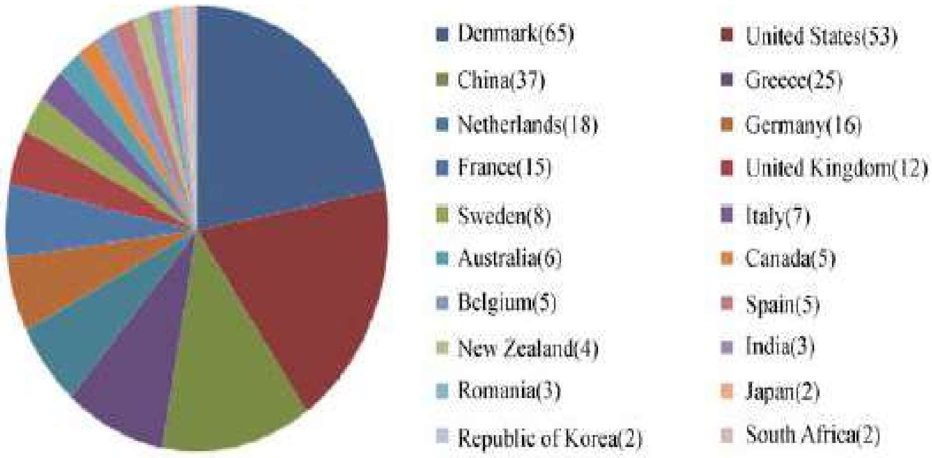

Figure 1.1. Distribution of Research papers on Aeroelasticity in different countries published in Engineering index.

Out of these various softwares available for aeroelastic simulations three of them are shortlisted for the final evaluation. FAST, BLADED and HAWC2 are analyzed in detail to choose the optimum software based on the following parameters.

- Validated software with extensive usage in research and Industry.
- Availability of the software.
- Availability of documentation and services.

- Ease to use.

FAST, BLADED and HAWC2 are analyzed in detail to choose the optimum analysis tool for our case.

5 Conclusions

The estimation of natural frequency of the system has been done with suitable linearisation of the whole system. The damping of the system has not been tuned to obtain the the damped frequency of the system. It is important to find the damped frequency and correspondonding mode shapes based on the need of the requirements of the study. The damping in the real structure can be far more different from the damping in the real case which depends upon the material , the material plane orientation, the friction acting between the layers etc. The more precise estimation of damping requires experience with usage of the material and suitable experimental case. Another way of addressing this problem is to estimate the required damping and give the design engineers the amount of damping corresponds to the particular mode shapes. Designers can achieve this value by tuned mass damper by distributing the mass accordingly or to choose fixation points which dissipate enough energy to insert sufficient damping.

Its very important to understand that how linearisation has been done in the design process. As we can see that the rotor blades are placed such that the first rotor blade is kept exactly vertical and the other two rotor blades at an angle of 120 degrees apart. This can be visualised in a clock as 0, 4 and 8 O'clock configurations. The mass of the rotor blades are distributed in this manner will be different when the rotor blades starts rotating. To taken this into account the eigen frequencies of the HAWT has been analysed by keeping the two rotor blades up and the third one, when we look in a clock its like, 2 O'clock, 6 O'clock and 10 O'clock.

This configuration is then analysed and it is found that the natural frequencies remains the same. The changes of the natural frequency in between these two configurations is given below. It has been found that the natural frequency of the structure has no change with respect to the different configurations depending upon how the rotor mass is being distributed at any instant of time. This can been interpreted from the fact that the mass of the rotor blades are very less compared to the mass of the big structural components like the tower or the hub mass.

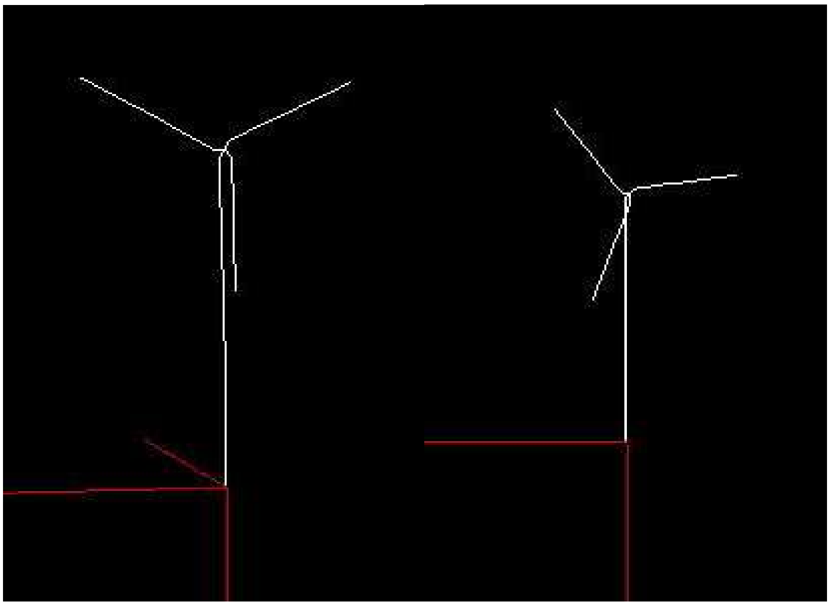

Figure 5.1. (a) 2 O'clock, 6 O'clock and 10 O'clock configuration (b)3O'clock, 7 O'clock and 11 O'clock configuratin

Mode shapes	**Natural frequency F_N (Hz) Default**	**Natural frequency F_N (Hz) Configuration 2**	**Natural frequency F_N (Hz) Configuration 3**
Mode nr: 1	1.29174E+00	1.29174E+00	1.29174E+00
Mode nr: 2	1.31710E+00	1.31710E+00	1.31710E+00
Mode nr: 3	2.02101E+00	2.02101E+00	2.02101E+00
Mode nr: 4	2.87379E+00	2.87379E+00	2.87379E+00
Mode nr: 5	2.99097E+00	2.99097E+00	2.99097E+00

6 Future works

The structural and aerodynamic modelling of the whole wind turbine is completed. The wind is modelled inside the turbulence box and the wind turbine is being positioned inside the turbulence box and has been simulated. It can be seen that at some instant of the simulation the simulation colapses due to the hitting of the rotor blades into the tower. This is due to the the lack of time in estimating the correct damping in the structure. As discussed before it is really hard to estimate the real damping in the structure due to its complex behaviour in the real structures compared to theoretical model. The major future works required are

- Estimation of real damping in the structures and implementing in the model.
- Tuning of damping for 3% logarithimic decrement between mode shapes as per RISOE DTU HAWC2 program developers method.
- Implementing Enbreeze pitch control mechanism DLL and connect it to the HAWC2 interface
- IEC simulations for certifications procedures.
- Modelling of Soil and foundation.

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