

# Site Specific Load Simulations Using HAWC2 and WAsP Engineering

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Wind turbines are normally categorised using the IEC classification of I, II or III with turbulence levels classified between A and C. This is a very practical way of categorising as it reduces the work of turbine approval. However, in some cases the site conditions are not fulfilled in all requirements for the classes which then require site-specific load simulations. One example could be high turbulence levels from a specific wind sector, significant wind shears, or turbulence effects from a neighbouring wind turbine. In these circumstances, the site requirements are not fulfilled, but the design loads on the turbine might still be unaffected, but however, have to be examined using an aeroelastic code.

An example of such a code is the HAWC2 code intended for calculating wind turbine response in time domain. The core of this code, which was developed mainly within the years 2003-2007, by the Aeroelastic Design Research Programme at Risø DTU in Denmark, has been used in numerous research projects and industrial applications. The code is now part of the commercially available codes from Risø DTU, which also include the software programmes WAsP and WAsP Engineering. WAsP is used for wind resource assessment, and WAsP Engineering is used for site-specific wind conditions, which can be used as input for HAWC2.

The HAWC2 code, which is state of the art within wind turbine simulations, has many significant features, particularly related to design and load simulation of large wind turbines in multi MW size. One example is the fully non-linear structural formulation based on the multibody formulation, which includes effects of large

deflections and rotations, and a new wake load simulation procedure known as the Dynamic Wake Meander (DWM) model, which enables highly detailed simulations of load and power production in wake situations. Furthermore, it is possible to couple external controllers through DLL interfaces, where the multibody approach enables a full coupling between, for example, pitch actions and inertial loads in the structure. Another DLL interface enables a full coupling to externally defined multibody systems. This could, for instance, be a dynamic model of a gearbox, a generator or even a connection to other programmes, such as a coupling to an external hydrodynamic code like WAMSIM from the Danish Hydraulic Institute (DHI).

A load basis consists of approximately 1,000 different simulations, covering normal production in different turbulence conditions, start-up and shutdown situations, fault situations and extreme wind loading in storm situations etc. In order to enable and keep an overview of these simulations, an Excel spreadsheet with built-in macro functions is combined with a tool for handling distributed computing on multiple computers. The WAsP Engineering software is used to obtain site specific input parameters for the different surrounding wind sectors.

## STRUCTURAL MODEL

The structural part of HAWC2 is based on a multibody formulation using the floating frame of reference approach. In this formulation, the wind turbine main structures are subdivided into a number of bodies where each body consists of an assembly of Timoshenko beam elements. Each body includes its own co-ordinate system, with

calculation of internal inertia loads when this co-ordinate system is moved in space, so that large rotation and translation of the body motion is accounted for. Inside a body, the formulation is linear, assuming small deflections and rotations. This means that a blade modelled as a single body will not include the same non-linear geometric effects related to large deflections as a blade divided into several bodies. The bodies representing the mechanical parts of the turbine are connected by joints, also referred to as constraints. The constraints are formulated as algebraic equations, which impose limitations of the bodies' motion. This formulation is fairly general, and could in principle just be a trajectory which the body needs to follow. So far the constraints implemented for turbine simulation are: fixed connection to a global point (e.g. tower bottom clamping), fixed coupling of relative motions (e.g. fixed pitch or yaw), frictionless bearings, and bearings with rotation angles controlled by the user. The code will account for inertial forces, also when rotations of bodies are externally specified.

External forces are in general placed on the structure in the deformed state, which is especially important for pitch loads and twist of the blades. Since large rotations are handled by a proper subdivision of bodies, the code is also particularly well suited for calculations on very flexible turbines subjected to, for instance, large blade deflections.

## AERODYNAMIC MODELS

The aerodynamic part of HAWC2 is based on the blade element momentum theory, although extended from the classic approach to handle dynamic inflow, dynamic stall, skew inflow, shear effects on the induction, and effects from large deflections. Large flapwise blade deflections will cause a change in the effective rotor diameter, and blade forces will no longer be perpendicular to the rotor plane. This reduces the thrust on the rotor and

thereby change the induced velocities and vice versa.

Two dynamic stall models have been implemented. The first one is generally known as the Øye model, which includes the effect of stall separation lag. The second model is a modified Beddoes-Leishmann model, which includes the effects of shed vorticity from the trailing edge (Theodorsen Theory), as well as the effects of stall separation lag caused by an instationary trailing edge separation point, influencing both lift, drag and pitch moment coefficients. These effects are especially important related to flutter analysis, but also generally to calculate loads and stability of blades with very low torsion stiffness.

## HYDRODYNAMIC MODELS

The hydrodynamic loads are based on the, within offshore technology, well-known Morrison's equation. The wave kinematics are not calculated within the HAWC2 code, but provided externally through a defined DLL (Dynamic Link Library) interface, where the present open source DLL includes regular and irregular airy waves. A second option, which is currently under development, is the possibility of coupling the HAWC2 code to WAMSIM from the Danish Hydraulic Institute. This is especially useful for floating structures where the Morrison's equation is no longer valid. This, however, is a special application, which can be performed by Risø DTU as consultancy work.

## WIND, TURBULENCE AND WAKE MODELS

The wind conditions are divided into deterministic and stochastic wind. The deterministic part of the wind includes mean wind velocity, sudden acceleration, linear trend, special gust events, and special shears. The user may prescribe wind shear and wind direction changes as a function of height. The stochastic wind, usually referred to as turbulence, is generated outside the HAWC2 code, using the Mann turbulence model.

Tower shadow effects are also a part of the wind module, as it changes the wind conditions locally near the tower. For upwind turbines, a potential flow method is used, whereas a jet-model produces much better results for downwind turbines.

Wake effects can be treated using the effective turbulence intensity method,

suggested in the optional Annex D of the IEC 61400-1 Ed. 3 standard, or a new, more accurate method. The new Dynamic Wake Meander (DWM) model is basically a calculation of a cascade of velocity deficits emitted from the upwind turbine, which is then transported downstream by the wind. During this transport, a meandering process of the wake position occurs caused by the large scale turbulence components of the surrounding turbulence field. The DWM method has successfully been verified against detailed CFD simulations and measurements on turbines operating in wake conditions and equipped with pitot tubes, lidars, and sensors for load and power measurements.

As a further supplement to built-in wind models, HAWC2 can work with wind and turbulence fields produced by external programmes such as WASP Engineering. This enables site-specific turbine simulations. Turbulence simulations in WASP Engineering are also done by the Mann method, although in this case using a target spectrum modified by terrain topography and upwind changes in surface roughness. With WASP Engineering, it is possible to export wind shear, veer and flow inclination in the file format accepted by HAWC2.

## CONNECTION TO TURBINE CONTROLLERS

Control of the turbine is performed through one or more DLL's. The format for these DLL's is very general, which means that any possible output sensor normally used for data file output can also be used as a sensor to the DLL. This allows the same DLL format to be used whether a control of a bearing angle, an external force or moment is submitted to the structure. The default controller supplied with code is an open source DLL including a pitch-regulated variable speed controller.

## SIMULATIONS SETUP

Once the turbine is defined with respect to structure, aerodynamics and control, the load case setup is handled using a spreadsheet with built-in macro functions, generating individual input files based on a master file. It is in this context that the interaction between HAWC2 and WASP Engineering occurs, since WASP Engineering will deliver the site-specific parameters for each surrounding wind sector, including weibull parameters used for post processing of fatigue loads in particular.

The calculation time is approximately a factor of 1-2 slower than real time on a 3GHz CPU, which is obtained using a Newmark beta solution scheme together with Newton-Raphson iterations within each time-step. The code is limited to Windows 32, primarily caused by its use of DLLs, although execution on Linux platforms works well using the WINE Windows Emulator. The source code is not public, but through the general DLL interface a lot of external coding can be performed by the user. These possibilities will be further expanded in the future. ■

## CONTACT INFORMATION

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