DIGITAL SOLUTIONS

BLADED

Engineering feature summary
1. Sesam HydroD has gained status as the market leader due to renowned efficiency and accuracy, based on decades of experience in the industry.

2. Sesam HydroD saves significant man-hours compared with previous data entry methods.

3. Sesam HydroD facilitates easy and efficient graphic modelling and verification of data.

4. Sesam HydroD is unique in its ability to offer a complete package including hydrostatic analysis, frequency domain, and structural dynamics.

5. The user interface is Windows-based and intuitive, allowing new users to learn the program quickly and efficiently from online user documentation and tutorials.

6. Compartment data may be changed easily to form several loading conditions in stability and hydrodynamic analyses.

7. It is fully integrated with finite element analysis.

8. The ability to make a sub-model and analyse it independently of the global model.

9. We are constantly developing and improving the software according to customer need.

10. DNV Software has offered this type of software to the market for more than 40 years, so users can rely on proven solutions.
DNV GL is a world-leading provider of digital solutions for managing risk and improving safety and asset performance for ships, pipelines, processing plants, offshore structures, electric grids, smart cities and more.

Our open industry platform Veracity, cyber security and software solutions support business-critical activities across many industries, including maritime, energy and healthcare.

Nearly 50 years of developing quality software
In providing your business with the best software solutions we are always striving to live up to our values: • We build trust and confidence • We never compromise on quality or integrity • We care for our customers and each other • We are committed to teamwork and innovation • We embrace change and deliver results
Bladed is the industry standard wind turbine aero-elastic design tool, providing a sophisticated numerical model of your wind turbine and its environment. Bladed’s engineering model capability has been developed for over 20 years and is continually enhanced to meet the needs of today’s wind turbine designers.

This brochure briefly describes the main technical features in Bladed to achieve an accurate model of onshore, offshore and floating wind turbines in their environment. The turbine model is described in terms of structural dynamics, aerodynamics, offshore modelling, control systems and electrical modelling. Environmental models are also discussed.
Bladed utilizes a completely self-consistent and rigorous multibody formulation of a wind turbine's structural dynamics. This provides consistently reliable and accurate results and forms a solid foundation from which to extend the structural model with many new features in the ongoing development programme.

**Multibody dynamics**

The Bladed structural dynamics code is based on a flexible multibody dynamics approach, similar to the approach defined by Shabana “[1]”.

The multibody system allows various flexible and rigid bodies to be connected in an arbitrary tree-like structure.

This flexible and powerful approach allows easy definition of many pre-defined turbine configurations in Bladed. The dynamic response of novel systems can be confidently predicted, as the behaviour of each component and the coupling between them is thoroughly validated.

**Modal analysis and Campbell diagram**

Bladed includes structural flexibility for wind turbines blades, support structure and drive train. Mode shapes and frequencies are calculated for each flexible body using the Craig-Bampton method “[2]”.

Modal analysis is always performed for the tower, whereas the blade can use vibration modes or direct integration of the finite element degrees of freedom. Modal reduction facilitates improved simulation speed without significant loss of accuracy.

The modes from each component are coupled through the multibody code. Bladed can calculate the coupled modes in the steady state for the whole structure. These coupled frequencies can be compared to the rotor rotational frequency in a Campbell diagram to check for possible resonance issues. This calculation also derives the coupled modes damping and the contributions of the blade and tower modes to each coupled mode.
**Non-linear blade dynamics**
Each flexible body in Bladed is a linear finite element body. Very flexible wind turbine blades can be split into multiple flexible bodies to achieve a geometrically non-linear model of blade deflection, as the outer blade parts can undergo large rotations relative to the blade root. This “multi-part” blade approach is key to analyse the stability and dynamic response of large modern wind turbine blades. In Bladed, the blade can be split into any number of bodies. The schematic below illustrates a 2-part blade. The model has been recently validated against full scale measurements from the GE 6MW Haliade turbine “[3]”

**Blade stability analysis**
Flexible modern wind turbine blades may be susceptible to instability at high rotor speeds. Bladed’s blade stability tool creates a linearized model at a large range of input conditions for a rotor in power production or parked configurations. During power production, the damping of the blade modes with increasing wind speed is evaluated, either at a fixed TSR or in a free-spin scenario. The rotor speed where the instability occurs and the vibration modes that contribute to the instability can be identified, providing key insight into the cause of the instability.

![Diagram of blade deflection and modes](image)
**Pitch and yaw actuator models**
Physical devices, such as pitch drives, are also modelled using Bladed’s multibody dynamics framework. Bladed comes pre-loaded with an array of detailed and versatile models of pitch and yaw actuation.

Pitch actuators can be modelled using a characteristic response time or by defining gains for implementing a torque feedback loop. Models are provided for linear or rotary actuators, and various other devices, such as limit switches and end stops.

Bladed also supports pitch actuator modelling through an external DLL interface, as part of the Advanced pitch actuator module.

**Drive train modelling**
Geared and direct drive turbines can be modelled as a 1 degree of freedom system. These can be enhanced by LSS and HSS flexibility as necessary and a slipping clutch, which is also directly included in the multibody structural dynamics framework.

For more detailed drive train modelling, Bladed can be coupled to an external drive train model via a DLL interface. This approach allows the complex behaviour of a detailed drive train model to be coupled to the dynamics of the rest of the turbine.

The DLL interface supports non-linear and time-varying, models and supports discontinuities, for example frictional stick-slip and backlash. The gearbox DLL interface can be activated with torsional degrees of freedom only or with a full 6 degrees of freedom giving a complete dynamic model.

The gearbox DLL functionality is available in the Bladed Advanced transmission interface module.
Offshore modelling

Bladed can model the offshore environment to design turbines to withstand the challenges of the harsh offshore environment.

**Integrated offshore analysis**
Arbitrary space frame structures like jackets can be modelled in Bladed using beam elements and flexible joints. Models can be built in the Bladed user interface or imported from third party offshore design tools, such as SESAM or SACS. Foundations can be modelled as linear springs or through non-linear P-Y curve definition.

Bladed can generate irregular airy waves, regular airy or stream function waves. Loads are applied to the model using Morison’s equation. Linear or non-linear extreme waves can be inserted into an irregular sea as a constrained wave.

Inclusion of the wind loads, turbine and jacket model and marine environment in the Bladed calculation allows for fully coupled aero-hyrodenso-elastic simulation. This integrated approach aids the overall optimization of the wind turbine and support structure design. The cost reduction benefits of this approach were explored in DNV GL’s Project FORCE innovation report. For further information, please read about the Bladed Offshore support structure module.

**Superelement analysis**
Instead of defining the jacket structure in Bladed, it is also possible to import a jacket superelement derived from an offshore support structure code, such as DNV GL’s SESAM tool. In this case, the modal mass and stiffness matrices of the jacket, along with the wave loads, are imported into Bladed and included in the simulation.

Although the hydro-elastic coupling is excluded, this approach provides an accurate structural response and avoids the need for jacket details to be shared between the foundation designer and the turbine designer or to redefine the jacket and marine environment in Bladed.
Floating turbines
Bladed can model floating wind turbines using a variety of mooring line and hydrodynamic models.

Bladed dynamic mooring line model includes moorings in the multibody system by connecting several bar components together with universal joints to form a chain. This allows the mooring dynamics to be fully coupled to the rest of the turbine structure. The mooring lines also attract hydrodynamic loads through Morison’s equation.

To enable faster simulation, simple lookup moorings can be included through the addition of point masses and applied loads. Lookup tables of applied stiffness and damping forces can be pre-calculated for catenary and tension leg moorings.

Advanced hydrodynamics
Structures with very large members may require wave diffraction and radiation to be considered, using a boundary element method to calculate hydrodynamic loads. Large structures’ hydrodynamic properties can be imported from a third party panel method code, such as WAMIT, AQWA or WADAM and then imported into Bladed for use in the simulation. This functionality is included in the Advanced hydrodynamics module.
Aerodynamics

Bladed uses a modern and rigorous blade element momentum (BEM) implementation which includes best practice aerodynamic models. The fundamental BEM theory is extended to deal with complex unsteady flow conditions by the following models.

**Tip and root loss**
The model includes Prandtl’s tip and root loss corrections, to account for the effect of the blade tip vortices on induced velocity. This model corrects the BEM assumption of an infinite number of blades, allowing the induction to vary around the rotor azimuth. The correction is based on modelling the wake as helicoidal vortex sheets.

**Dynamic wake models**
When inflow conditions change, there is a delay in reaching the new equilibrium condition. Dynamic wake models from Øye and Pitt & Peters model the lagged effect of trailing vorticity on the induced flow. The Øye model is the recommended model, including a larger time for induction lag.

**Glauert skew wake model**
Glauert’s skew wake correction extends the BEM theory to incude effects from non-zero yaw angels. The model improves the accuracy of yaw moment predictions by better capturing the angle of attack variations in cases of high yaw error.
Dynamic stall
Dynamic stall models extend the BEM model to more accurately predict aerofoil lift and drag with varying inflow. In attached flow, the dynamic stall models introduce hysteresis to the lift and drag predictions. At high angles of attack, the dynamic stall models can account for leading edge and trailing edge separation.

Three models of dynamic stall are included in Bladed:
- Compressible Beddoes-Leishman
- Incompressible Beddoes-Leishman
- Øye dynamic stall

Ailerons
The effect of ailerons can also be included by interpolation between sets of aerofoil lift and drag curves.
Environmental models

Bladed includes in-built models of the key environmental phenomena to enable safe design of onshore and offshore wind turbines, including the effect of extreme events like earthquakes and typhoons.

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**Wind models**
Bladed’s wind models include various steady and dynamic models necessary to cover all the required load cases.

The deterministic wind components in Bladed include:

- Wind shear following a power law, exponential or user-defined profile
- Wind direction veer with user-defined profile
- Wind speed and direction transients following the standard IEC profiles
- Wake deficit distribution from upstream turbines
- Tower shadow models for upwind and downwind configurations
Turbulent wind files can be generated in Bladed according to the following spectral formulations:

- Kaimal
- von Karman
- Mann

The wind speed at hub height can be matched to measured anemometer values in validation studies. When conducting LiDAR simulations, two wind files can be used together to allow the wind field to evolve in a realistic manner.

As an alternative to the inbuilt wind models users can substitute the wind field created by Bladed with their own dynamic link library (DLL). The DLL should return a wind velocity vector at any requested time and location in three-dimensional global space.
Bladed includes models for regular and irregular wave states, and sea currents.

Regular waves follow linear airy or stream function models, with the stream function order automatically determined.

Irregular wave states comprise of linear airy waves, according to JONSWAP, Pierson Moskowitz or a user-defined spectrum. Constrained linear of stream function waves can be included within the irregular sea state.

By applying Bladed’s external SEA file definition, users can use their own tools to create any sea states comprised of linear wave components and can include directional spreading.

Wave loads are typically applied to the structure through Morison’s equation. A MacCamy-Fuchs correction is used to approximate diffraction effects for large members.

Morison’s equation may not be appropriate for structures with very large members. Wave diffraction and radiation become important and the boundary element method can be used to calculate hydrodynamic loads. A mesh of the structure is used to determine hydrodynamic properties using an external code, such as WAMIT, AQWA or WADAM. This can then be imported to Bladed for use in the simulation. This functionality is included in the Advanced hydrodynamics module.
Earthquakes
For turbines in seismic areas, coupled aero-elastic analysis during earthquakes is required by design standards to accurately determine the effect on turbine loads.

Bladed can generate earthquake acceleration time histories based on a target spectrum. The acceleration time history is shaped according to an appropriate shape function. Alternatively, recorded ground acceleration time histories can be used.

Bladed supports a full 6 degree of freedom time history (3 translational and 3 rotational DoFs) allowing maximum fidelity to investigate realistic earthquake conditions.

This functionality is available through the Bladed Seismic module.
Control systems

Bladed helps you to design controllers, use them in Bladed and evaluate the impact on loading and power production.

**Internal and external controllers**
Bladed provides an in-built controller with basic PI generator torque, blade pitch control and drive train damping feedback. Such controllers are useful for simple initial calculations.

For more advanced control features for turbine design, Bladed enables you to define your own external controller in a DLL (dynamic-linked library). Bladed provides a modern, function based controller API (Application Programming Interface) to allow robust and extendible communication between Bladed and an external controller DLL. External controllers are in discrete time, meaning that they communicate with Bladed on a fixed time step, just like controllers on an actual turbine.

**LiDAR control**
LiDAR is a laser Doppler anemometer technology that can be used to estimate upstream flow speeds.

Bladed allows a LiDAR device to be defined with multiple beams which take velocity measurements at intervals and pass the data to the external controllers. There are options for blade, hub or nacelle mounted LiDAR and for different scanning patterns.

During LiDAR simulations, two wind files can be used together to allow the wind field to evolve in a realistic manner.

The LiDAR functionality is available in the Bladed Control module.

**Linearisation**
Bladed can create a linearised version of the wind turbine aero-elastic model by perturbing the states and environmental inputs.

These linearised models are extremely valuable for linear control design for the complex wind turbine system with coupled structural and environmental dynamics.

The linearised models are given in state-space form, both as text and directly in Matlab format, ready for use by the Matlab Control toolbox as used by many control engineers. This functionality is available in the Bladed Control module.
Electrical modelling

Typically simple generator models are sufficient to determine most component turbine loads. Bladed provides simple models of generator torque for load calculation, as well as more detailed models to analyse electrical component and grid interaction in details.

Simple electrical models
Bladed has three simple in-built generator models to model the generator air-gap torque:

- Fixed speed induction generator
- Variable slip generator
- Variable speed generator

Simple time lags can be included to approximate the generator dynamics. Such simplified models of the electrical system are generally suitable for turbine load calculations.

Grid loss can be simulated, as well as a generator short circuit, which is simulated by applying a known generator torque time history. Low voltage ride through can be modelled including a simple model of a breaking resistor.

References

About DNV GL

DNV GL is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. Operating in more than 100 countries, our professionals are dedicated to helping customers in the maritime, oil & gas, power and renewables and other industries to make the world safer, smarter and greener.

Digital Solutions

DNV GL is a world-leading provider of digital solutions for managing risk and improving safety and asset performance for ships, pipelines, processing plants, offshore structures, electric grids, smart cities and more. Our open industry platform Veracity, cyber security and software solutions support business-critical activities across many industries, including maritime, energy and healthcare.