

Load Calculations for Wind Turbines

SIMPACK scripts are now available for easily defining, running and analyzing the thousands of load cases required for proper dimensioning of components and fulfilling certification requirements for wind turbines. The load calculation process can be used with any SIMPACK wind turbine model, i.e., from simple models used for initial concept studies and certification purposes to detailed models used for component analysis, optimization and extreme event investigations. Because these scripts are freely available to all customers and are fully documented, users can easily further extend the existing functionality to include any company specific enhancements and/or future requirements.

HISTORY OF SIMPACK IN THE WIND INDUSTRY

Initially used as a high-end tool for investigating potential resonances and maximum loading of individual components, such as within gearboxes, SIMPACK has seen its way from being a simulation tool used in a reserved area of analyses, to becoming software applicable to all aspects of wind turbine simulation.

Over the years, many new features have been developed to assist users in generating and investigating wind turbine behavior. For example, the Rotorblade Generator module used for easily creating flexible blades out of standard cross-sectional blade data; interfaces to state-of-the-art aerodynamic codes; and interfaces to standard wind turbine controllers (to name just a few). Added to this, the SIMPACK solver technology, world

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renowned for speed, accuracy and stability, along with countless other features, such as the Gear Pair module, initially developed for Formula 1 engine simulations, and interfaces to Simulink, SIMPACK has now gained a significant presence within the wind turbine sector. More recently, several wind turbine companies have invested significant effort to develop their own in-house solutions for carrying out and processing multiple parallel load calculations with SIMPACK. After initial calculations, component models can then be easily exchanged with higher fidelity models for more specific analyses (Fig. 2). In order to assist companies in setting up these standard processes, fully documented SIMPACK scripts have now been developed and are available for any SIMPACK user. These scripts represent another major milestone

in the history of SIMPACK wind turbine simulation.

PROCESS REQUIREMENTS

Resulting from collaboration with commercial partners within the wind sector, the SIMPACK scripts build upon years of experience gained from company specific in-house software solutions for load calculations. The main objectives of the load calculation scripts can be summed up as follows:

- An intuitive window based GUI (Graphical User Interface) for entering simulation runs
- Use with any SIMPACK wind turbine model, including any level of model detail
- Easy entry of load cases with automatic generation of wind fields
- Additional ability to vary model specific parameters
- Automatic job allocation on multiple processors
- Easy review of results for plausibility
- Fast and parallel statistical analysis
- Saving and retrieval of simulated models, load configurations and results
- Open QSA (Qt Script for Applications) scripts for user specific enhancements

The final requirement was of particular importance to our partners. Open scripts can be enhanced to fulfill any company specific requirements, or even future requirements, thus ensuring the longevity of the loads process.

LOADS PROCESS: PRE, SOLVING, POST

Once the Load Calculation Script has been started, the loads process is as follows:

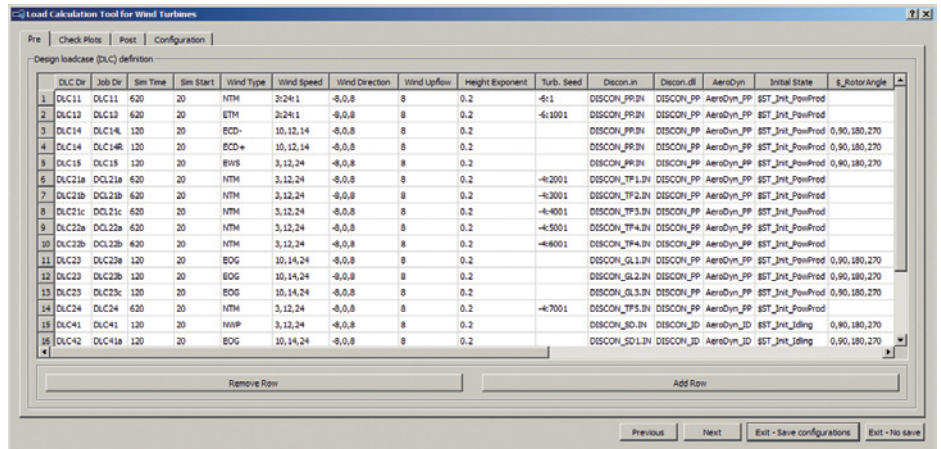


Fig. 1: Load case definition window

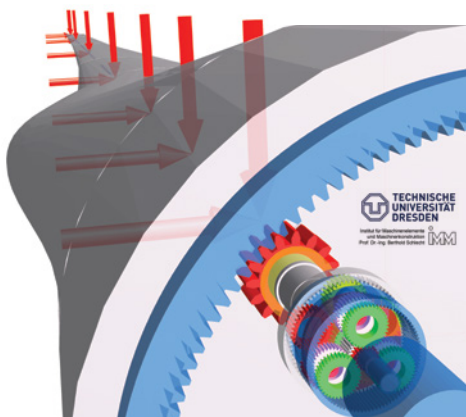
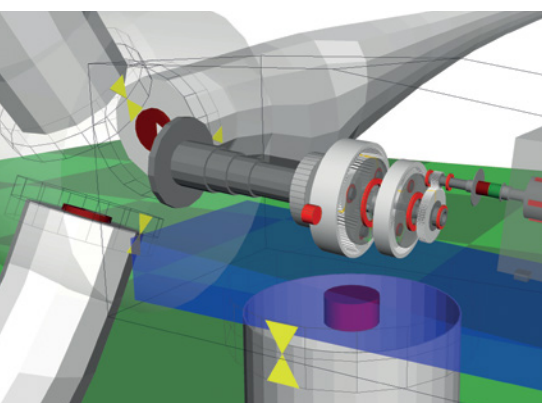


Fig. 2: Example of wind turbine models with different component models

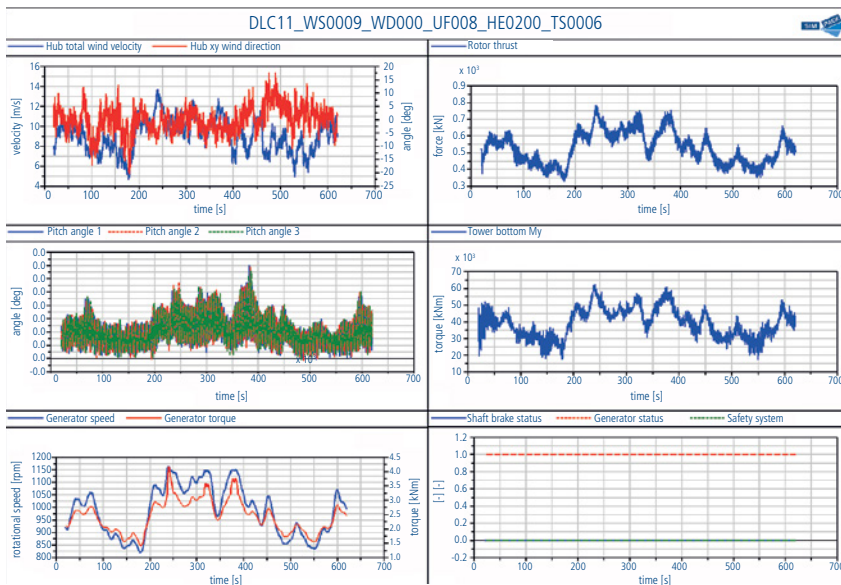


Fig. 3: Check Plot

1. Loads simulation folder

A folder is chosen in which all models, time domain results and statistical analyses will be stored.

2. Simulation Model

A selected simulation model is copied to the loads simulation folder. This model is then used as the basis model for all following simulations.

3. Check Plot configuration

A user predefined SIMPACK Plot File (spf) is selected in which important characteristic simulation results have been plotted, e.g., wind speed and direction, generator power, hub and tower loads, pitch angle, etc. After each simulation, this file is used as a template for creating the check plots, in png format, for easy review (Fig. 3).

4. Execution of the initialization runs

Initial conditions are generated for each simulation. This minimizes initial transients which require simulation time to settle down (Fig. 4). State Sets, which include all model states, e.g., pitch angles, rotor speed, bending of blades and tower, are generated for each wind speed and wind direction. Each defined simulation run uses the corresponding State Set for the model's initial condition.

5. DLC Definition

Generation of all variations (Fig. 1) required for each Design Load Case (DLC). The entered variations include:

- Simulation parameters (directory, DLC name, simulation time, etc.)

- Wind conditions (mean speed, direction, type, turbulence seed)
- Controller configuration
- Aerodynamic configuration
- User defined parameters

6. Wind field generation

All required wind fields for the defined DLCs are automatically generated using TurbSim for turbulent wind fields, and IECWind for transient wind fields.

7. Simulation

The user can set the number of CPU cores to be used. Job allocation is automatic. A Check Plot is generated as soon as an individual job is complete.

8. Statistical analysis

Once the simulation jobs are complete, several statistical analyses can be executed. Lists of result files are defined by the user and then allocated to a particular analysis method. Safety and Weibull distribution factors are entered for extreme predictions and fatigue analysis. The individual output channels of the result file are predefined within SIMPACK Post.

Several scripts are available for the statistical analysis:

- Ultimate loads (Fig. 5)
- Generation of input data, power production time series, for load extrapolation tools

- Rainflow count algorithm; calculation and output of Markov-Matrices, Load Spectrum and Damage Equivalent Load (DEL) calculation (Fig. 6)
- Load Duration Distribution (LDD); calculation of the Load Spectrum with multi-dimensional output, up to five channels
- Load Revolution Distribution (LRD)
- ASCII export of time series (e.g., for use with fatigue tools)

9. Saving and selecting of load configurations

All GUI entries are stored within text based ASCII files. These files can be loaded and used as a basis for defining further configurations. Since the files are text based, the load process can also be run as a batch process from the command line.

MODEL DESCRIPTION

An example wind turbine model is available with the scripts (Fig. 7). This model is comparable in detail to the NREL 5 MW model. In addition to demonstrating the Loads Calculation process within SIMPACK, this model serves as a good starting point for wind turbine dynamists new to SIMPACK. The model consists of several submodels (foundation, tower, nacelle and rotor). The rotor is further broken down into submodels of the hub and blades. All submodels are fully parameterized and can also be easily exchanged with corresponding models in order to vary the level of detail. The tower is a parameterized SIMBEAM model, and the rotor blades have been generated using the SIMPACK Rotorblade Generator. Aerodynamics are integrated using AeroDyn v13. A DLL (Dynamic Link Library), which complies

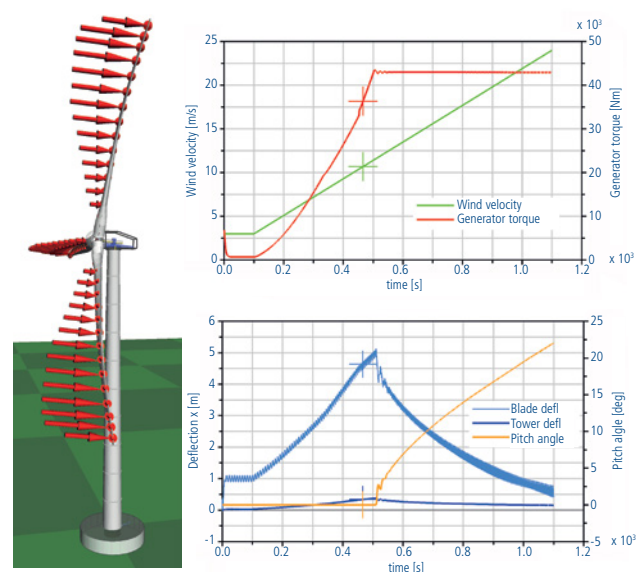


Fig. 4: Initialization run

Hub flange rotating		HF_Fx	HF_Fy	HF_Fz	HF_Fxyz	HF_Mx	HF_My	HF_Mz	HF_Mxyz	
max/min DLC	SF	[kN]	[kN]	[kN]	[kN]	[kNm]	[kNm]	[kNm]	[kNm]	
max	DLC14L_WS0010_WD0008_RA0180	1.35	1408.4	1441.7	-380.7	2051.1	5920.9	-4063.2	2705.8	7673.8
min	DLC61_WS0040_WD-008_TS0100	1.35	22.6	103.3	947.5	953.3	-104.8	1806.5	-2233.2	2874.3
max	DLC11_WS0012_WD0000_TS0007	1.35	964.3	1554.1	45.6	1829.5	5774.0	-3593.9	5304.5	8625.2
min	DLC11_WS0012_WD0000_TS0008	1.35	1068.6	-1540.2	-2.8	1874.6	5773.2	268.0	-2229.5	6194.6
max	DLC11_WS0012_WD0000_TS0007	1.35	929.5	16.9	1554.4	1811.2	5424.3	-2546.3	-5525.2	8150.7
min	DLC11_WS0015_WD0000_TS0009	1.35	807.1	14.5	-1555.6	1752.6	5716.3	6354.5	5187.2	9998.1
max	DLC14L_WS0010_WD0008_RA0180	1.35	1408.4	1441.7	-380.7	2051.1	5920.9	-4063.2	2705.8	7673.8
min	DLC61_WS0040_WD0000_TS0102	1.35	117.4	755.7	192.8	788.7	-69.5	-3063.3	1003.9	3224.4
max	DLC11_WS0024_WD0000_TS0016	1.35	530.6	-1335.1	466.1	1510.4	7334.0	-2266.1	-2902.9	8206.6
min	DLC61_WS0040_WD0008_TS0105	1.35	179.4	369.1	1040.8	1118.8	-1272.3	-1420.2	752.1	2049.7
max	DLC11_WS0024_WD0000_TS0016	1.35	297.7	933.7	-845.9	1294.6	4934.7	13992.9	388.7	14842.6
min	DLC14R_WS0014_WD-008_RA0000	1.35	116.1	609.3	1296.0	1436.8	4718.5	-14277.2	452.3	15043.5
max	DLC11_WS0024_WD0000_TS0016	1.35	275.6	508.9	1223.0	1353.0	5339.4	-6106.4	12591.3	14977.9
min	DLC14R_WS0014_WD-008_RA0000	1.35	136.5	-1423.7	165.9	1439.8	4518.0	4286.0	-12365.9	13845.5
max	DLC14R_WS0014_WD-008_RA0000	1.35	116.1	609.3	1296.0	1436.8	4718.5	-14277.2	452.3	15043.5
min	DLC61_WS0040_WD0008_TS0105	1.35	145.1	422.7	1176.2	1258.3	-9.3	5.2	21.0	23.5

Fig. 5: Ultimate loads

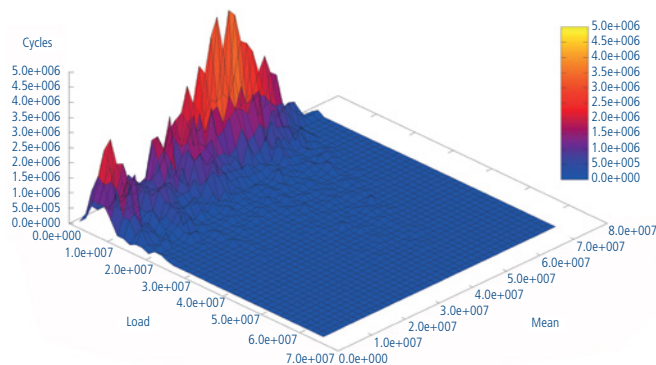


Fig. 6: Markov results

with the Garrad Hassan standard, is used for the control.

PACKAGE DESCRIPTION

Included within the SIMPACK documentation, 9.6 and above, is the demonstration wind turbine model, load calculation scripts and documentation. The scripts consist of solver scripts for the load calculation process and Post scripts for the statistical analysis. The scripts have been created using a modular structure with an individual script for each statistical analysis. The scripts are also internally commented in order to assist users wishing to extend their functionality. The documentation contains a step-by-step guide on how to set-up, configure and run load calculations; and how to carry out statistical analyses with the scripts.

FURTHER POSSIBILITIES

Detailed models of drivetrains, pitch and yaw systems are easily substituted for the available submodels. Detailed FE (Finite Element) models of gearbox housings, planet carriers, bedplates, etc., may also be used. Advanced rotorblades containing coupled twist/bend terms are easily generated and implemented within the model. Component foundation models for on- and off-shore wind turbines can also be included. In essence, any SIMPACK wind turbine model, regardless of the level of detail, can be used with the load calculation scripts. Since simulation time depends upon the detail contained within the model, users may easily generate model variants which fit the requirements of a particular analysis and have optimal simulation times. The DLC (Design Load Case) examples do not cover all requirements within the current guidelines but, with the included parameter variation functionality, all necessary load cases can be readily configured.

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The available script for statistical analysis provides a solid basis for generating all design relevant loads. All scripts, including those for statistical analysis, can be easily enhanced to fit within any design process. In order to enable user specific interfaces and/or user routines to comply with the load calculation process, some scripts may need to be adapted.

LICENSING

For the design and certification of wind turbines, often several thousand simulation runs are required. Computers with many multi-core processors are commonly used within the wind industry in order to speed-up these load calculations. A specific SIMPACK solver license package is available which enables multiple solver jobs to be carried out simultaneously. This package is only available for simulating load calculations of wind turbines and some restrictions do apply. More information about this solver package may be acquired from your local SIMPACK distributor.

CONCLUSION

Fully documented and commented scripts are now available for carrying out load calculations with SIMPACK wind turbine models. These scripts can essentially be used with any wind turbine model, regardless of the level of modeling detail, for any load case. All SIMPACK users have access to these scripts which can be readily enhanced to suite any company specific process. A specific solver license package enables multiple simultaneous job runs. With the addition of Load Calculation functionality within SIMPACK, wind turbine users can now readily carry out analyses of initial concept designs through to detailed component investigations of final designs all within one software tool, and all with one database of interchangeable components.

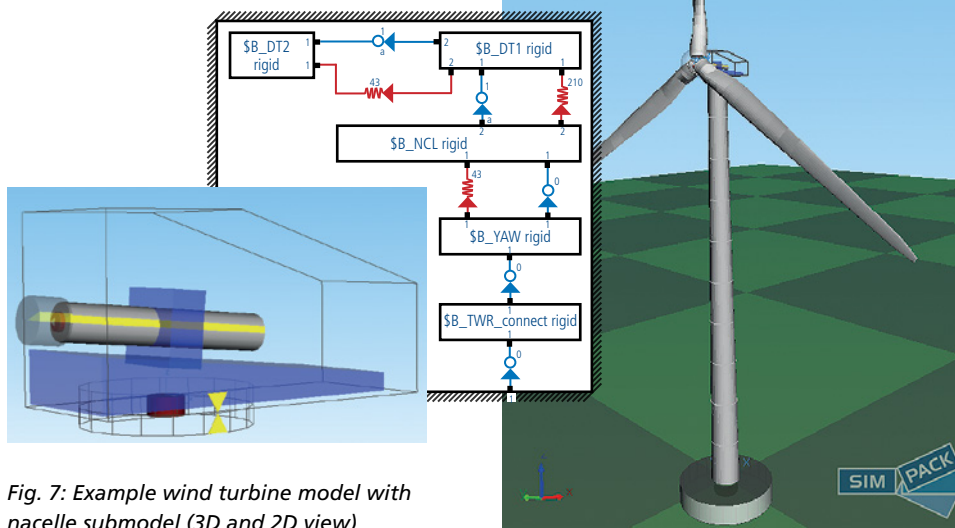


Fig. 7: Example wind turbine model with nacelle submodel (3D and 2D view)