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 load process.

LOADS PROCESS: PRE, SOLVING, POST
Once the Load Calculation Script has been started, the loads process is as follows:

1. **Preparation Phase**
   - The user specifies the model parameters, including material properties, geometrical dimensions, and load cases.

2. **Solution Phase**
   - The Load Calculator Script processes the model and generates load cases.
   - The calculation is performed in parallel using multiple processors to optimize the speed.

3. **Post-Processing Phase**
   - The results are reviewed and saved in formats like txt, xml, or csv.
   - The user can further extend the functionality of the resulting models with company specific enhancements.

**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 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, **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 aeroelastic codes; and interfaces to standard wind turbine controllers (to name just a few). Added to this, the **SIMPACK** solver technology, world-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 load cases
- Saving and retrieval of simulated models, fast and parallel statistical analysis
- Easy review of results for plausibility
- Automatic job allocation on multiple processors
- Users can easily further extend the existing functionality to include any company specific enhancements...

**BIBLIOGRAPHY**


**SUMMARY AND VIEW**

The simulation of the cyclic leg movement while cycling, based on EMG-measured muscle activation patterns, shows a correspondence with the collected data. In the first approximation, it can be proved that the model is valid. But it is obvious that modification and fine tuning of the muscle activation routines is necessary. To further fine tune the model, it may be necessary to pay attention to the smaller muscles of the leg. Specifically it can be assumed that implementation of a feedback loop for muscle stimulation control might enhance the quality of the results. The generated model together with the **SIMPACK** model is a good basis for expanding and modification of the existing model, to possibly create more realistic results in future simulations.

**Fig. 1: Load case definition window**

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

**Fig. 3: Muscle activation patterns measured with EMG**

**Fig. 4: Crank velocity of an average cycle in measurement (top) and results of simulations with different crank reaction torques**

**Fig. 6: Muscle activation patterns of pedaling measured with EMG**

Looking at the animation or the joint angle velocities of the human body model revealed that the approach to activate the muscles by measured data is not sufficient to get a smooth and effective pedaling motion. This is based on the fact that our model contains only feed forward control so far. The lack of feedback partially leads to suboptimal stimulation timing. But the results of this study are very promising, and the model will be extended with a closed loop control for muscle stimulation.
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 folder where all models, time domain results and statistical analyses will be stored.

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 conditions.

5. DLC Definition

Generation of all variations (Fig. 1) is 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 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 multidimensional 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 GUL 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 dynamics 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 with the Garelh 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 with extending 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 drive trains, pitch and yaw systems are easily substituted for the simulation calculations; and how to carry out statistical analyses with the scripts.

**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 jobs run.

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. 3: Check Plot**

**Fig. 4: Initialization run**

**Fig. 5: Ultimate loads**

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 users specific interfaces and/or user interfaces to comply with the load calculation process, some scripts may need to be adapted.

**Fig. 6: Markov results**

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

---

**Steve Mubske, SIMPACK AG; Jochen Harms, els|sim|engineering**