PLECS

DEMO MODEL

Windpower System with Permanent Magnet Synchronous Generator

Last updated in PLECS 4.7.1

1 Overview

This demonstration shows a 2 MW wind power system with a permanent-magnet synchronous generator (PMSG). The PLECS thermal and mechanical physical domains are also integrated into the model. A schematic of the system overview is given in Fig. 1. Two scenarios can be investigated with the model, which can be configured in the initialization commands.

- Short simulation with switched power electronic model, to observe the interaction between the electrical circuit and the mechanical drivetrain during normal operation, including fault conditions and thermal behavior.
- Long simulation with fast averaged power electronic model, to observe maximum power pint tracking (MPPT) at a variation of wind speed.

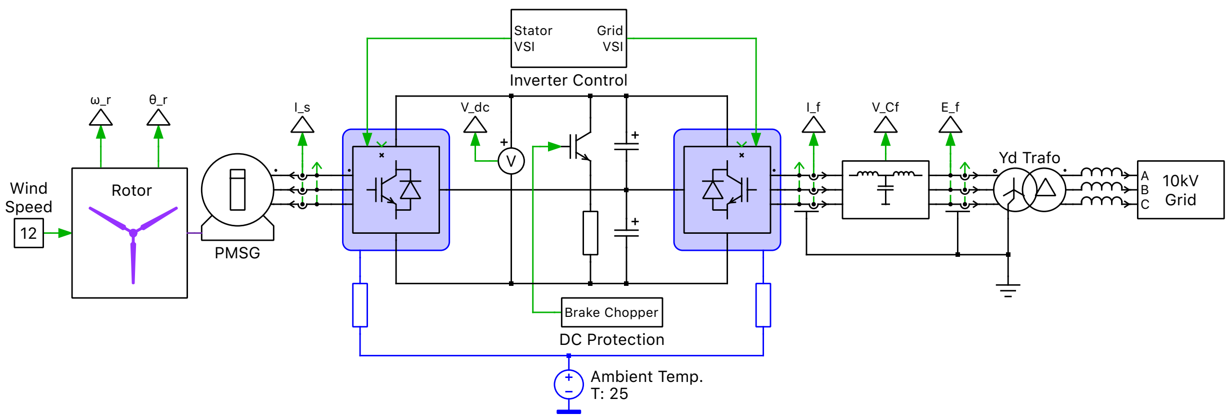

Figure 1: System overview

Note This model contains model initialization commands that are accessible from:
PLECS Standalone: The menu **Simulation + Simulation Parameters... + Initializations**
PLECS Blockset: Right click in the **Simulink model window + Model Properties + Callbacks + InitFcn***

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2 Model

2.1 Power circuit

The electrical power circuit includes a PMSG with pole pair number of 30. The stator is directly connected to a three-level neutral-point clamped (NPC) back-to-back converter, with the detailed NPC converter model shown in Fig. 2. The grid-side of the converter is connected to a step-up star-delta transformer, which feeds the generated power into the 10 kV medium voltage network.

2.2 Mechanical Drivetrain

The machine's rotor is directly connected to the hub and blades of the propeller without a gearbox, which together make up the mechanical part of the wind turbine, as shown in Fig. 3. They are coupled elastically with each other, which introduces resonant oscillations into the system.

The value of the wind torque applied on the turbine blades comes from a look-up table, where the value varies with the wind and shaft rotation speeds.

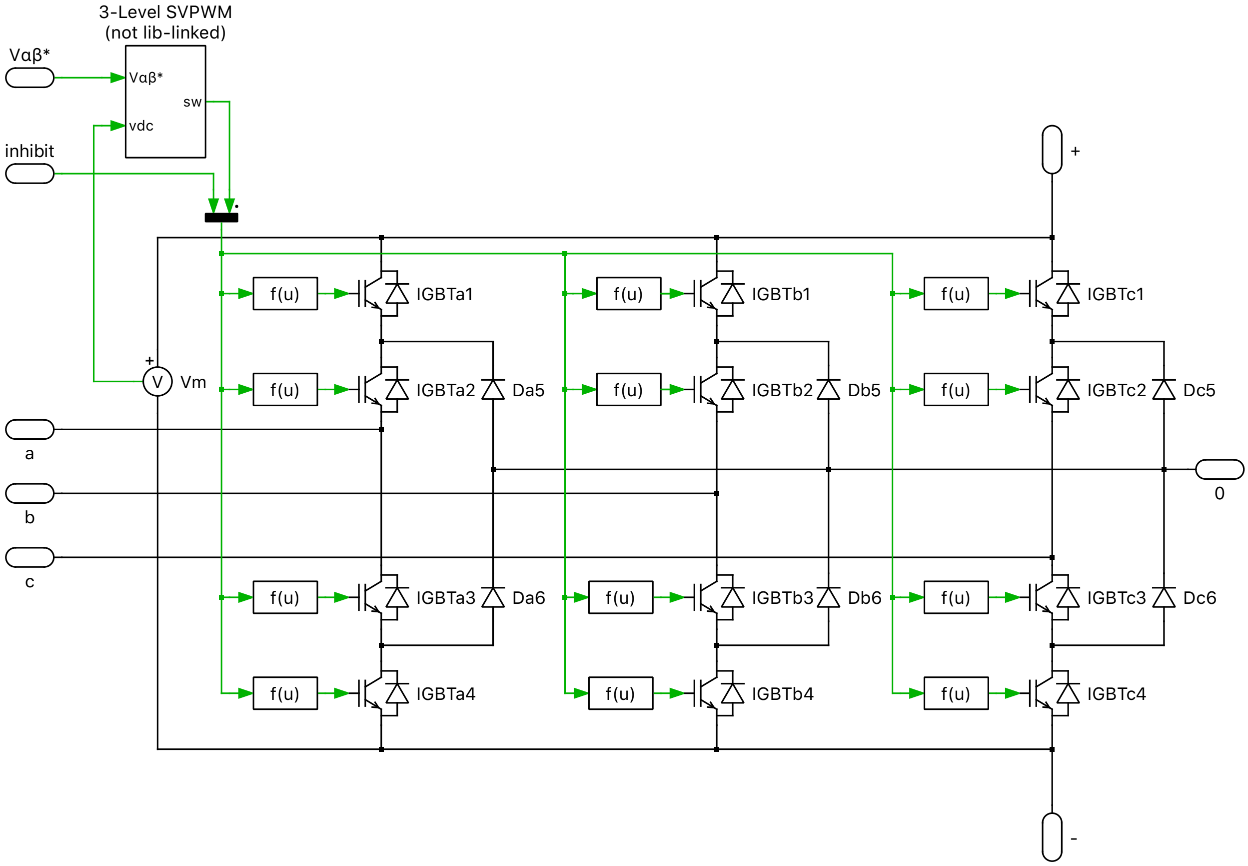

Figure 2: Three-level NPC converter overview including the space-vector PWM block

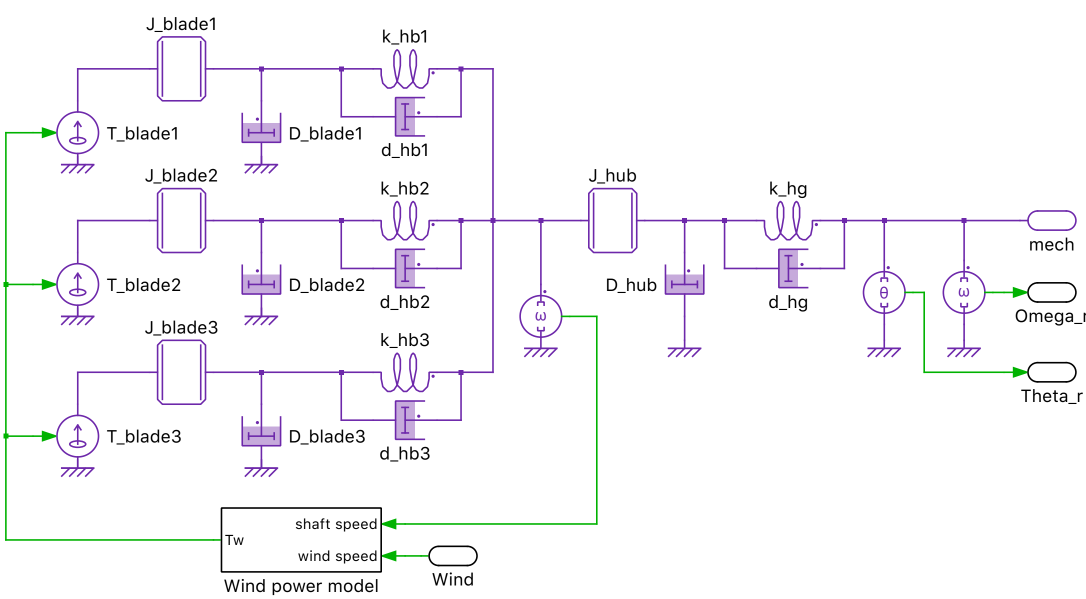

Figure 3: Mechanical shaft model of the wind turbine including the wind/shaft speed to torque conversion

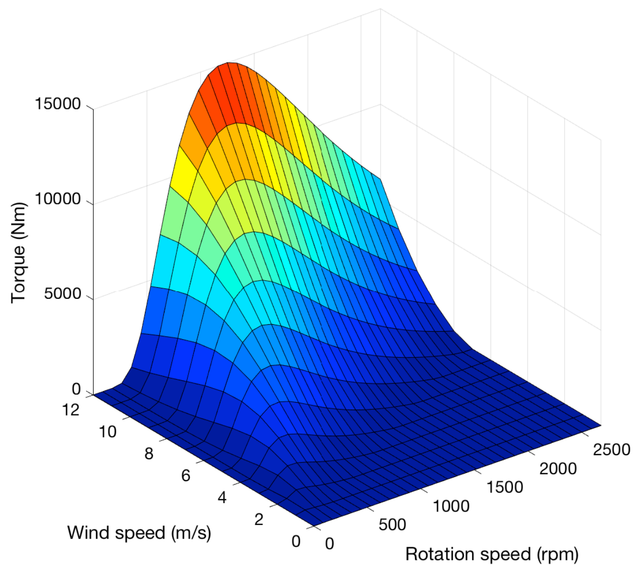

Figure 4: Wind turbine dynamics modeled as a torque surface

2.3 Control

The back-to-back converter comprises separate machine-side and grid-side portions, which are connected with each other via two DC-link capacitors with a mid-point connection. The machine-side converter regulates the torque of the PMSG and the rotational speed with a double loop structure, where the outer speed loop generates the reference signal for the inner current loop, as shown in Fig. 5. The current control is carried out in a rotating reference frame (dq) with stator flux orientation. The grid-side converter transfers the active power from the machine-side converter into the grid through an LCL filter, and maintains the DC-link voltage at 1500 V. The methods of active damping, feed forward and integrator anti-windup are adopted for the PI controllers.

The converters operate using 3-level space-vector pulse-width modulation (SVPWM). Note that the 3-Level SVPWM block used in this demo is a non-library-linked component. It features an extra `Alternating zero vector` modulation strategy apart from the `Symmetrical` option. In `Alternating zero vector` method, the zero vector is alternated in each switching sector to minimize the number of switching transitions thus lower switching losses, but results in higher THD content in modulated voltages. On the other side, for `Symmetrical` modulation both zero vectors are applied during a single switching sequence — one is split into both the start and the end of the switching cycle and the other is applied at the middle of the switching cycle. This method results in higher switching losses but lower THD.

MPPT-Algorithm

In this demo model a basic perturbation and observation (P&O) was implemented. In the P&O method, the rotor speed is perturbed by a small step, then the power output is observed to adjust the next perturbation on the rotor speed. The algorithm is implemented with the PLECS State Machine block, as shown in Fig. 6. According to the wind turbine dynamics from Fig. 4 and the power generated from this, the algorithm finds the maximum power point at the given step wind speed, see more in the Simulation section. The P&O method tracks the systems maximum power point under normal circumstances. However this MPPT method without additional functionality, is not capable for heavy disturbances such as sudden wind speed changes like wind gusts but more for slow changes over a longer time horizon. [1]

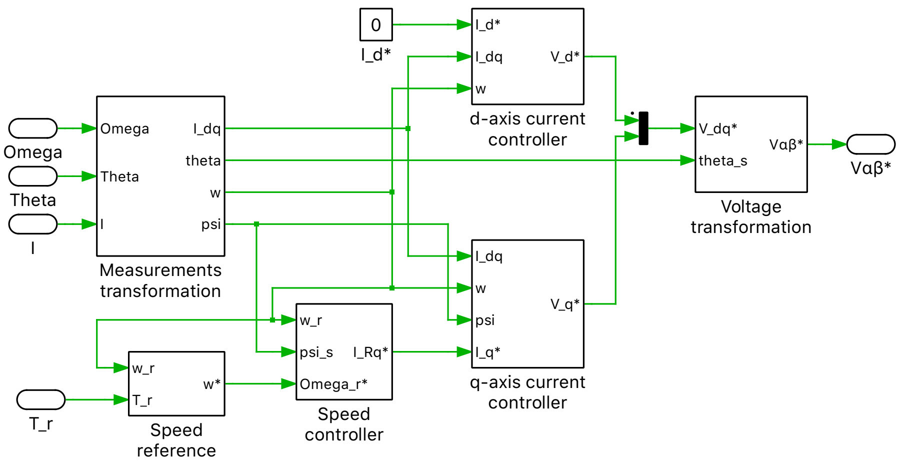

Figure 5: Cascaded speed/current control for one of the back-to-back NPC converters

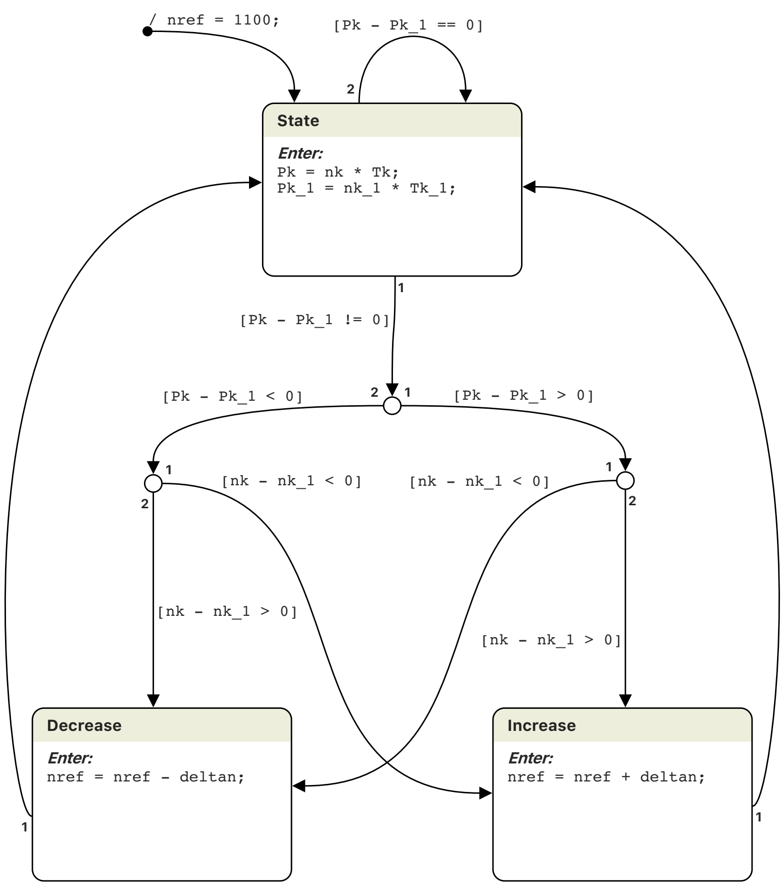

Figure 6: P&O MPPT-Algorithm implemented with the PLECS State Machine

2.4 Thermal

The converter model can be simulated in either an `Averaged model` or a `Switched model with thermal` configuration. With the averaged converter model there is no loss analysis implemented as the information about switching losses is missing. In the switched model the conduction losses and switching losses of the IGBTs, as well as the effect of the cooling system, can be investigated. Thermal models for the 5SNA 3600E170300 and 5SLA3600E170300 IGBT and anti parallel diode packages are used for the machine-side and grid-side converters, respectively. Included with the look-up tables for power losses is the thermal impedance chain information from the device junction to the case, which was also supplied by the data sheets. These descriptions can be viewed and edited by double-clicking on the converter component symbol and selecting **Edit...** from the drop-down menu of the **Thermal description** parameter. The thermal descriptions for the IGBTs are stored in the directory `wind_power_system_pmsg_plecs` that is packaged with this demo model.

The “Switch Loss Calculator” component is placed within the "Switched model with thermal" subsystem of the inverter models to easily calculate the total losses. For more details, browse the **Help** section of this block.

For more information on thermal modeling and the calculation of device losses and efficiency, see the demo model “Buck Converter with Thermal Model” in the PLECS demo models library.

Note Thermal simulation results are only available in this demo model if the switched configuration is used inside the initialization commands.

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3 Simulation

3.1 Grid fault condition

The simulation shows a complete system operation under a grid fault condition. There are several events:

- As the simulation starts up the PMSG operates at synchronous speed.
- Shortly after the system enters the new balanced state, a voltage sag occurs on the $10\,\mathrm{kV}$ stiff network at $t = 4\,\mathrm{s}$, as shown in Fig. 7. This fault is modeled as the $t = 0.2\,\mathrm{s}$ voltage sag corresponding to the worst-case scenario as defined by the Germany Grid Code of 2007.
- As a result of the fault, a transient with high frequency oscillation in both the electrical and mechanical systems can be observed.
- After the grid voltage recovers, the system returns to its steady state. This is indicated in Fig. 8, where the average active and reactive power is plotted.
- At $t = 6\,\mathrm{s}$, the speed reference signal then ramps up from $1.05\,\mathrm{rad/s}$ with an acceleration of $0.004\,\mathrm{rad/s^2}$.

3.2 MPPT at variation of wind speed

In the scenario, the wind speed is gradually increased from $6\,\mathrm{m/s}$ to $12\,\mathrm{m/s}$, the MPPT algorithm tracks for the rotor speed with the maximum power point for each wind speed step. The wind speed is then reduced in the same way, with each point being approached again. The profile is shown once in an XY plot Fig. 9, where the operating points are shown, and in the comparison the time profile is shown in Fig. 10. After each step change of the wind speed, an adjustment of the speed and the torque is performed, which results in a slight increase of the power.

References

[1] Jogendra Singh Thongam and Mohand Ouhrouche, "MPPT control methods in wind energy conversion systems", Fundamental and advanced topics in wind power, vol. 1, no. 2011, pp. 339-360.

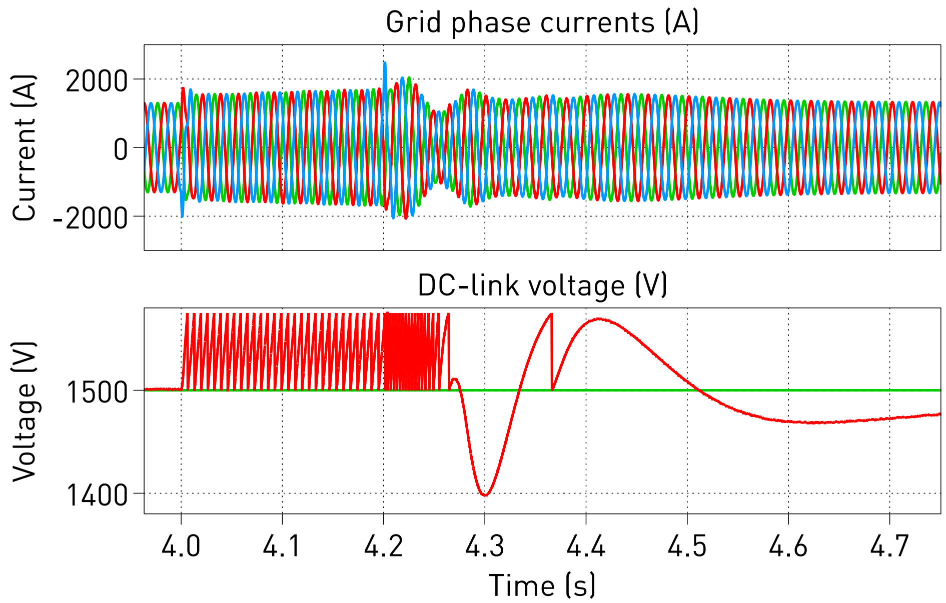

Figure 7: System behavior during a voltage sag in a connected $10\,\mathrm{kV}$ stiff grid

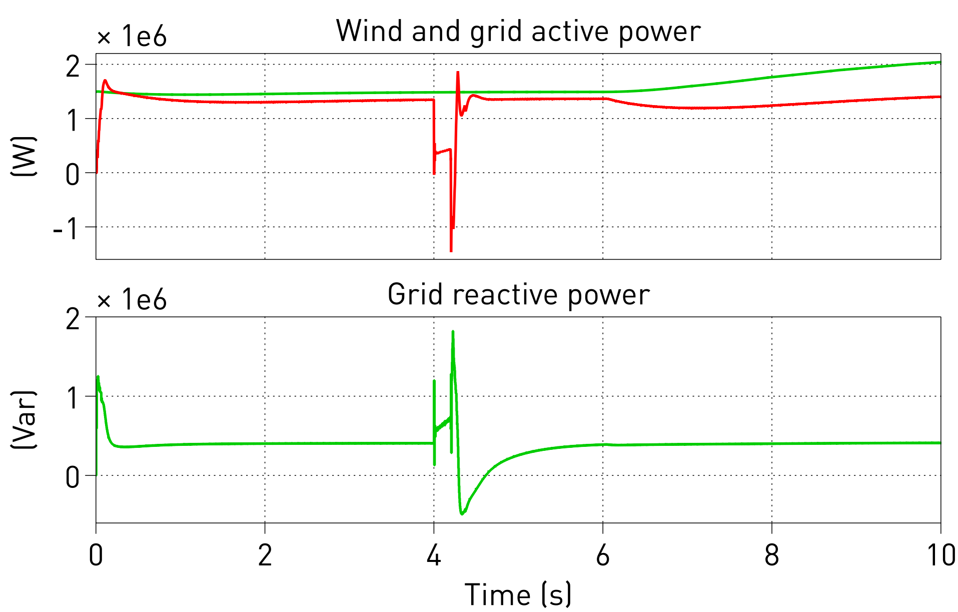

Figure 8: Wind and grid active power and grid reactive power

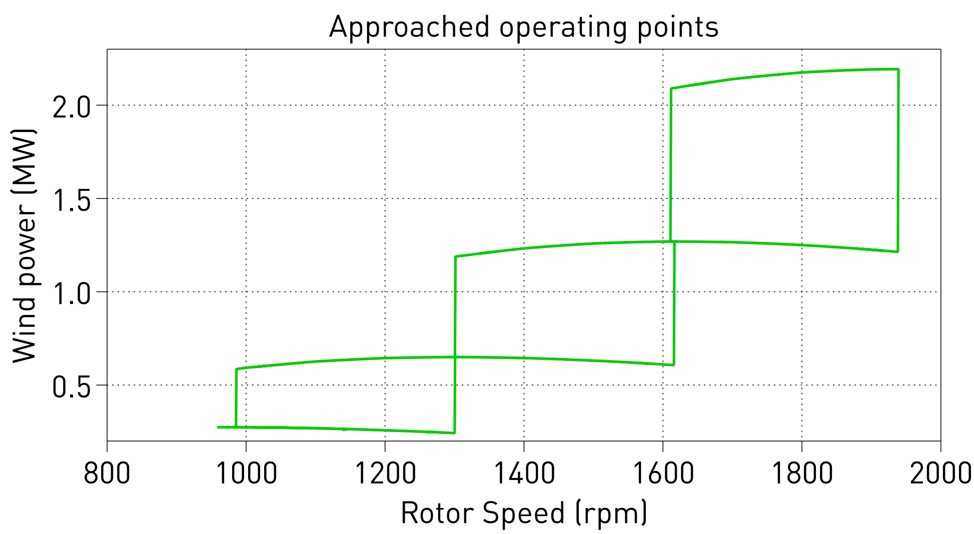

Figure 9: Approached operating points of MPPT-Algorithm under step wind speed profile

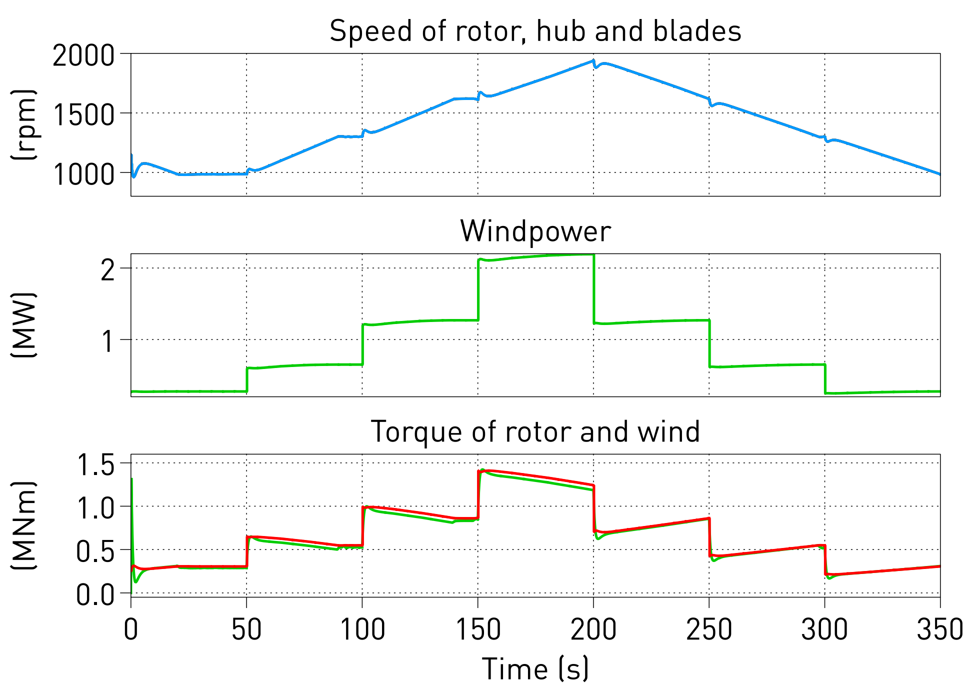

Figure 10: Approached operating points of MPPT-Algorithm over time under step wind speed profile

Revision History:

PLECS 4.4.1	First release
PLECS 4.5.5	Update MPPT-Algorithm
PLECS 4.7.1	Updated the model with the Switch Loss Calculator

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PLECS Demo Model