Wind Energ. Sci. Discuss.,
https://doi.org/10.5194/wes-2020-42-AC2, 2020

Interactive comment on "Comparison of HiL Control Methods for Wind Turbine System Test Benches" *by* Lennard Kaven et al.

Lennard Kaven et al.

l.kaven@irt.rwth-aachen.de

Received and published: 25 May 2020

We thank the referee Amir R. Nejad for the detailed review. We considered the remarks very helpful to further improve the manuscript's quality.

General remarks:

Referee general remarks: This article presents the application of HiL for drivetrain testing in onshore wind turbines.The article is well-structed and topic is of interest.

Author's response to general remarks: We thank the referee for the positive feedback.

Further remarks:

Referee remark (1): Title: please add "drivetrain" to the title.

Printer-friendly version

Discussion paper

Author’s response on remark (1): Indeed, the HiL control methods focus on the drive train of the system test bench. We agree that adding the keywords to the title will increase the paper’s impact. Changes in the manuscript: The title has been changed to "Comparison of Hardware-in-the-Loop Control Methods for Wind Turbine Drive Trains on System Test Benches"

Referee remark (2): Apart from the inertia and stiffness which are considered by the 3-mass model, there are “external excitations” in particular “tower shadow” or “blade passing frequency” (often shown as 1P, 3P, 6P,: : :). How authors have modelled them? I would expect to see some peaks less than 1 Hz for 3P (with rated speed of 17.5 rpm, the 3P would be 0.85 Hz) which could be seen in Fig. 6 if it is modelled.

Author’s response to remark (2): Fig. 6 shows the transfer function of the wind turbine’s drive train, i.e. aerodynamic torque to generator speed. Thus, external excitations are not visible here. However, external excitations as the tower shadow are included in the aerodynamic rotor model. As the topic of the paper are the control methods, we had left out most of the details concerning the aerodynamic simulation in the discussion paper. We now decided, that for sake of interpretation of the results and reproducibility, information on the aerodynamic rotor model is added to the text. Changes in the manuscript: We added the requirements for an aerodynamic rotor model to section 1 (l.38): ("The requirements for the aerodynamic model depend on the use case. For simple tests, a CP-lambda curve might be sufficient, but to realistically reproduce oscillations, an aeroelastic model that considers blade elasticity and tower shadow is required. Additionally, the aerodynamic model needs to be executable in real-time, because the aerodynamic torque is calculated online during test procedure."). Secondly, details on the aerodynamic model used for simulation results is added to section 3 (l.101): “To model the aerodynamic properties, we use the rotor-aeroelastic-integrated-simulation-environment (RAISE) introduced by Marnett et al. (2014). RAISE takes into account elastic blades and tower shadow excitation and is capable of real time execution.”

Referee remark (3): Abstract: some of the abbreviation are not defined (IE, MRC) in the abstract.

Author's response to remark (3): This has been corrected. The abbreviations of the HiL control methods IE and MRC are now introduced in the abstract.

Referee remark (4): Fig 1: please clarify what are "measured signals" in this figure.

Author's response to remark (4): As stated in the text, the measured signals differ "depending on the applied HiL control method" (l.40,f). Deducting the measured signals from the respective HiL control method is possible, though not intuitive. Hence, we added the possible measured signals to Fig. 1 as suggested by the referee. Changes in the manuscript: In Fig. 1, we have changed the label of the feedback variables from DUT to HiL control from "Measured signals" to "Generator speed, (Generator torque)" to indicate that all of the HiL control methods use the generator speed, but only some of the HiL control methods use the generator torque. Additionally, this information has been clarified in the text.

Referee remark (5): Introduction: authors can extend the introduction by referring to several works on the HiL application in wind industry, for example for offshore turbines. HiL has been used in testing the offshore wind turbines. Please also extend the literature review for the control methods used in this paper – specially refer to their applications in other fields.

Author's response to remark (5): We thank the referee for pointing at the HiL application on a test bench for floating offshore wind turbines. We included this work in the literature overview. Furthermore, we extended the literature overview to HiL control for scaled system test benches, comparison of control methods without HiL functionality, and HiL control for different test benches. (a) HiL control for system test benches: Song et al. (2005): "Emulation of output characteristics of rotor blades using a hardware-in-loop wind turbine simulator"; Schkoda et al. (2015): "A Hardware-in-the-Loop Strategy for Control of a Wind Turbine Test Bench"; (b) comparison of control methods without

HiL functionality: Thomsen et al. (2011): "PI control, PI-based state space control, and model-based predictive control for drive systems with elastically coupled loads - A comparative study"; (c) HiL control for different test benches: Thun (1984): "Verfahren zum Simulieren von Trägheitsmomenten und geregelter Prüfstand zur Durchführung des Verfahrens [Procedure for simulating moments of inertia and a controlled test bench for validation of the procedure]"; Bayati et al. (2018): "A wind tunnel/HIL setup for integrated tests of Floating Offshore Wind Turbines"

Referee remark (6): Page 3 (65) “As a reference, we use the 3-mass oscillator model of a WT drive train, and for HiL controller synthesis the 3-mass oscillator model of a STB drive train parameterized as by Leisten et al. (2019b).” Please mention the main futures of the WT and drivetrain used as reference case in this study.

Author’s response to remark (6): As the topic of the paper are the control methods, we had left out most of the details concerning the reference wind turbine and the device under test in the discussion paper. We now decided, that for sake of interpretation of the results and reproducibility, information is added to the text. Changes in the manuscript: Since information on the reference wind turbine and the device under test is not part of the HiL control methods, but is required for the analytical comparison and simulation results we added it to section 3 (l.101,f):" For the comparison of HiL control methods, we use WT and STB models based upon an NEG Mincon WT with a rated power of 2.75 MW at a rated rotational speed of 17.5 rpm (Leisten et al., 2019). The dominant eigenfrequencies and the drive train parameters have been derived from a multi-body simulation (Baseer et al., 2019). The two dominant eigenfrequencies of the WT drive train are the first edgewise blade mode and the first drive train torsional mode, located at 2.5 and 4.6 Hz, respectively. Drive train parameters of the 3-mass oscillators for WT and STB can be found in the appendix (Table A2).” Please note that Table A2 of the manuscript’s appendix is attached to this document

Referee remark (7): Fig 6: please discuss the results more in details, specially why the results for each method differs to others.

Author's response to remark (7): The discussion of analytical results has been expanded. Additionally, the discussion has been extended to a comparison of the respective phase responses. Changes in the manuscript: The discussion for results in Fig. 6 has been replaced by the following text: "Analytical results are presented as transfer functions. Fig. 6 depicts a bode plot for the transfer function from input torque to generator speed for the WT and STB drive trains. The inertia difference and eigenfrequencies of the WT and STB drive trains are observable by an offset towards low frequencies and peaks in the magnitude response, respectively. Additionally, the transfer function for the HiL controlled drive train of the STB is shown for IE and MRC methods. The transfer function with IE method achieves good accordance with the transfer function of the WT up to 1 Hz. The accordance is enabled by the virtual rotor that lowers the magnitude response of the STB until it matches the transfer behaviour of the WT drive train. For frequencies above 1 Hz, the transfer functions mismatch as the first WT drive train eigenfrequency dominates. Thus, a reproduction of the eigenfrequencies seems not achievable with IE method. In contrast to the IE method, the MRC method matches the desired behaviour in the magnitude response up to 6 Hz, despite small deviations. Fig. 3 reveals that the small deviations in magnitude response are caused by the implemented speed controller. The reference model of the WT drive train provides the required WT eigenfrequencies, at the same time eliminating the inertia difference. For frequencies above 6 Hz, the bandwidth of the speed controller becomes a limiting factor and transfer functions of the WT drive train and the STB drive train with MRC method drift apart. However, the reproduction of the WT eigenfrequencies seems possible with the MRC method. The phase response of none of the methods exactly matches the desired transfer function for frequencies above 0.5 Hz. The deviation in phase response is uncritical for HiL operation if WT pitch control provides sufficient phase margin."

Referee remark (8): Please consider including a nomenclature listing all abbreviations.

Author's response to remark (8): In total, six abbreviations are used throughout the paper. All of them are introduced in the abstract and thus, we avoid the usage of a nomenclature.

Interactive comment on Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2020-42, 2020.

Table A2. 3-mass oscillator drive train parameters for WT and STB with DUT

Drive train parameter	WT	STB with DUT	[unit]
$\mathbf{I_1}$	3.42e6	8e4	[kgm^2]
$\mathbf{I_2}$	4.06e6	3.3e4	[kgm^2]
$\mathbf{I_3}$	1e6	1e6	[kgm^2]
$\mathbf{c_{12}}$	5.2e8	3.7e8	[Nm/rad]
$\mathbf{d_{12}}$	1.3e6	2e4	[Nm/(rad/s)]
$\mathbf{c_{23}}$	6.2e8	2.3e8	[Nm/rad]
$\mathbf{d_{23}}$	1.3e6	2e5	[Nm/(rad/s)]
$\mathbf{f_{eig,1}}$	2.5	6.5	[Hz]
$\mathbf{f_{eig,2}}$	4.6	23	[Hz]

Fig. 1.