

## Response to reviewers

**Title:** Design and Simulation of a Continuously Variable Hydraulic Power-Split Drivetrain for Wind Turbines

**Manuscript No.:** wes-2025-282

The authors thank the reviewers and the editor for their careful reading of the manuscript and for their constructive and valuable comments and suggestions. Their efforts and insights are greatly appreciated and have helped to improve the clarity and quality of the paper.

All comments raised by the referees have been carefully considered and addressed. Minor corrections, including linguistic improvements and small editorial suggestions, were directly implemented in the revised manuscript. More substantial comments are addressed individually below, with references to the corresponding locations in the manuscript where the modifications were made. We hope that the revised version adequately addresses all concerns and is now suitable for publication.

Line numbers shown in light grey refer to the corresponding lines in the preprint, whereas line numbers shown in light blue indicate the locations of the revisions in the revised manuscript.

### Comments of referee #1 and their respective answers are listed below:

1. “Most important is to change an efficiency in Fig. 15 that appears larger 1. Here the base must be changed or it must be explicitly explained why it shows this numbers that are technically and per definition not possible.”
  - The quantity shown in the graph is not an efficiency but an energy ratio, defined as the energy produced by the HyDrive concept divided by the AEP of the DTU reference turbine. Values greater than one therefore indicate that the HyDrive turbine produces more energy than the reference turbine in context of the same site conditions. To avoid any misunderstanding, we have revised the ordinate label and the legend text to clearly distinguish this metric from an efficiency.

### Additional comments of referee #1 from pdf:

2. “Fendt Power split drive should be mentioned and quoted as a mature technology and used mobile application.” (line 46)
  - An addition has been made in line 52: “Power-split drivetrains are well established in the commercial vehicle sector and have been used since the 1990’s as the primary drivetrain in agricultural machinery (Yu et al., 2019). For example, Fendt introduced their Vario drivetrain in 1996 (Matthies and Renius, 2021; Dziuba and Honzek, 1997) as the first series-produced power-split tractor drivetrain.”
3. “e.g., TSR: Create a legend for abbreviations and formula symbols.” (line 106)
  - Following the consultation with the editor at Copernicus, we learned that including a list of abbreviations or nomenclature is generally uncommon for WES papers, at least at the beginning of the paper. However, such a list may be provided in the appendix. To improve clarity and readability, we have therefore added a list of all used abbreviations in the appendix of the paper. (p.25)
4. “extremely? What are the max pressures?” (line 455)
  - We have deleted the word extremely as it is not scientific. For our simulations, we defined a maximum hydraulic pressure of 350 bar, corresponding to the maximum continuous operating pressure specified in the datasheet of the Parker P14 axial

piston machine that we used as a reference. As the point of the sentence is to raise awareness about high pressures and its leaking risks in any hydrostatic machine, we do not include specific values.

5. “Dissertation of Thorsten Kohmäscher, ifas could be quoted.” (line 558)
  - This dissertation and related documents are not publicly accessible and require purchase from the publisher, so we must refrain from citing them, although we appreciate the reviewer’s recommendation and the highlighting of the potential relevance of Thorsten Kohmäscher’s dissertation on our paper.

### Comments of referee #2 and their respective answers are listed below:

1. “It remains unclear to which extend it goes beyond already existing knowledge in the field (novelty).”
  - We have revised the abstract to more clearly highlight the novelty of the paper. This aspect is also addressed in section 2. Our work extends existing research in several respects:
    - Similar to Bottiglione et al., we investigate the efficiency of the overall system. However, the hydraulic efficiencies are assessed in a more conservative manner by using commercially available and axial piston machines as a reference. In contrast, Bottiglione et al. refer to hydraulic machines using the floating cup technology developed by Innas, which represent the upper limit of achievable efficiencies and are not yet implemented into practical applications. Furthermore, the analysis is expanded to include different direct transmission concepts and the optimization of the drivetrain through their variation.
    - Unlike the Voith WinDrive concept, the hydraulic section of the power split used here consists of a conventional hydrostatic transmission with pump and motor, rather than a hydrodynamic converter (and, depending on the configuration, an additional turbo coupling). In contrast to Bottiglione et al. (250 kW) and Ibrahim et al. (100 kW, stall-regulated), the present study focuses on a modern multi-megawatt wind turbine (10 MW). Furthermore, the overall context is extended by considering aspects of mechanical design, physical rotational inertia, failure rates, and maintenance.
2. “The abstract should get a major overhaul to represent the context, motivation, and results of the work more to the point.”
  - We completely reworked the abstract, trying to include all your mentioned aspects.
3. “While the results of parameters changes to a simulation model are described, the model itself does not have a suitable subsection.”
  - We added a subsection “3.1 Simulation model”, moved, and extended the model description from section 5 in the new subsection. (line 140 et seq.)

### Additional comments of referee #2 from pdf:

4. “I think it is worthwhile to describe what you mean by "realistic rotational inertia". I got a hunch you refer to decentral power units replacing the inertia of huge centralized power plant turbines, but from the writing it does not become clear.” (line 13)
  - Related to a later comment, we changed the term real/realistic inertia to physical rotational inertia. We included a short insert describing what we mean: *“In addition to achieving high efficiencies, the provision of physical rotational inertia by decentralized generation units, compensating for the loss of inertia from large centralized power plants, is becoming increasingly important in grids with a high share of renewable energy.”* (line 20)
5. “It is hard to follow the vein of thought here. Perhaps you can take the reader by the hand and explain what common drive trains do and what hydraulic power transmission is in the first place, and then describe the possible merits that make it a worthwhile endeavor to take a look at them.” (line 15)
 

“I am missing an explanation of the terms hydromechanical, hydrostatic, "full" hydraulic transmission, "power-split" drivetrain, and "fully hydrostatic drivetrain" somewhere here.” (line 15)

“I think the key point of these drive trains is the constant output speed, and while it is mentioned here in a circumferential manner I cannot help to wonder why you do not get to the point?” (line 19)

  - We reworked the introduction section to define the different terms and explain how they differentiate from standard drivetrains in a more comprehensible way. (line 17 et seq.)
6. “Which irrelevant are there and how did you draw the line?” (line 22)
  - We deleted the word 'relevant' as it suggests 'irrelevant' concepts or a specific metric for decision-making. We added a sentence to describe our metric: *“Table 1 presents an overview of fully hydraulic transmission concepts from recent years, including only those that have been realized at least at laboratory test bench level.”* (line 36)
7. “It so seems there are quite a few test results out there and also efficiencies. I haven't gotten to the point of model validation of the model in the present works, but I am very much hoping you used the existing results for it or at least explain why this hasn't been possible.” (line 26)
  - The intention of this clause is to provide the reader with an order of magnitude of the efficiencies. Since the efficiency value of the DTU turbine is used later in the paper, we decided to state it here as a reference. When reporting efficiency values, several factors must be considered (turbine size, drivetrain design - direct drive or gearbox - and the defined system boundary), which makes it difficult to extract a specific value from the literature that is directly comparable in this context.  
We now provide a range of values based on Zhang et al. (2025), Hau and Siegfriedsen (2025), Song et al. (2023), and the reference turbine: *“For all fully hydrostatic drivetrains that have been realized at prototype scale, results indicate that the overall drivetrain efficiency from rotor to generator remains below that of conventional wind turbines which ranges about 89- 94% (Hau and Siegfriedsen, 2025; Zhang et al., 2025; Song et al., 2023; Bak et al., 2013).”* (line 40)
8. “Can I suggest to use TRLs in addition to the status description?” (table 1)
  - We added a row with estimated TRL levels in table 1+2.
9. “It might just be me, but I am not a big fan of negative speeds. Are you trying to show the rotational direction is opposite to the one of the rotor?” (fig. 2)

- We have added a note about the meaning of the sign. Particular in Fig. 8, information would be lost if only the absolute values were shown: „Sign indicates direction of rotational speed.“
10. “I am not too familiar with power-split drivetrains and perhaps this is something very normal, but I have a hard time understanding how the power on the generator side can be larger than the power the rotor puts in? (up to 5.5 m/s)” (fig. 3)
- Good observation! We discuss this in section 5.1 and added a reference to this section. (line 139)
11. “maybe say left or right in this cross-reference” (line 104)  
 “Fig 2, left” (line 109)
- We would reference with a) or b) when meaning a specific variation (side) of Figure 1. But in this case, we just wanted to take reference to the general setup of the drivetrain components, particularly the connection to the individual gears of the summation stage (see (IV) in Fig. 1 a) and b)). In this context it does not matter which variation (side) of Fig 1 is referred to as the design is identical in a) on the left as well as in b) on the right. In contrast, Fig. 2 does not have a subdivision similarly to Fig 1, as the plot on the right next to Fig. 2 is Fig. 3.  
 In general, we use lowercase letters and a single figure number to denote variations of the same or similar illustration, while figures with different content - even when related or arranged together - are assigned with separate figure numbers.
12. “I think you might get a bit more into the details here, as "established" and "appropriate" are rather vague” (line 129)
- The calculations are intended as first-order estimates to approximate the overall gearbox dimensions and those of its main components, to be mainly used for visualization purposes. Nevertheless, we replaced the mentioned words with a little more detailed description of the applied calculation methods, assumptions and simplifications:  
*“The key dimensions for the CAD model were preliminarily determined through first-order sizing of the gears and the hydraulic machines, based on anticipated static loads, which were derived from the nominal output power of the wind turbine and the required total transmission ratio (see Table 3). For the distribution of the mechanical and hydraulic power flows, a direct transmission at rated wind speed is assumed (see Fig. 2 and 3). Total mechanical losses are estimated to 1% for each planetary stage and 2% for the spur gear stage (Hau and Siegfriedsen, 2025, S. 438). The calculations are performed using standard analytical formulas for involute gears and hydraulic systems, while in line with the primary purpose of visualization, variable hydraulic losses, detailed load analyses and microgeometry optimization are not included.” (line 178 et seq.)*
13. “I highly doubt that replacing the second planetary stage with a spur gear has the described effect. As far as I understand it is hard to impossible to beat the power per kg density of a planetary stage” (line 138)
- Planetary stages offer a significantly higher power density than spur gear stages. However, gearboxes used in conventional wind turbine drivetrains can achieve the required overall transmission ratio with a configuration of two planetary stages followed by a spur gear stage, even at rated powers in the double-digit megawatt range, to drive generators operating at speeds comparable to or higher than the 750 rpm assumed in this study. In the conceptual design, the maximum transmission ratios of the individual planetary stages were initially assumed very conservatively.

Therefore, we consider it feasible to eliminate one of the three planetary stages shown in Fig. 4 b) through appropriate design of the transmission ratios and replace it by the additional spur gear. We acknowledge that this was maybe not sufficiently clear in the original manuscript, so we have revised the wording as follows: “Since the selected transmission ratios of the individual stages are relatively conservative, the additional spur gear could potentially replace the second planetary gear entirely, provided that the transmission ratios of the remaining stages are increased accordingly. With that, material and mass could be reduced.” (line 188)

(e.g. “high and medium speed gearboxes” by Winergy with 2 planetary stages in their 8-10 MW transmissions: <https://www.winergy-group.com/en/products/gearboxes> (26.02.2026))

14. “Where did you get that interval from?” (line 390)

- “Manufacturers of oil-hydraulic systems recommend oil change intervals of between 1,000 and 5,000 operating hours when using mineral oil and under normal operating conditions (continuous temperature below 70 °C) with unmonitored oil filling.” (Bauer and Niebergall, 2020, p.61)