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WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on "Control design, implementation and evaluation for an in-field 500 kW wind turbine with a fixed-displacement hydraulic drivetrain" *by* Sebastiaan Paul Mulders et al.

Anonymous Referee #1

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Review of Paper: Control design, implementation and evaluation for an in-field 500kW wind turbine with a fixed-displacement hydraulic drivetrain by S.P. Mulders, N.F. Boudewijn Diepeveen, and J.W. van Wingerden submitted to Wing Energy Science Discussions

General Recommendation This paper presents an interesting analysis of a novel hydraulic wind turbine concept. The concept consists on replacing the conventional mechanical drivetrain components with a seawater pump directly driven by the wind turbine, whose outlet flow is directed to a Pelton generator. However, the analysis pre-

sented in the paper refers to an intermediate solution, in which the seawater pump is driven by a close loop oil-based hydrostatic transmission. The paper topic is certainly relevant for the journal; the approach is rigorous and the authors appear to be very familiar and qualified for work in the field. However, the paper could be significantly improved in certain aspects. Therefore, this Reviewer recommend its publication only after major changes are implemented to the submitted manuscript. Recommendations details [Major] The paper is quite long, it contains too many equations and figures. This Reviewer suggests the authors to reduce the number of equations and figures. Some suggestions are provided in the following comments. Consider also that this Reviewers is asking for some additional details, therefore some additional figures might be necessary in the revised version of the paper. [Minor] Not sure about the significance of Fig. 2, since the concept is quite obvious. In any case, if the authors decide to keep this image, this Reviewer suggests to include labels for the different components represented [Major] The authors provide a quite exhaustive overview of the past effort, which is very appreciated. However, at pag. 2, they affirm "To date, none of the 5 above described full hydraulic concepts made its way to a commercial product. All concepts use oil as the hydraulic medium because of the favorable fluid properties and wide component availability, but therefore also need to operate in closed-loop." This Reviewer has two problems with such sentence: - For the size of the components required for wind turbine applications, there are almost no available commercial products. Those chosen by the authors in their work are probably the among the very few ones available (considering also that they had to turn a motor into a pump!). This is because as the authors stated, there are no successful application for hydraulic wind turbines. Therefore, if there is no market (thus no demand), there is no offer. The message is that nowadays someone wants to design a hydraulic wind turbine, he/she necessitates to design the hydraulic components as well (or partner with a component manufacturer to get a unit specially designed). - The reference to close loop (close circuit ?) hydraulic transmissions (HTs) is questionable. HTs for many mobile applications (wheel loaders, excavators, etc) are close loop, but again the components for these HTs are too small for wind turbine applications. HTs can also be open-loop. Many HTs for areal platforms, forklifts, hydraulic fan drives are open-loop. What are the requirements that determine the need of having a close loop HT for a wind turbine application? This Reviewer can have some guesses, but this should be better addressed.

[Minor] Was the concept of the paper presented also at the IFK2018 conference? A better reference to that paper, and the novel contents of this paper, should be provided.

[Minor] Figure 3 might not be necessary, can be removed.

[Major] Section 2.2. The hydraulic circuit needs to be better detailed. A more realistic ISO schematic with respect to the one provided in Fig. 6 is needed. The authors give the impression that a pump can be simply be coupled with a motor to form a close loop HT. However, other components are needed to guarantee the operation of the system: - Is a charge pump present? How was that sized? Can be neglected in the analysis? Why? What is the pressure level of the low pressure line? Is a flushing valve / cooling of the hydraulic motor present / necessary for the long operation of the system? A HTs for continuous operation usually necessitates for a significant oversizing of the charge unit for cooling purposes. - Circuit of the water pump. The authors say that there is an external centrifugal pump, which seems to be connected in series with the fixed displacement pump. How is the schematic? Is there a relief valve in between to provide a reference pressure level? Why this part can be neglected in the subsequent analysis? - Pelton Turbine. The concept of using a Pelton Turbine is very interesting. However, it seems that the Head [m] of this turbine is way above to the existing Pelton turbines, so that it might be impossible to borrow an existing design. What is the specific speed of the Pelton Turbine of this paper? Is a commercial Pelton wheel available? Is a two-jet turbine such as the one of Fig. 5 sufficient? This is not the scope of this paper, however, the authors could be more clear on this part, perhaps using more references.

[Major] At page 7, the authors say "After the water flow exits the spear valve, the aim to operate the Pelton turbine generator combination at maximum efficiency is a decoupled

control objective from the rest of the drivetrain, and is outside the scope of this paper." Actually, this sentence is at the basis of many assumptions made in the development of the model and the controller design. This Reviewer, although without specific experience in designing HTs for wind turbine applications, has some conceptual doubts on this choice made by the authors. A HT has to be designed according to the features of both the load and the prime mover; this also drives several choices of constant torque (variable displacement pump) or constant power (variable displacement motor) HTs. In this case, the authors decide to neglect the features of the user (the Pelton wheel). Is that correct? To this Reviewer, it is like affirming that all the points that satisfies Eq. 12 (relation nozzle area and HT pressure) are indifferent for the Pelton turbine. This is quite hard to believe. The Pelton turbine should have preferred operating points that the HTs should be able to handle. This is a very basic question that the authors should address properly. Otherwise their proposed controller might not be beneficial on a real application.

[Major] Section 3.1.2. The authors here affirm "the volumetric efficiency of a pump or motor is generally high and fairly constant over the entire operating range". For a simplified model the assumption of constant efficiency could be a fair starting point. But the statement that hydraulic pumps and motors have a constant volumetric efficiency for any pressure and shaft speed is clearly wrong. Otherwise, all the literature on empirical efficiency models (starting from Merritt in the 60s), standards for measuring volumetric efficiency (ISO, etc), tribological models for studying the lubricating gap flows, would not be justified. Particularly at low speed, the volumetric efficiency can be particularly low for both pumps and motors. Please revise this statement and better justify the assumption of constant efficiency, which can be very limited.

[Minor] Section 3.2.1. here there are several equations that are well known. This section could be reduced

[Major] Section 3.2.2. In the list of assumptions it is stated that the inertia of the hydraulic components is neglected. While it is true that hydraulic components have fast dynamic, in comparison with other technologies for transmitting power, it has to be proven that within a hydraulic system the hydraulic line is the element with slowest dynamic. This statement, in general is not true, and Merritt never affirmed that. Moreover, the authors consider infinitely rigid lines, therefore the “fastest” lines possible (is this realistic?). Please justify this statement.

[Major] Section 4.4.1. The authors say “hydraulic components are known to be more efficient in high-load operating conditions, it might be advantageous for a hydraulic drivetrain to operate the rotor at a lower tip-speed ratio.”. This statement can be arguable. First, shaft speed has a major effect, and not all units have a clear trend with load. Can the authors provide the overall efficiency plot for the commercial units they utilize (even in normalized form?). This is very important, because all the controllers of case 1 and case 2 are based on this assumption!

[Minor] Pag. 21. The reference to Fig 14 might be wrong, since the figure refers to mechanical efficiency.

[Major] 4.2.1. L=50m... are the pump and motor connected by a 50 m straight line? If there are line discontinuities, some terms, particularly the inductance terms, can be entirely wrong.

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