Author response to reviewer #1

Thank you to the reviewer for the comments on the paper. The specific replies to the reviewer comments [RC1] are addressed by the author [AC] in the following lines with respect to the revised version:

1. [RC1] “The paper should probably mention (e.g. in a footnote) that it is an extended and updated version of a paper previously presented at TORQUE2016 conference, and published in IOP Journal of Physics: Conference Series.”

[AC] As this paper was invited for the special Issue on The Science of Making Torque from Wind (TORQUE) 2016, this was not considered necessary following the example of the other papers submitted for this special issue. The author will comply to the editors instructions.

2. [RC1] “Continuing from the previous item, the paper needs to contain at least 40 percent new content, which is currently not the case.”

[AC] The revised version includes now a more detailed explanation of the motivation of the proposed concept together with opportunities for cost reduction. A expanded description of the different models employed, new figures and schematics are now included. The details and description of the controller are added with respect to the conference paper. New results are also presented in the form of an extra case scenario where the hydraulic wind farm is simulated while two turbines are brought to a full stop. The new results give better insight on the behaviour of the hydraulic model in particular with the proposed pressure controller (See also Figures 18 and 19). The conclusions also include further work. More references were also employed in the revised version

3. [RC1] “Introduction: ‘This paper continues with previous work’ - It would help the reader if the scope and achievements of the previous work were briefly reported. That way the research is placed more into context, and it becomes easier to evaluate what is new here.”

[AC] The author agrees, similar comment was done by RC2. The following paragraph has been added:
The modelling and analysis of a single turbine with hydraulic technology has been previously presented for variable-speed control strategies. Simulations of an individual turbine with an oil based hydrostatic transmission have been presented in (Jarquin Laguna et al., 2014). The results showed good dynamic behaviour for turbulent wind conditions where reduced fluctuations of the drivetrain torque and power are obtained despite the reduced energy capture. The integration of a single turbine with a Pelton runner using water hydraulics was introduced in (Jarquin Laguna, 2015), where a passive variable speed strategy was proposed. However, the addition and simulation of more turbines to the hydraulic network was not included. In an effort to assess the trade-offs implied by the proposed hydraulic concept, this paper extends the time-domain simulations to evaluate the performance and operational parameters of five turbines coupled to a common hydraulic network for a hypothetical wind farm with centralized electricity generation. In the first part of this work, an overview of the wind farm model is presented together with the control strategy of the hydraulic components; the second part describes a case example where the results are compared with those of a typical wind farm based on conventional wind turbine generator technology.

4. [RC1] "Are there any system effects when running the concept with more than one turbine? The performance and results obtained for the wind farm should be compared (in a meaningful way) with results for a single turbine.

[AC] That is correct, the system effects are better illustrated in the extra case scenario included in the revised version where two turbines are brought to a full stop during above rated wind conditions, see description in section 4.4

5. [RC1] "The concept is based on the use of seawater. I assume that corrosion becomes an important issue then. Does the author have some comments for the readers on this? "

[AC] The following paragraph and reference has been added in the introduction:

In the proposed concept, an open-loop circuit is considered (i.e. the fluid is not circulating) with seawater as hydraulic fluid. The choice of seawater as hydraulic fluid is preferred because of its availability and environmental friendly nature when compared to oil hydraulics. It is important to consider that seawater contains a high concentration of minerals, which give it a high degree of hardness. It also contains dissolved gases such as oxygen and chlorine which cause corrosion. Despite its corrosive nature, the use of seawater hydraulics has already been used in some industrial applications, where in terms of safety, water hydraulics might be preferred due to potential fire hazards or risk of leakage as is the case of the mining industry. An example in the offshore industry includes the seawater hydraulic system for deep sea pile driving incorporating high pressure water pumps (Schaap 2012). A key advantage of this system is that the use of an open loop circuit cancels the need for cooling equipment, a disadvantage is that it is likely that filters have to be cleaned more frequently.

[1]M. Schaap. Seawater Driven Piling Hammer, IHC Hydrohammer. In Proceedings of the Dutch Fluid Power Conference in Ede, September 2012. . (reference added)

6. [RC1] "As it is proposed to use only one turbine and generator, reliability of these becomes a critical issue. Has the author any thought on this that he would like to share with the readers?"

[AC] Indeed, by using only one or a few turbines and generators, the reliability of these components become an important aspect. Modern hydro-turbines have been developed with typical capacities of 500 MW operating for decades with enough operational and maintenance experience gained from conventional hydro-power plants. On the other hand using hydro turbines in combination with renewable energy sources such as offshore wind energy has not been explored. The concept itself is still in pre-development phase and therefore there is a lack of real data supporting the reliability.
It is also expected that by having the whole electrical generation equipment in one offshore central platform instead of having it in a constraint space hundred meters above sea level, would have a positive impact regarding O&M costs.

7. [RC1] "Eqs. 6-7: The notation is slightly confusing. I assume that $V(e)$ is a function depending on the variable e, later shown in Eq. 8. However, also other terms in Eqs. 6-7 are functions that depend on parameters. To be consistent, I suggest that you simply use V in Eqs. 6-7 and clarify $V(e)$ = eV_p;max in Eq. 8."

[AC] Equations have been modified accordingly.

8. [RC1] "Section 2.1.3: The pitch actuator model is based on a proportional regulator. Why not also a derivative or integrator component? Why is the pitch actuator model needed?"

[AC] The pitch actuator model is needed to account for any blade-pitch actuator dynamic effects. This means the slow or fast response of the pitching mechanism to the control command signal. The derivative or integrator components are considered to be included in the pitch control which is in series with the pitch actuator, see Section 3.3.

9. [RC1] "Section 2.3: The nozzle length L_{nz} should be indicated in Figure 4 as well."

[AC] Figure 4 is now modified including L_{nz}

10. [RC1] "Section 2.4: What is the value of the vena contracta coefficient used here?"

[AC] A value of $C_v=0.99$ was used according to (Thake, 2000)[2]. Please note that the vena contracta phenomenon does not influence the nozzle efficiency.

[2]Thake, J. The Micro-hydro Pelton Turbine Manual. Practical Action Publishing, 2000. (reference added)

11. [RC1] "Section 3.1: 'A low pass filter on the pressure measured is employed' What are the filter characteristics?"

[AC] A first order low pass filter was used with the following transfer function form:

$LPF(s)= 1/(1+s/\omega_c)$

where the cut-off frequency ω_c was set at 32π [rad s^{-1}]. This description is now included in the manuscript. Table 1 was added with the parameters of the augmented controller.

The author hopes that the modifications to the manuscript and replies to the reviewers satisfy your requests.

Author response to reviewer #2

Thank you to the reviewer for the comments on the paper. The specific replies to the reviewer comments [RC2] are addressed by the author [AC] in the following lines:

1. [RC2] “Introduction, Page 2: the paper should present a more detailed overview of work carried out in this area so far and what new work is being presented in this study.”

[AC] The author agrees, similar comment was done by RC1. The following paragraph has been added:
The modelling and analysis of a single turbine with hydraulic technology has been previously presented for variable-speed control strategies. Simulations of an individual turbine with an oil based hydrostatic transmission have been presented in (Jarquin Laguna et al., 2014). The results showed good dynamic behaviour for turbulent wind conditions where reduced fluctuations of the drivetrain torque and power are obtained despite the reduced energy capture. The integration of a single turbine with a Pelton runner using water hydraulics was introduced in (Jarquin Laguna, 2015), where a passive variable speed strategy was proposed. However, the addition and simulation of more turbines to the hydraulic network was not included. In an effort to assess the trade-offs implied by the proposed hydraulic concept, this paper extends the time-domain simulations to evaluate the performance and operational parameters of five turbines coupled to a common hydraulic network for a hypothetical wind farm with centralized electricity generation. In the first part of this work, an overview of the wind farm model is presented together with the control strategy of the hydraulic components; the second part describes a case example where the results are compared with those of a typical wind farm based on conventional wind turbine generator technology.

2. [RC2] “Page 2, line 8: amend sentence to end as follows: `where the results are compared with those of a typical wind farm based on conventional wind turbine generator technology’”

[AC] Sentence has been amended.

3. [RC2] “Page 3: Equation (3) is missing. The equation number (3) is being indicated.

[AC] The equation indicating the aerodynamic power is now included.

4 to 9. [RC2] Specific comments to the text.

[AC] All the corrections to the text have been incorporated in the revised version.

10. [RC2] “Page 4, Eqt (12): Section 2.1.4 should include a brief explanation of how eqt (2) is used in conjunction with eqts (1,2) to determine the rotor torque.”

[AC] . The following explanation has been added:
The thrust force is calculated through Eq. (2) using the tip speed ratio from Eq. (4) and the rotor speed obtained from the solution of Eq. (5).

11. [RC2] “Page 5, section 2.2, line 17: it should be clarified in the text that linearity only holds for laminar flows. For turbulent flow, the non-linear equations have to be applied.”

[AC] . The following lines and references have been added in the revised document:

The linear models are only given for laminar flow, for steady flow the criteria for occurrence of turbulence is simply given by the Reynolds number; however, for unsteady flow neither the criteria used to predict flow instability, nor the manner in which it occurs is well understood. In the case of an oscillating flow component which is superimposed on a mean turbulent flow, the laminar flow solutions might be still applicable over a limited turbulent flow range. Both physical and empirical-based corrections to the shear stress model have been proposed for turbulent pipe transients (Vardy et al., 1993; Vardy and Brown, 1995). The correct modelling of turbulence in transient flows is an ongoing research topic; it is not addressed in this work.

Vardy, A. and Brown, J.: Transient, Turbulent, Smooth Pipe Friction, J. Hydraul. Res., vol. 33, p.435–456, 1995.
Vardy, A., Hwang, K., and Brown, J.: A Weighting Model of Transient Turbulent Pipe Friction, J. Hydraul. Res., vol. 31, p.533–548, 1993.

12. [RC2] “Page 7, line 16: a more elaborate explanation is required about the fundamental physics governing Pelton wheel operation: If the rpm is kept fixed, then the jet velocity and hence the press drop across the nozzle should be also fixed. k should also be fixed at the optimal value of 0.5 for optimal efficiency. An explanation of how this condition is applied in the numerical solution is necessary.”

[AC] . A new paragraph and figure 6 have been added to clarify the Pelton operation:
The theoretical Pelton efficiency is shown in Fig. 6 for different friction factors and constant bucket angle. Optimal efficiency is obtained when the water jet velocity is twice the tangential velocity of the runner at PCD. If the Pelton runner speed is kept constant, then the jet velocity and hence the pressure drop across the nozzle should be also kept constant in order to operate at maximum efficiency. A Pelton turbine operating with a constant rotational speed considerably simplifies the integration with the electrical grid. The constant rotational speed is realized by using a grid-connected synchronous generator, similar to most large scale hydroelectric generation plants.

13. [RC2] “Page 9, first line: `so-called’ ”

[AC] . Correction is made in revised version.

14. [RC2] “Page 9, line 9: this is linked to comment 12 above. Explain in the text why you have a constant pressure supply. To what extent is the control system able to maintain a constant pressure when intermittent wind conditions cause the water flowrate to change abruptly?”

[AC] . The following explanation is now included in section 3.3 Pump controller:
A constant pressure in the hydraulic network is desired, not only to keep the Pelton turbine operating at maximum efficiency as described in section 2.4 , but to be able to connect the water

pumps from the individual turbines to the hydraulic network. In addition, maintaining a constant pressure supply is beneficial in minimizing fatigue damage to the hydraulic system components

15. [RC2] “Page 9, section 3.2, first line: it is worth mentioning that maintaining a constant pressure supply is beneficial in minimising fatigue damage to the hydraulic system components.”

[AC] . Added, see previous comment.

16. [RC2] “Page 19, first line. Explain the difference between the control systems of Buhagiar et al and that being proposal here.”

[AC] . The following clarification is now included in section 3.2 Spear valve controller:
Another option is to implement a constant pressure control as proposed in (Buhagiar at al, 2016), where a feedback controller is used in combination with feed-forward compensation.

17. [RC2] “Page 11, line 9: Include a table with the derive values for the different gains.”

[AC] . Table 1 with Controller parameters of the spear valve augmented controller is now added.

18. [RC2] “Page 12, line 15: wouldn’t a compressed air or weighted accumulator help solve the problem of increased activity of the pitch controller?”

[AC] This could be possible if a pneumatic or hydraulic actuator is used for the pitching system, however in this work the pitch actuator and controller is maintained from the NREL reference turbine without modifications to allow an easier comparison of the proposed hydraulic concept.

19. [RC2] “Page 13, Figure 10: if the hydraulic turbine only includes an open-loop system with the pump housed at the nacelle, then a separate boost pump is required to be able to supply the sea water up the hub height. Has this been factored in the analysis?”

[AC] This is correct, the following lines have been added for clarification:
For the hydraulic turbines, a separate boost pump is required to supply the water to the pump located at the nacelle. Together with the filters and cooling system these components comprise the auxiliary equipment which is not included in the analysis. The same consideration is made in the conventional wind turbine technology where the lubrication, filtering and cooling power required by the gearbox and generator is not included in the analysis.

20. [RC2] “Page 18, line 1: add a full stop – ‘conventional technology. For the presented..’ “

[AC] Sentence has been corrected.

21. [RC2] “Page 18, line 3: quote here the percentage efficiency of the pump and that of the hydraulic network. “

[AC] Both efficiencies are included in the conversion from point A to point B. Making distinction of the separate efficiencies is in the author opinion more confusing and not consistent with the rest of the presented results.

22. [RC2] “Page 18: Conclusions - comment on any opportunities for costs reduction offered by the new concept”.

[AC] . Opportunities for cost reduction are now included in the introduction with references. The conclusions also include further work.

“Hydraulic systems have already shown their effectiveness when used for demanding applications where performance, durability and reliability are critical aspects. In particular, the efficient and easy generation of linear movements, together with their good dynamic performance give hydraulic drives a clear advantage over mechanical or electrical solutions. Furthermore, hydraulic drives have the potential to facilitate the integration with energy storage devices such as hydraulic accumulators which are important to smooth the energy output from wind energy applications (Innes-Wimsatt and Loth, 2014). In any industry where robust machinery is required to handle large torques, hydraulic drive systems are a common choice. They have a long and successful track record of service in, for example, mobile, industrial, aircraft and offshore applications (Cundiff, 2001; Albers, 2010). Therefore, it is evident that the use of hydraulic technology is recognized as an attractive alternative solution for power conversion wind turbines (Salter, 1984).
For the proposed concept, using high pressure makes it possible to reduce the top mass of the individual rotor-nacelle assemblies. For this reason, a high potential exists to reduce the amount of structural steel needed in the support structures as well; for a 5 MW turbine in 30 m water depth, 1.9 ton of structural steel of the monopile can be saved for every ton of top mass reduction (Segeren and Diepeveen, 2014). Using high pressures makes the use of fluid power an attractive means to transmit the captured energy from the rotor-nacelle assemblies to a central platform.”

The author hopes that the modifications to the manuscript and replies to the reviewers satisfy your requests.