

Considerations regarding the use of hydraulic drive systems in the construction and maintenance of wind turbines

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Abstract. In the current world scientific-technical context, the boundaries between the applications of the various engineering fields are in a continuous movement and interweaving; the field of hydraulics is a representative one for this, lately hydrostatic drives entering new areas. This material presents some considerations regarding two types of applications of the hydraulic drive systems dedicated to the wind turbines, respectively: 1) applications meant to replace a gear transmission, from the construction of a wind turbine, with a hydrostatic transmission; 2) applications intended to replace the crane, necessary for the installation and maintenance of a wind turbine, with a hydraulic pole, provided with a removable hydraulic cylinder, powered by a pump assembly with double overcenter valve.

Keywords: *wind turbines, hydrostatic transmission, hydraulic pillar, overcenter valve.*

1. Introduction

In 2018, the electricity obtained from wind power covered 5.5% of the total consumption worldwide, using capacities of energy production of 591 GW. Of the 181 GW representing new capacities installed in 2018 for electricity generation, 51 GW are wind turbines of various sizes. Most of this energy production is obtained with horizontal axis wind turbines. For this type of turbine, the location of the electric generator in the turbine platform leads to a significant increase in the mass of the platform, and implicitly the mass of the pillar supporting the turbine. The platform (excluding the rotor) represents between 20 ... 35% of the total weight of a large turbine reaching in some cases the order of hundreds of tons. In the case of the VESTAS V90, the platform weighs 75 tons, the rotor 40 tons, and the tower 152 tons. [1]. In the case of small turbines, the same values are kept as a percentage. In current offshore turbines, one of the main issues is gearbox failure, with current designs requiring replacement or capital intervention every 4 years. With the gearbox contributing to around 10% of turbine cost [2], such frequent replacements are very detrimental to the overall viability of offshore wind energy conversion. These problems can be overcome by using a hydrostatic transmission located between the wind rotor and the electric generator. On the other hand, small and medium turbines can be raised and placed with other means, besides the large cranes, whose use price is very high. And in this case, a hydraulic drive solution can be applied, using large lifting forces using one or two hydraulic cylinders properly positioned on the ground.

2. Use of hydrostatic transmissions in the construction of wind turbines

Basically, a hydrostatic transmission (HST), figure 1, transfers the rotor power P_{Rotor} to the generator while transforming the variable rotor speed n_{Rotor} into the required constant generator speed n_{Gen} . The rotor speed is regulated using the motor's displacement setting α_m [3]. Low wind speeds require low displacement settings as less flow is generated by the rotor, while higher wind speeds generate more flow and require larger motor displacements.

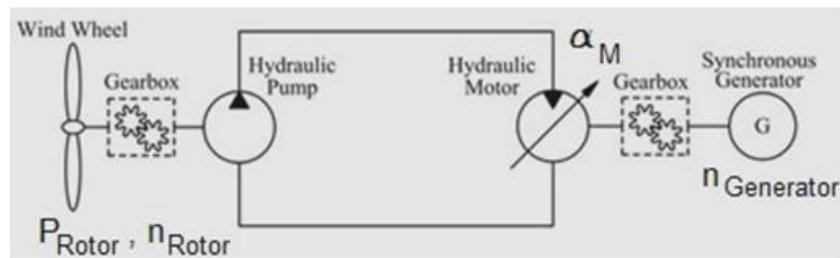


Figure 1. Fundamental principle of hydrostatic transmission (HST).

To ensure good efficiency throughout the wind speed, range a switched displacement hydrostatic transmission (HST) for a 1 MW turbine has been developed at IFAS Germany [4], see figure 2(a). The new architecture allows individual pumps and motors to be switched on and off depending on the current operating point. Two fixed displacement pumps convert the wind power into hydraulic power in the form of pressurized fluid. Two sets of motors are then used to drive two generators. Each component, except for the smallest pump, can be switched to idle mode, which allows different pump-motor combinations for different operating points. By allowing individual pumps and motors to be switched on and off depending on the current operating point the new architecture leads to an improved system efficiency throughout the operating range, see figure 2 (b).

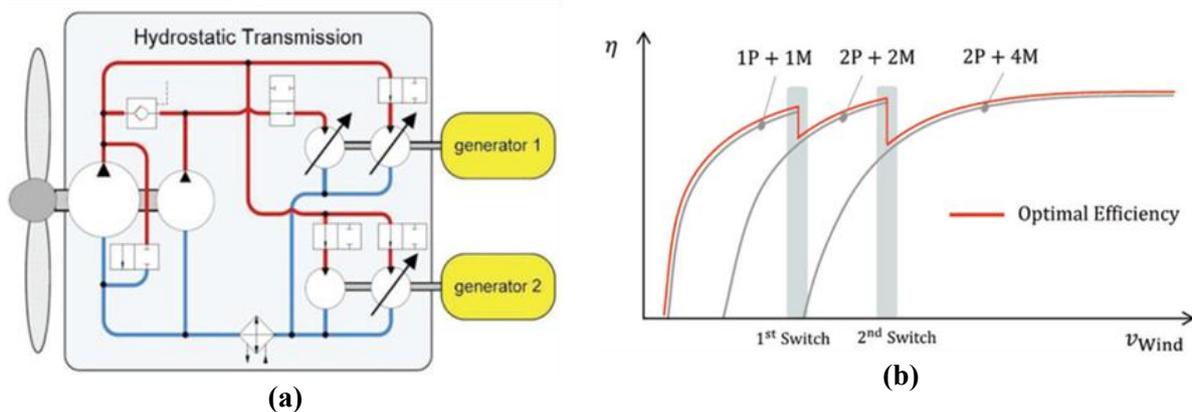


Figure 2. HST for a 1 MW turbine has been developed at IFAS: (a) Structure of the hydraulic scheme; (b) Diagram of system efficiency.

Another approach, also for an offshore turbine, is that in which the hydraulic pump driven by the wind turbine is a water pump, which sends water to a Pelton turbine, driving a generator, figure 3. A hydraulic accumulator is provided to supplement the flow that drives the turbine, as the wind speed decreases. This accumulator performs energy storage and reuse, but the idea has limited applicability due to the small volume of the accumulator, and the stored energy is mainly used to reduce the

variation in the drive speed of the generator. As in the previous case, the system uses seawater as a working fluid.

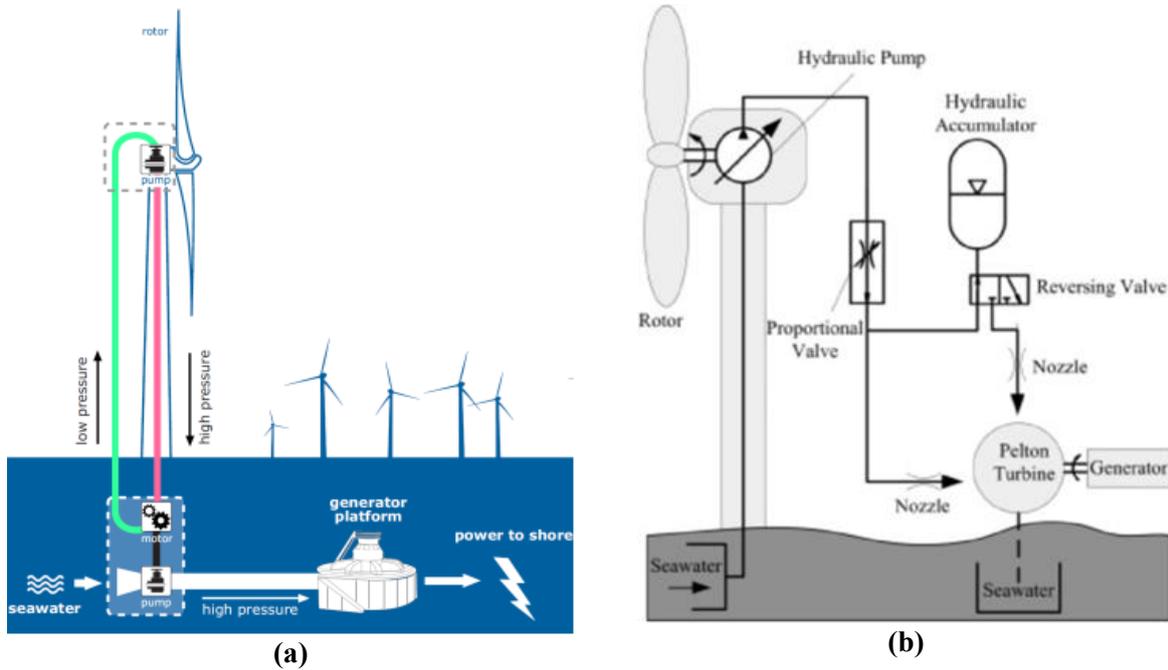


Figure 3. Offshore wind turbine with sea water: a) The principle works; b) Structure of the HST.

A proposed solution from Hydraulics & Pneumatics Research Institute (INOE 2000 – IHP Bucharest) aims, in addition to developing a hydrostatic transmission for a low power turbine (20...50 kW), to develop a pneumatic storage system, where the compressor is also driven by a hydraulic motor. After compression, the air is stored in a pressure tank, to be used for electricity generation using a pneumatic engine or for other purposes. The electricity thus obtained can be combined with that obtained in the main branch (hydrostatic transmission), but can also be used for auxiliary purposes (for auxiliary systems of the closed-loop hydrostatic transmission: cooling, additional pump drive, etc.). The diagram of the entire proposed installation, in parallel with the principle diagram of a classical wind turbine, is presented in figure 4. The pneumatic storage facility was approached at theoretical level and by physical realization within INOE 2000-IHP in 2016.

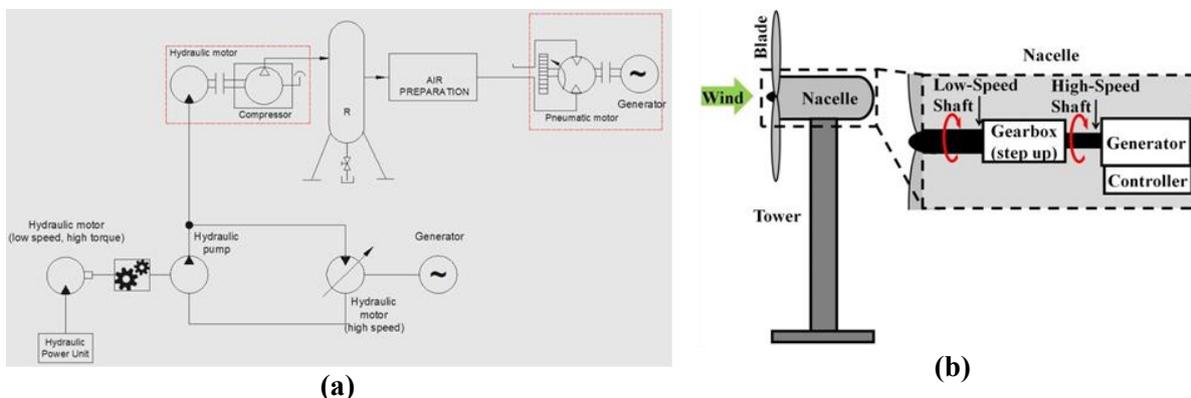


Figure 4. HST combined with energy pneumatic storage system (a), compared to a classical turbine (b).

Figure 5 shows the location of the main components of the wind turbine equipped with HST: the rotor and the main pump - in the nacelle; the hydraulic lines - inside the tower; the electric generator and the rest of HST components at the base of the tower.

In order to ensure the efficient and sustainable operation of the hydrostatic transmission, it is necessary to have a preliminary test in the laboratory. Figure 6 shows the main subassemblies of the stand where the hydrostatic transmission will be tested. The transmission will be executed in a closed circuit (excluding the volume loss recovery system). It will contain a fixed capacity main pump, a variable-capacity main motor, hydraulic circuits, hydraulic accumulators, safety valves, sensors, filters, heat exchanger, anti-cavitation volume loss compensation pump, hydraulic motor capacity controller with hydraulic circuit with feedback from the high pressure hydraulic circuit, aerodynamic rotor speed and wind speed.

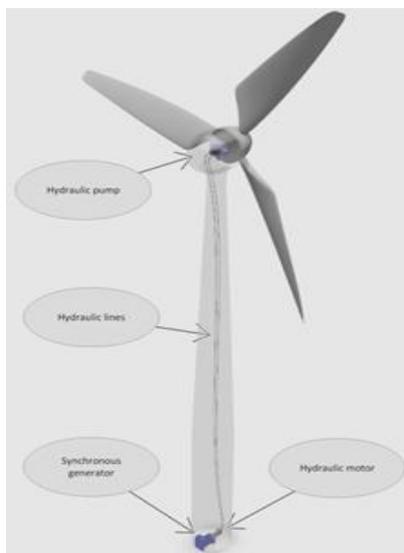


Figure 5. The main components of the wind turbine with HST

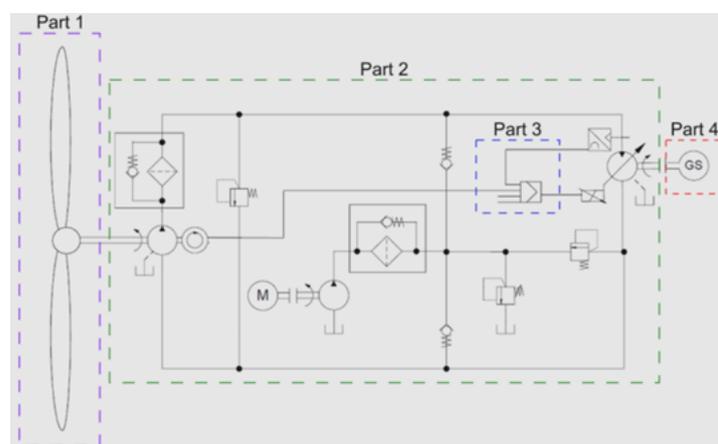


Figure 6. The subassemblies of the HST testing bench: **Part 1** = wind turbine simulated with variable electric/hydraulic motor; **Part 2** = HST for low-power turbines; **Part 3** = HST controller; **Part 4** = synchronous generator.

3. Use of hydraulic props when lifting / lowering wind turbines for installation / maintenance

A second direction of action on hydrostatic applications for wind turbines, proposed by INOE 2000-IHP, is a system of lifting the turbine completely assembled with hydraulic means.

The wind turbine supporting pillars, props and towers are components embedded in reinforced concrete foundations, and they have the following functions: to ensure the optimal operating height for the rotor; to support the turbine components; to allow access to operating, maintenance and repair personnel [5]. For small and medium wind turbines capacity three variants of supporting props (towers) are used: guyed, fig. 7; free standing, fig. 8 and hydraulic, fig. 9, props (towers). From a comparative analysis of the need for machinery and human operators for a repair intervention on a vertical-axis wind turbine mounted on a free standing prop, figure 10, and a horizontal-axis wind turbine mounted on a hydraulic prop respectively, figure 11, one can note the following:

- **For the turbine mounted on the free standing prop:** lowering / lifting of the wind turbine requires a large mobile crane and four operators (one controls the crane, two of them climb the prop and disassemble / assemble the turbine, while the latter coordinates the activities of the former three operators. In this case the repair operations are carried out on the ground and the disassembling and assembling operations are carried out at altitude, under special work safety conditions.

- **For the turbine mounted on the hydraulic prop:** lowering / lifting of the wind turbine requires a mobile pumping, distribution and control unit and a single human operator. In this case, all disassembling, repair and installation operations are carried out on the ground, under maximum safety conditions.

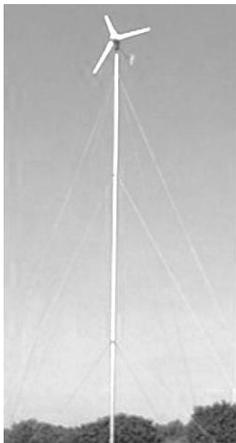


Figure 7. Guyed prop.



Figure 8. Free standing prop.



Figure 9. Hydraulic prop.



Figure 10. Free standing prop- turbine lifting by crane.



Figure 11. Hydraulic prop- wind turbine lifting by mobile pumping, distribution and control unit.

Savings made on intervention equipment (special mobile crane versus low power mobile pumping unit) and labor costs (four operators versus one operator) are obviously in favor of the solution with hydraulic prop. As to ensuring maximum work safety conditions, during the rigging operations on the hydraulic prop, the following must be considered: to ensure axial clearance of max. 0.5 mm in the hydraulic prop hinge and hydraulic cylinder fastening joints; to dimension the hydraulic cylinder so as to resist to double its maximum load; to place a modular hydraulic device inside the pumping, distribution and control unit, thus allowing control of the displacement of the hydraulic cylinder, both when lifting and lowering the prop, and lock of the hydraulic prop in place respectively, in the event of a malfunction of the hydraulic drive system.

In figure 12 the main subassemblies of a wind turbine mounted on a hydraulic prop are depicted, namely: 1 = horizontal-axis wind turbine; 2 = hydraulic prop mobile section; 3 = hinge; 4 = hydraulic prop fixed section; 5 = hydraulic cylinder; 6 = reinforced concrete foundation.

The hydraulic prop mobile section can be lowered to the ground or lifted upright and fastened with bolts, washers and nuts to the fixed section. Lifting / lowering the prop are done only under the action of a hydraulic cylinder with body and rod fastened by a hinge to the foundation and hydraulic prop mobile section respectively.

Figure 13 shows the main subassemblies of the pumping, distribution and control unit for the hydraulic prop in figure 12, namely: 1 = fixed flow gear pump; 2 = constant speed electric (or thermal) drive motor; 3 = oil tank; 4 = pump relief valve; 5 = 4/3 hydraulic directional control valve, electrically operated; 6.1, 6.2 = check valves of dual overcenter valve; 7.1, 7.2 = relief valves of dual overcenter valve.

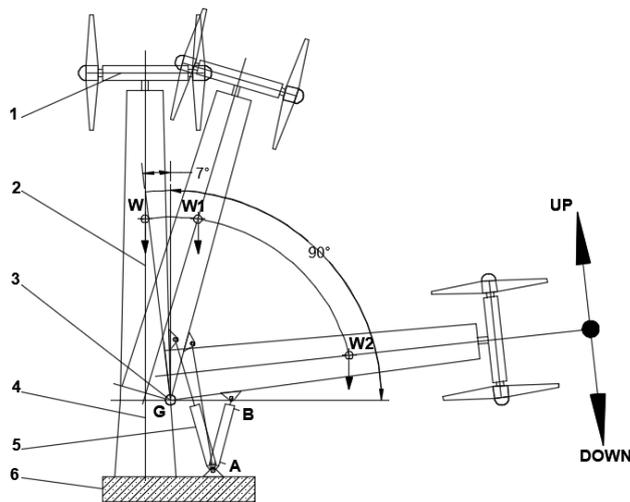


Figure 12. Wind turbine with hydraulic support prop.

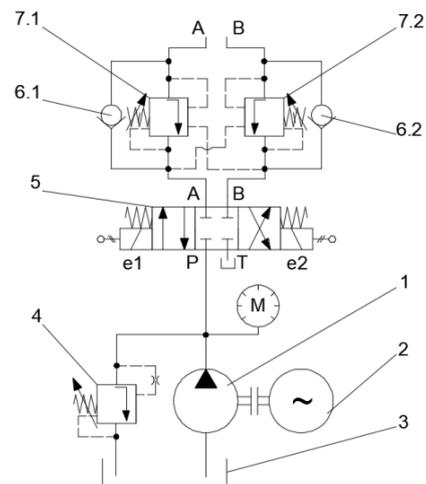


Figure 13. Pumping, distribution and control unit for a hydraulic prop.

4. Conclusion

It is proposed to promote a hydrostatic transmission for low-power wind turbines in order to increase the extraction of electricity from the available wind energy and also to demonstrate the following advantages: • the possibility of practical implementation of a transmission for low-power wind turbines, from standard and specially designed components, with a continuous variable ratio in the capacity adjustment range of variable hydraulic machines; • increasing the efficiency of wind turbines equipped with HST by using control strategies dedicated to the wind turbine system comprising the wind rotor, the hydrostatic transmission and electric synchronous generator; • the possibility of maintaining a predetermined constant rotational speed of the electric generator when braking or acceleration loads occurs at the wind rotor; • the possibility of obtaining a faster response to sudden wind speed variations compared to mechanical or electromechanical transmissions; • the possibility of low-maintenance of the turbine with reduced costs by placing some components on the ground.

The hydraulic prop is an economic solution for supporting small and medium size wind turbines: lifting and lowering the prop can be done by a single operator, totally safely and it does not require a crane. INOE 2000-IHP have developed and tested under real conditions a pumping, distribution and control unit which can actuate the hydraulic lifting / lowering cylinder of this type of prop.

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