

Hydraulic systems used for pitch control of wind turbines: a literature overview

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Abstract. This paper contains an analysis of some researches regarding hydraulic systems used for pitch control of wind turbines. As is already known pitch control is important for the aerodynamic efficiency of wind turbine influencing the energy capture, pitch angle being an important parameter by its influence on the angle of attack of the wind. This kind of control is also important in order to protect the turbine in the case of high values of the wind speed reducing the extreme loads. In many cases the system used to change pitch is a hydraulic system. Considering the tendencies in using hydraulic systems in wind turbines, some research directions resulted from reviewed scientific articles. In the case of high-power wind turbines, the load on the blade being important, the rotation of the blades around their own axes in order to change the pitch angle supposes great acting forces. Hydraulic systems provide them in reduce size equipment. The blade rotation may be controlled simultaneously, in the case of collective pitch control, or separately for each one of the blades, in the case of individual control of the blades.

1. Introduction

Wind energy is currently an important energy source in the world. There are still many unsolved challenges in expanding wind power, and there are numerous problems of interest to systems and control researchers.

As noted in [8], wind turbines can either be with a fixed-pitch or variable-pitch blades. Although, fixed-pitch turbines are less expensive, their inability to adjust pitch angle is an important disadvantage. Wind turbines can also be variable-speed or fixed-speed [29].

In order to configure the control objectives, it is important to establish the working operational region for the wind turbine, operational region that relates with the wind speed.

Burton et al. [4] states that there are three operational regions.

For power control of the wind turbine one can use:

- no control.
- power control by change of the rotor direction and swept area by:
 - furling;
 - tilting;
 - furling and tilting drawback.



- full power control through pitch (variable pitch means blades can pivot back and forth around their longitudinal axis) includes:
 - full power control through fixed pitch, passive stall;
 - hybrid systems, fixed pitch and stall control;
 - full power control through pitch change.

The active control of the turbine improves the aerodynamic efficiency, reduces the dynamic loads, increases the reliability and operating safety [1, 2, 14, 34, 36, 37].

Lately for the horizontal axis wind turbines are used hydraulic systems to transport energy to the ground [2, 24].

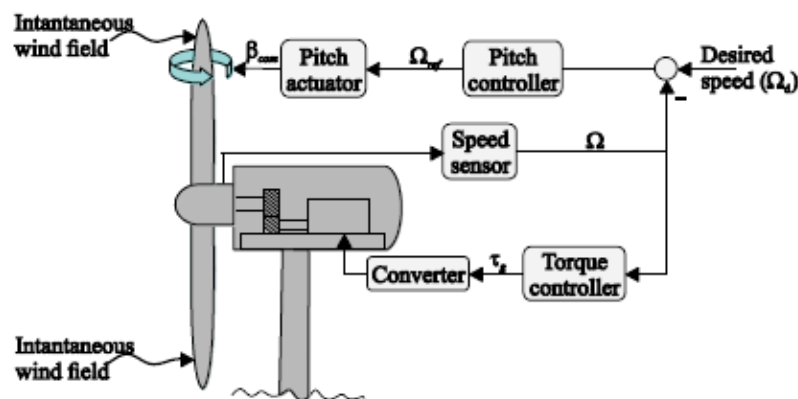


Figure 1. Wind turbine standard control loops [28].

2. Pitch control of wind turbines

Power coefficient depends with the angle of attack of the wind on the blade. It is important to keep the blades at the optimum angle according to wind speed. Consequently, the power extracted from the wind by rotor of the wind turbine is crucial determined by the pitch angle. On the other hand, the protection of the turbine at high values of the wind speed may be done by aerodynamic breaking namely turning the rotor blades about 90 degrees along their own longitudinal axis. Pitch control also limits the loads to wind turbine rotor and structure [17].

Usually the rotation angle is a fraction of a degree each time so the pitch control system must assure precisely the desired blades pitch. Over time different concepts of pitch control was proposed in order to reduce the load and to maximize the extracted power and problem remains open.

Early versions of wind turbines used passive stall control. In this case the wind turbine is subjected to varying load, variations of the power and torque [25]. In the case of passive stall control the angle of the blades is fixed and is based on natural stall. Stall control has the advantage of avoiding presence of control system and moving subsystems. Because of the advantages nearly two thirds of the wind turbines currently installed are stall controlled.

The typical curves for the pitch and stall-controlled wind turbines are presented in figure 2. Although the stall regulation requires fewer moving parts and cost, the pitch regulation is more flexible and results in higher power quality and efficiency and lower stress on the mechanical parts [10].

Hydraulic and electrical active pitch control, collective or individual, gains ground in wind turbine construction [7]. The feedback signal used is the rotational speed of the turbine and the commanded value is the pitch angle, simultaneously for all blades in the case of collective control. The modification of the pitch angle using the control system accelerates or decelerates the turbine and modifies. Regarding individual pitch control, researchers have in view load reduction and power optimizing.

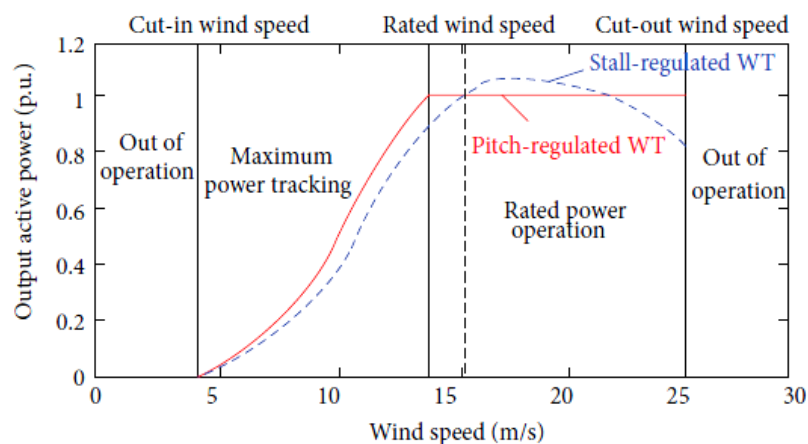


Figure 2. Power curves of fixed pitch and variable pitch wind turbines [10].

Collective pitch control means that the commanded value for the pitch is sent simultaneous to all the blades. This is the traditional method and most of the wind turbines are provided with on the basis of main advantages [28]. Implementation of collective pitch control uses a PID control law included in a feedback loop for which the error signal is the wind turbine rotor speed variation. In [13] one can find a proposed procedure which may be used to establish the control gain for PID controller. Wind turbine is a nonlinear system. In order to apply PID linear control law it is required the method of linearization around an operating point. The performances of the controller are determined by the operational conditions. Because of this, methods used to determine the gain are necessary for improving efficiency [2, 17, 20]. Modern adaptive methods are used also in the case of collective pitch control for modelling uncertainties [8, 9]. There are authors which propose both active and passive fault tolerant pitch controllers in some cases [35].

Last years was researched a new method for pitch control: individual pitch control. It is expected to be largely applied in the next generation of turbines to shift wind turbines design for more and more larger and flexible blades [34]. Researches presented in [3] demonstrate that a very significant reduction in operational loading can be achieved by means of individual pitch action, provided a suitable measurement of the asymmetric loading is available. In [11] it has been shown that collective pitch and cyclic pitch can be treated as decoupled, even if blade flexibility is considered. Recent development consists in using technology for feedforward control. In [19] is investigated preview-based disturbance feedforward control. Some other researches consider individual pitch control applications in offshore wind turbines [25]. As it regards very large wind turbines with rating up to 15MW a research on this case [5] confirm individual pitch control as a future.

3. Hydraulic systems for pitch control

Modern wind turbines use active pitch control, with electrical or hydraulic pitch actuators [6]. Comparing with electrical motor driving system, hydraulic driving system not only replaces the gear sets but also enhance the robustness. Hydraulic devices have also some already known difficulties such as lower efficiency and higher nonlinearity problems which should not be neglected.

A study was developed regarding leakage estimation for a wind turbine hydraulic pitching system [40] considering a time-varying load on hydraulic system. Leakage may reduce the effective stiffness and efficiency and these are the reasons it is considered a critical fault for hydraulic systems.

The structure chosen for that has classical components used in similar cases: a positive displacement pump, a servo valve or a proportional directional valve, a double acting single rod cylinder, a relief valve and a check. The force exerted at the cylinder rod produces the pitching motion with a slider-crank mechanism which connects the rod of cylinder to the pitching blade shaft through a rigid bar.

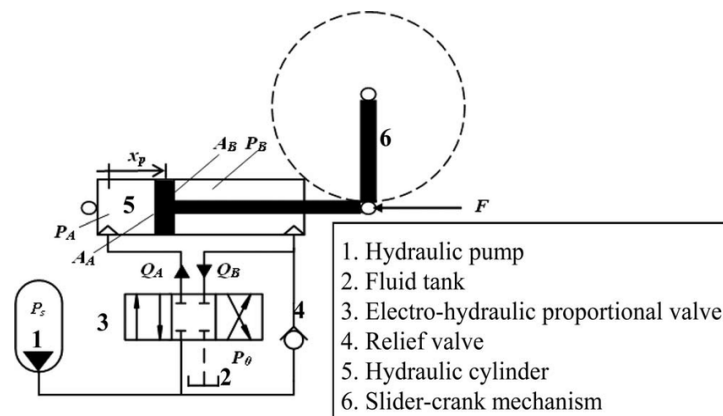


Figure 3. Hydraulic actuation system for wind turbine blade pitching mechanism [40].

In the last decade of nineteenth century was investigated an electro-hydraulic actuator by using gear pump and electromotor [12, 15]. This kind of system was revealed to be a high response and high energy efficiency hydraulic system. It involves an electric-hydrostatic driven system with an AC servomotor and a constant displacement internal gear pump for power-saving. A servo system structure with an AC servo motor and a constant displacement hydraulic piston pump realises both high response and high energy efficiency.

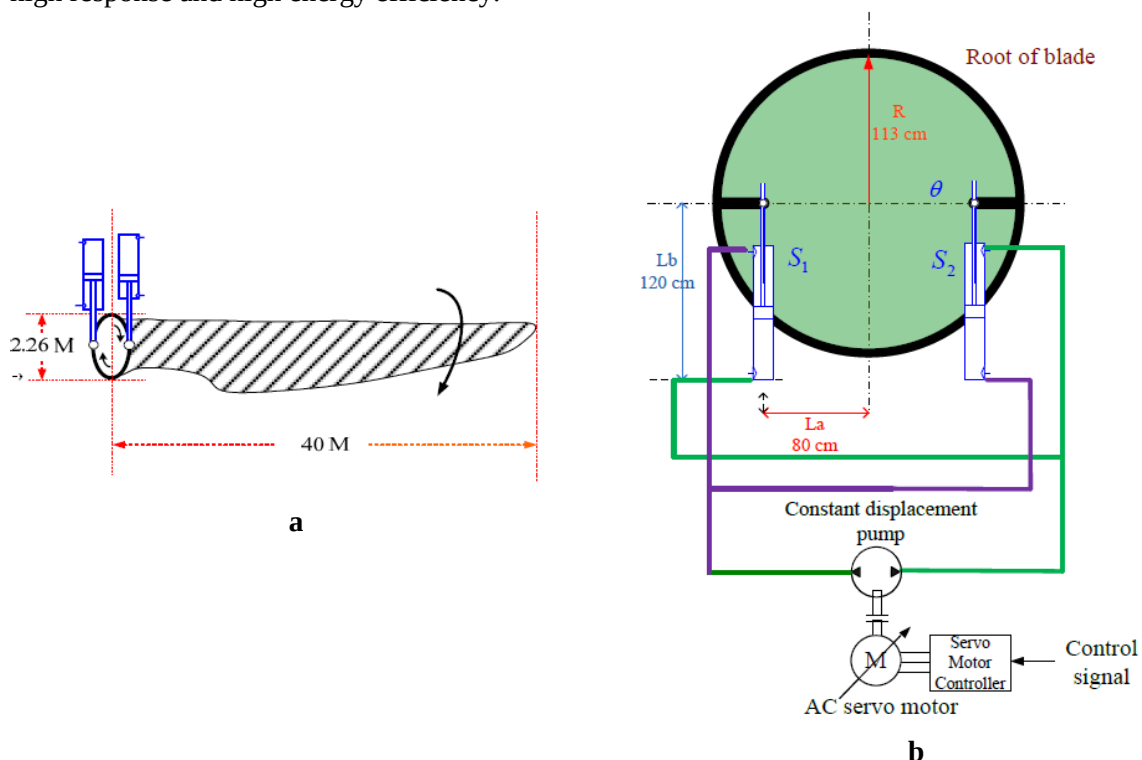


Figure 4. Novel hydraulic pitch control system

a) pitch control by two hydraulic cylinders; b) variable-speed hydraulic pump-controlled system [38].

The research developed in [6, 7] show effects of an adaptive fuzzy controller with self-tuning fuzzy sliding-mode compensation on pitch control performance. Hydraulic systems used in wind turbines are difficult to mathematical modelling due to the nonlinearities and it is necessary to simplify or linearize the equations in order to obtain a model-based controller.

The experimental results clarify that the pitch control controlled by self-organizing fuzzy sliding mode control can perform better than that controlled by fuzzy sliding mode control [7]. This structure is considered for collective pitch control in the test rig.

In [23] is stated that hydraulic pitching systems have slower response, but bear much larger stiffness, little backlash and higher reliability. Hydraulic systems are considered suitable in the case of high values of aerodynamic loads assuming that their failure cover an important portion among different factors of wind turbine failure.

A statistical study on Swedish wind farm during 2000 to 2004 [32], found that 13.3% of failure events during 2000 to 2004 were due to the hydraulic system. In order to prevent the failure of wind turbine must be prevented the failure of hydraulic pitching system

The functioning of the hydraulic system depends on the effective bulk modulus of the fluid and can be greatly reduced due to a small amount of air contamination. Reduction of fluid bulk modulus leads to the reduction of plant bandwidth, and thus reducing the stability robustness of the corresponding closed loop system. Similar issue occurs for significant leakage in the hydraulic system [39].

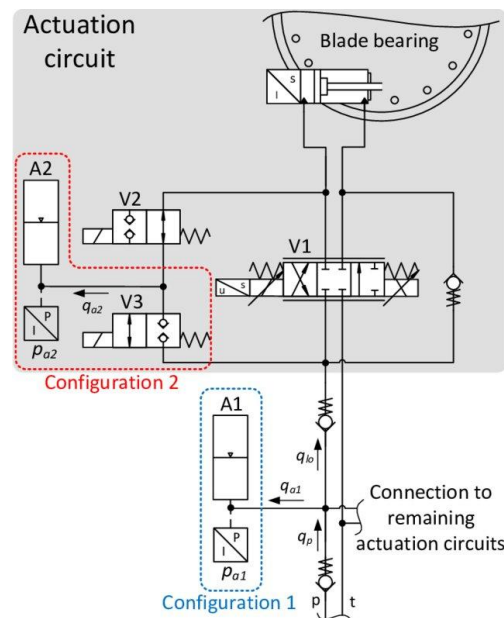


Figure 5. Individual pitch system diagram with accumulator in two configurations [21].

Liniger et al [21] propose a hydraulic system diagram for individual pitch control including an accumulator (figure 5) in two possible configurations. Considering that the accumulator is a component which has a high failure rate, especially through gas leakage, in the paper was proposed an estimation method in order to detect this specific problem.

Modelling the pitch control system has an important role in the development of systems, because it helps us to identify the possible abnormalities which can appear in the whole system, between certain parameters. A study, conducted by researchers from Université Libre de Bruxelles [31], considered the hydraulic circuit in figure 6.a and introduced a nonlinear mathematical model for certain situations under normal operating conditions and under malfunctioning of a hydraulic actuator, in a FAST/AERODYN wind turbine simulator (figure 6.b). It was noted that a linear model is enough for situations in which the system is operating in normal conditions, however, when it comes to the study of the diagnosis of fault, it is recommended to use a nonlinear model.

In [16] is presented an in-depth study of the thermo-dynamical processes involved in a hydraulic accumulator during operation, and how they affect the energy efficiency of the component

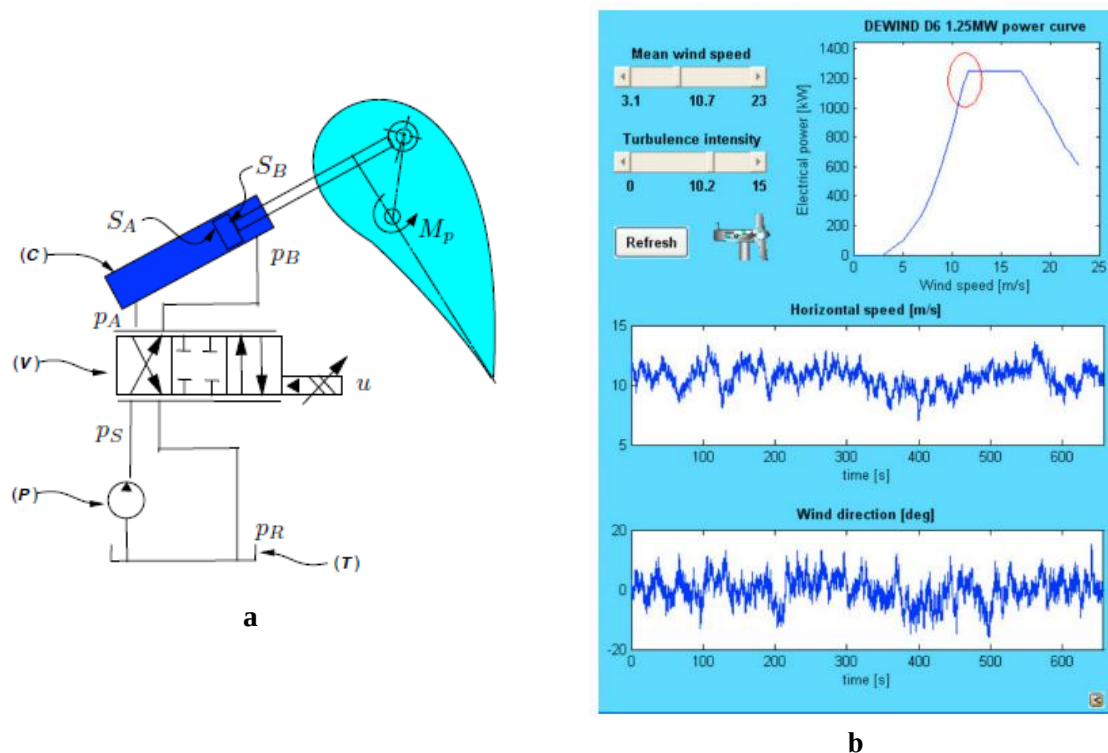


Figure 6. Modelling and simulation of hydraulic pitch control system

a) hydraulic circuit; b) wind simulation [31].

4. Conclusions

Considering the tendencies in using hydraulic systems in wind turbines, some research directions resulted from reviewed scientific articles. In the case of high-power wind turbines, the load on the blade being important, the rotation of the blades around their own axes in order to change the pitch angle supposes great acting forces. Hydraulic systems provide them in reduce size equipment.

The use of accumulator is beneficial but it is important to study the possibility of gas leakage in order to prevent failure. Regarding accumulators it is important to study the influence of and the recommended pre-charge pressure and the influence of temperature considering that along a year it has an amount of variation of near 60 Celsius degrees. This is important both for gas and liquid. The effective bulk modulus of the fluid has also an important influence.

It is important to analyse the PID control law and to state the error and the gain. Modelling the system is recommended.

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