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Dynamic Transmission Response of a Hydrostatic Transmission measured on a Test Bench

Johannes Schmitz
RWTH Aachen University, IFAS
johannes.schmitz@
ifas.rwth-aachen.de

Niels Diepeveen
TU Delft
N.F.B.Diepeveen@
tudelft.nl

Nils Vatheuer
RWTH Aachen University, IFAS
nils.vatheuer@
ifas.rwth-aachen.de

Hubertus Murrenhoff
RWTH Aachen University, IFAS
hubertus.murrenhoff@
ifas.rwth-aachen.de

Abstract

Within the scope of a current research project a hydrostatic transmission for wind turbines is being developed at IFAS. In this paper, two different strategies to control a hydrostatic transmission in wind turbines are presented and discussed. Main criteria are the optimal adaption of the system to the current wind situation and at the same time the reduction of loads on the system. In the second part of the paper the two strategies are analysed on a test bench. Therefore three different types of loads are applied considering the behaviour of the controller and the drive train. It is proven that a torque based controller has the ability to adjust the rotation speed and at the same time reduce peak loads on the drive train. In an outlook, the next steps on the way into a pilot plant are described.

KEYWORDS: hydrostatic transmission, hardware-in-the-loop, dynamic input response

1 INTRODUCTION

The high demand for renewable energy sources being driven by the target to replace all fossil and nuclear power plants has lead to a rapidly growing market for new energy technologies. One major sector here is wind energy. In the past 20 years a huge number of new turbines has been installed and within this process technology to generate electrical power from wind has been improved significantly.

Today the market is dominated by two different types of turbines, both using a three bladed rotor with a horizontal axle of rotation. The first type uses a mechanical transmission to transfer the slow turning shaft of the rotor into a higher rotation speed and drive a generator. With the second one no mechanical transmission is required since a huge generator is installed that can utilize the high torque directly and convert it to electrical energy. In both cases the rotation of the generator and therefore the frequency of the produced electricity is coupled with the turbine. Due to a variable rotation speed of the turbine a frequency converter is needed to connect each turbine to the grid. Furthermore reliability problems with mechanical gear boxes have occurred and the weight of the directly driven generator is becoming a problem when increasing turbine sizes. The usage of rare earths could reduce this disadvantage but their rapidly increasing costs due to high demand are a big element of uncertainty when making the decision on a drive train concept [1]. The most important value to compare the effectiveness of a turbine is the cost of energy since all resulting costs for production and operation are opposed to the produced energy.

A new concept, transferring the power via a hydrostatic drive train is considered to combine good efficiency and grid stability with high reliability and low costs. In the scope of a research project funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety of Germany, IFAS has developed a prototype of a hydrostatic transmission for wind energy plants of the 1-MW power class which is intended to replace the commonly used gearbox and the frequency converter. The idea is to use a slow turning pump that is directly connected to the turbine shaft to transfer the power into a high pressure oil flow and to use a hydrostatic motor that can convert this oil flow back into mechanical power to drive the generator. The high transmission ratio that is needed in a turbine can easily be achieved by the displacement ratio of pump and motor. By using a variable displacement motor the transmission ratio can be varied so that the generator can run at constant speed directly connected to the grid.

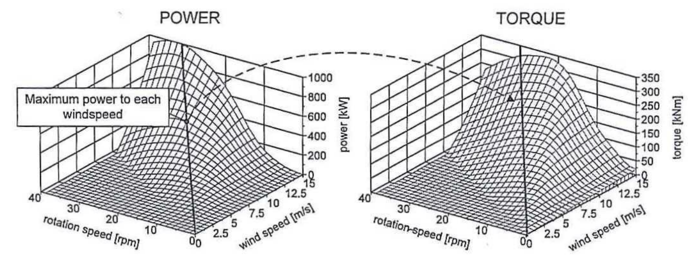

Figure 1: Power and torque of a three bladed wind turbine

One of the main requirements when dimensioning a transmission is a good efficiency at rated power as well as in partial load, where the turbine is operating most of the time. At the same time the rotor also influences the total power output, since the energy captured from the wind can be optimised by adjusting the rotation speed of the turbine to the actual wind situation. Figure 1 shows a power and a torque plot of a three bladed rotor over wind speed and over rotation speed. It can be seen that to each wind speed a specific rotation speed maximises the captured power. At the same time these points of operation are not at maximum torque.

Optimal power production of a wind turbine is achieved by optimizing the drive train to the important points of operation and simultaneous use of a control strategy ensuring operation in these points. Therefore a compromise between steady state operation and controllability has to be found. Chapter 2 describes previous presented work of optimization the hydrostatic drive train. The main properties of the control strategy are described in Chapters 3 and 4.

2 Previous work

2.1 Design of the transmission

Initial point for the dimensioning of the hydrostatic transmission was the selection of a wind turbine providing a torque curve over wind speed and rotation speed. Furthermore, previous simulations had proven that by switching of single pumps and motors of a hydrostatic transmission the overall efficiency in partial load can be increased. Subsequently, different combinations of pumps and motors were analysed leading to the transmission shown in Figure 2.

Two radial piston pumps with a total displacement of 66 l/rev drive three variable and one constant displacement hydraulic motor. The four motors are mounted to two generators. In partial load the pump with 80% of the total displacement can be switched off by opening a valve to low pressure. Due to the reduced flow rate to the motors three of these are switched off in this point of operation [2].

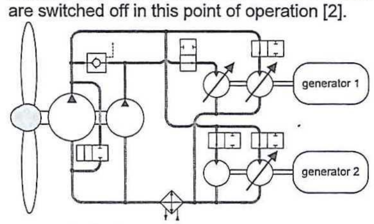

Figure 2: Hydraulic diagram of the hydrostatic transmission

2.2 Test bench to validate simulation results

Since not all component data for the simulation were available in this project a test bench to measure single components as well as the entire transmission was designed and built up in the IFAS laboratory. This test bench can be used to validate static and dynamic measurements. In order to operate the test bench efficiently and to avoid a 1.2 MW electric motor and a 1 MW generator, a hydrostatic power feedback was installed. It allows using the output power of the transmission to drive the slow turning input shaft. Figure 3 shows a picture as well as the layout of the hydrostatic transmission and the test bench drive. Two electric motors, powering two axial piston pumps (A1 & A2), feed in losses of the transmission and the drive. A radial piston motor (A3) is used to represent the wind turbine and drives the slow turning shaft. The output power of the transmission is fed back to the electric motors. In this way, the installed electric power is only 2x 200 kW whereas 1 MW can be applied on the turbine shaft.

In this case the turbine can speed up about 2 rpm and thereby store most of the peak energy of the gust. The maximum torque measured on the test bench is 120 kNm lower than the applied load. When this torque is going down again, rotation speed decreases also extracting stored energy in the flywheel and going back to constant operation.

4.4.3 Real wind conditions

In the last measurement all usual effects like the tower shadow effect, short gusts of wind and a changing wind speed in the long term were considered. Figure 17 shows the measured torque and the behaviour of the rotation speed with the two different control strategies.

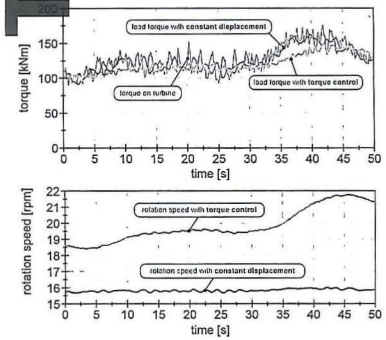

Figure 17: Measurement result of a real wind load

In case the motor displacement is set constant, the measured torque follows the applied torque and smoothes out torque peaks with a short delay. In case the torque controller is activated the power smoothening is much better due to a changing rotation speed. The short oscillations of this torque signal show that the controller of the transmission has to be optimised.

5 Conclusion and Outlook

In this paper two different ways to control a wind turbine using a hydrostatic transmission have been discussed and validated on a test bench. The transmission is adapted to the desired point of operation by switching off single components of the drive train.

It is shown, that the torque based control strategy delivers a good compromise between ensuring optimal rotation speed and guaranteeing continuous power production.

The uncontrolled input response of the drive train to a torque step-input shows the effect of the rotor mass moment of inertia on the response amplitude and frequency. The lower the rotor's inertia, the higher the overshoot and the higher the response frequency. In all cases the transmission response proved stable and well-damped. The controlled response to a torque step-input demonstrates how the effect of a sudden load on the drive train can be diminished to a gradual slope.

This ability is also demonstrated by the simulated load from an extreme gust. The uncontrolled response here results in an amplification of the rotor torque. Although the hydraulic drive train can cope and the response quickly dampens, this is undesirable. In the case of the controlled response, the effect of the gust is severely reduced.

The turbulent wind load case shows, although less apparent, that the controlled response presents a more smooth response. The smoothness of the drive train's response to dynamic loads contributes significantly to the quality of power delivered by a wind turbine.

In a next phase of the project funded by the Fluid Power Research Fund the different controller modules switching the components and controlling the rotation speed will be brought together with all required safety functions. In parallel all needed peripheral system like cooler and supply pumps will be installed at the test bench. An improved aerodynamic model that can run in the real-time simulation at the test bench will make it possible to apply direct data from wind measurements on the test bench. Thus the transmission will be acting if being installed in a turbine. At the end of this project the transmission will be ready to be installed in a pilot plant.

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