Adaptive hydraulic transmission for small power wind turbine

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Abstract

Hydraulic transmission of eolian energy to the ground is a research direction that we found in R-D programs related to renewable energy. Hydraulic transmission and driving included in the eolian plant has all the advantages of hydraulic driving. Small power horizontal-axis wind turbines equipped with adaptive hydraulic transmissions can operate at variable speed. The adaptive hydraulic transmission allows adjustment of the outlet to the consumer demands (power or constant speed), without affecting the performance of the turbine. Adaptive hydraulic transmission requires a constant speed of the motor shaft during variations in pump speed at the hydraulic motor shaft. For the cases analyzed, it is found that the adaptive hydraulic transmission behaves like a stable system of damped oscillatory type with good dynamic performance. The proper tuning of the regulator leads to an improved unit step response. The paper present the experimental testing stand concept, numerical simulation results and experimental data. The socio-economic impact of implementing small power wind turbines can be amplified by the fact that nearly half of the country's population lives in rural areas. These turbines are designed specifically for these rural areas.

KEYWORDS: adaptive hydraulic transmission (*AHT*), horizontal axis wind turbine (*HAWT*), small power wind turbine (*SPWT*).

1. Introduction

Wind potential is generally operated in areas with intense and constant wind, as the coastal areas of northwest Europe. Thus, large-scale wind turbines (500-1000 kW) have made remarkable progress in the last decade. A complementary orientation, with great expectations, is returning to small power wind turbines (<100 kW) integrated in decentralized/distributed applications, especially for rural areas with moderate winds. Compared with large wind turbines, small power wind turbines (SPWT) are more versatile and have a considerably higher technological development potential. In addition, SPWT, through its direct placement in areas of consumption, reduce energy losses due to energy transport from place of production to the user. American Wind Energy Association (AWEA) /1,2,3/ estimates that these features give SPWT an explosive market potential. SPWT development is one of the priorities contained in the European Research Agenda of Wind Energy Sector; European Wind Energy Association - 2005) /4,5/.

The economic, social and environmental impacts of energy production through SPWT are, on one hand, common to all renewable energy sources and, on the other hand, specific to wind energy using. Small power HAWT operate at moderate winds. In case of moderate winds, a particular problem is the difficulty to capture, convert and transmit relatively modest wind potential in terms of energy. There are limitations on the technical feasibility and performances related to energy conversion, transmission and practical use in various types of applications. Essentially, for small power HAWT to become profitable is necessary to increase the rate of extraction of basic energy and its use to consumers as a source of mechanical energy. Further, this energy can be used as it is or can be converted into electricity, hydraulic or pneumatic energy according to necessities and parameters of basic energy.

Generally, for energy conversion and transmission, solutions with mechanical speed multiplier or the direct coupling between the turbine and the slow electric generator are adopted. These transmissions contain difficult to manufacture or expensive components: slow electric generator, gear transmissions, frequency converters etc.

Replacing the mechanical speed multiplier with a hydraulic transmission can lead to a more robust behaviour and competitive cost prices /6,7,8,9/. If hydraulic transmission take over and the speed multiplier function, the system can use series AC motors as electric generator. This may prevent the electric recovery followed by a frequency inverter. To be competitive with systems with turbine speed control option (optimal

speed), in case of hydraulic transmission the speed control can be achieved by adjusting the displacement of pump from hydrostatic transmission. The wide range of variation of power and speed impose the use of positive displacement hydraulic machines, respectively adjustable volume pumps. Hydraulic transmissions have a reduced gauge, a high power density, they allow a continuous and widely adjustment of the output mechanical parameters (are flexible) and offer the possibility to attach rotation speed and/or torque adaptive control systems into conversion subsystem /10,11,12,13/.

Small power HAWT equipped with adaptive hydraulic transmission can operate with variable rotation speed. The hydraulic transmission allows the adaptation of the control outputs to user's requirements (constant power or speed), without affecting the performance of the turbine, which can operate at optimal parameters until the power limit /14,15/.

The paper presents the concept of an adaptive hydraulic transmission for small power wind turbines and the experimental results obtained for. The hydraulic transmission is based on specific operation elements of a wind turbine under variable wind speed and variable load at user. The realized experimental stand allows the testing of hydraulic transmission behaviour at turbine shaft speed variation (due to changes in wind speed) and at hydraulic motor shaft load variation.

2. The concept of adaptive hydraulic transmission for small power HAWT

The block diagram for the adaptive hydraulic transmission designed for low power horizontal-axis wind turbines is shown in **Figure 1**.



Figure 1: Block diagram of the adaptive hydraulic transmission system

Wind turbine **WT** transforms aeraulic power (wind speed *v*) in mechanical power with parameters ω_1 (angular velocity) and M_1 (moment). The pump with adjustable unit

volume **PAV** transforms mechanical power into hydraulic power with parameters Q (flow) and p (pressure). The hydraulic motor **HM** transforms hydraulic power into mechanical power transmitted to load **L**.

The feedback loop includes speed transducer **ST** which gives signal U_{ω} . This is compared with reference value U_r . At the outlet of the regulator **R** results the command value *c*. The servomechanism **SVM** transforms the command value into an execution value *m*, which acts on the pump flow control elements **PAV**.

In the absence of the feedback loop, changes in wind speed v will increase pump speed, pump flow and therefore the drive speed of load S as well. Similarly, load variation leads to a decrease in motor speed.

The feedback loop, which depends on the value of the engine speed *MHR*, allows maintaining a constant speed imposed by the reference value U_r on the hydraulic motor shaft, under variations of both the wind speed and the load *S*. The adaptive system allows adjustment of two disruptive values: wind speed *v* and load *S* variation on the engine.



Figure 2: Structure of auto adaptive hydraulic transmission

3. The testing stand

In order to simulate the working conditions of an adaptive hydraulic transmission designed for small power HAWT, we have made a test stand with the configuration showed in **Figure 2**.

Transmission module includes the pump 12 with adjustable flow and the hydraulic motor 16, connected in closed circuit. Double pump unit 12 is composed of a main unit with adjustable volume (flow) and a unit with constant flow that allows the compensation of hydraulic losses and the command of actuator in order to change the geometric volume. The pump 12 feeds the non-adjustable rotary hydraulic motor 16 which, in real system, either drives an electric generator or a load of mechanical nature, through the shaft 19.

Simulation of wind speed variation, which causes a change in speed at pump shaft 12, is achieved by asynchronous motor 13, controlled by frequency converter CF. Simulation of hydraulic rotary motor shaft load at 16 is achieved by the loading module, which consists of hydraulic pump 17 driven by shaft 19.

The change of load for hydraulic motor 16 is made hydraulically by adjusting the pressure through the valve 20 from the output circuit of pump 17. Information about pressure and flow values are given by transducers 18 and 21.

The adaptive operating condition for the hydraulic transmission from Figure 2 is to maintain constant the rotation speed at shaft 19 from the hydraulic motor output, shaft which drives the load (an electrical generator or a mechanical system whose rotation speed must maintain constant). To achieve the condition referred to, a control loop was considered, which consists of a data acquisition system DAS that collects information on rotation speed, torque or power to the shaft 19 and transforms these data in order to be entered into the computer and processed according to the schedule imposed. Here, these values are compared with reference value of the required parameters. Correction signal is processed by a controller and transmitted through a proportional distributor to actuator which will correct angle of the drive pump 12 (proportional distributor, linear motor, pressure valves and pump that compensates the flow, are embedded in the same block, which is why these are not marked in Figure 2). Pressure measured by transducer 18 and flow measured at flow-meter 21, are taken by DAS, but only for their digital display.

In addition, on the experimental stand were also introduced two more modules, namely filtering module and the open circuit module. Filtering module is designed to filter oil

which returns to the tank from compensation pump and pump drain. Open circuit module allows to test on this stand other elements from the structure of a hydraulic transmission. In the described experiment, this module is not used for research purposes.

Figure 3 presents the overall experimental stand. There are shown the load module, the closed circuit module, the control panel and the frequency converter.



Figure 3: General view of test stand

Technical characteristics of the working modules:

Load module - maximum flow: 20 l/min, maximum pressure: 300 bar, closed circuit module - variable work flow: 0...27 l/min, maximum pressure: 300 bar.

Data acquisition and control system include the following elements:

- Transducers (sensors) Pressure transducer 0-400 bar, accuracy ± 0.25% BFSL class; Flow-meter 10...318 l/min, working pressure of 0-400 bar, accuracy ± 0.25% BFSO class, inductive rotation speed sensor 0-3000 rpm, accuracy ± 0.15% BFSO class
- Distribution system National Instruments Compact FieldPoint Controller cFP 2020; Analogue module cFP AIO 600
- 3. Acquisition board NI DAQ DAQCard-6036E

- 4. Computing system IBM PC x86 type
- 5. Software LabView 8.5 and LabView 8.5.1 Real Time

An important component of experimental stand is the automatic control loop, shown as block diagram in **Figure 4**.



Figure 4: Block diagram of automatic control loop

The transducers receive the physical phenomenon and convert physical parameters (pressure, flow etc.) in a unified type parameter, mainly voltage, the resulting signal being proportional to the variation of monitored parameters.

Conditioning modules transform electrical signals generated by transducers in a form that the DAQ acquisition board can accept. Examples of conditioning are: signal amplification, linearization, filtering, isolation etc.

Acquisition board converts the electrical signals through its basic component: the analog-digital signal converter. A numerical value is attached to each voltage supplied by transducers, thus allowing interpretation of physical values by computing systems.

The virtual instrument used on test stand consists of the hardware - digital analog converter (Compact FieldPoint distribution system and data acquisition board NiDAQ) and the software. Both hardware and software were taken in conjunction with hydraulic stand working necessities. The resulting virtual instruments include meters and controls for automation installation. The graphical interface of this program includes controls and indicators graphically similar to real devices and the user can adjust them same way like real elements. Virtual instrumentation associated to hydraulic stand was developed using LabVIEW graphical programming environment in order to be used for signal acquisition, measurements analysis and graphical or tabular data presentation. The front panel includes a series of bar graphs that display signals corresponding to

physical parameters monitored through hardware part that receives signals from transducers mounted on the hydraulic stand. Also through the front panel, we can input the reference value (SETPOINT) of the control system (numerically or through a virtual potentiometer). The front panel was created using display elements and control procedures extracted from the library of LabVIEW programming environment and a series of filtering and signals interpretation procedures, adapted to the experimental stand. Data obtained during the experiment can be viewed numerical, as indicators corresponding to measured quantities or as graphic in window created especially for this purpose.

4. Experiments and results for the series of researches made for constant load at hydraulic motor shaft

Experimental researches were performed for a constant torque at the shaft of the rotary hydraulic motor simultaneously imposing the condition of constant rotation speed. Resistant torque of the motor is controlled through the pressure Δp from the load pump. Two values of reference rotation speed at the shaft of rotary motor (*n* = 600 and 700 rpm) and two values of load (Δp = 50 and 75 bar) were considered.

With these conditions, the step responses of the system to changes in rotation speed of the shaft of pump that simulates wind turbine rotor were obtained.

For each group from the series of researches there have been followed the next steps:

- The load pressure at the load pump is set at Δp value;
- The rotation speed at the hydraulic motor shaft is brought to the reference value, by switching the frequency converter;
- The reference value is entered in the computing system through virtual potentiometer;
- The rotation speed of the pump that simulates the turbine rotor is modified with $\Delta n = 50, 100, 150$ rpm, through the frequency converter;
- The step responses of the system are extracted from the computing system for each series of research.

In this way, we get step responses of the system that are shown in **Figures 5 to 8**. For all cases it is found that, for the increase of rotation speed of pump shaft with Δn , the response is of periodically amortized type, stabilizing near the reference value. Increasing the pump rotation speed leads, at the beginning, to an increase of the flow. After that, the stroke of the pump adjustment element changes, the flow decreases and the rotation speed error is corrected.



Figure 5: Step responses to changes in rotation speed of drive pump for reference rotation speed at the motor of 600 rpm and Δp = 50 bar



Figure 6: Step responses to changes in rotation speed of drive pump for reference rotation speed at the motor of 600 rpm and Δp = 75 bar



Figure 7: Step responses to changes in rotation speed of drive pump for reference rotation speed at the motor of 700 rpm and $\Delta p = 50$ bar



Figure 8: Step responses to changes in rotation speed of drive pump for reference rotation speed at the motor of 700 rpm and Δp = 75 bar

The step response analysis shows that, increasing the pump rotation speed, there is a tendency to increase motor rotation speed, but finally the speed reaches the imposed reference value. The system is stable, of a damped oscillatory type.

The dynamic regime analysis shows that overshoot is acceptable, less than 12%. The overshoot lowers with the decreasing of the applied speed step Δn .

The increase of reference rotation speed of the pump (figure 7 and 8) lead to an improvement in step response by reducing overshoot, raising time and duration of transitory regime. It follows that under a certain value of rotation drive speed of the pump increases the overshoot and duration of transitory regime. By giving a proper adjustment to regulator is possible to improve the dynamic response of the system.

The step response obtained by experimental tests is characterized by a longer period of transitory regime than the one obtained by numerical simulation. This is because, in the case of numerical simulation, a step variation of the signal can be effectively applied. In the case of experimental research conducted on the stand, the variation of rotation speed of pump that simulates turbine rotor can be achieved only in the ramp, because adjustment is achieved by manual handling of several potentiometers.

5. Conclusions

- Adaptive hydraulic transmission helps maintaining a constant rotation speed to motor shaft at step variations induced in rotation speed of the pump that simulates the wind turbine;
- Step responses obtained experimental have an adjustment error higher or lower related to reference rotation speed. The adjustment relative error does not exceed the limits allowed by the literature;
- Adjustment errors are inevitable due to the existence of inevitable backlashes in the tilt adjustment mechanism of the pump disc;
- Self-adaptive hydraulic system behaves in real operating conditions (wind speed variation) as a dynamically stable system.

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