ISSN 1454 - 8003
Proceedings of 2024 International Conference on Hydraulics and Pneumatics - HERVEX
November 13-15, Băile Govora, Romania

CONSIDERATIONS REGARDING THE IMPLEMENTATION OF HYDROSTATIC TRANSMISSIONS IN WIND TURBINE POWER TRANSMISSION SYSTEMS

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Abstract: *Hydrostatic systems are characterized by the possibility of generating and transmitting large forces and moments, which are more difficult to achieve mechanically or electrically. The hydraulic energy generator (pump) can be connected to the drive element (hydraulic motor) with rigid or flexible pipes, which allows the latter to be located at a distance from the pump. If this principle is applied to a wind turbine, it results that the electric generator, which is usually located in the nacelle and is mechanically driven, can also be mounted on the ground and driven by a hydraulic motor. In this way, the mass located in the turbine nacelle decreases significantly, and the hydrostatic transmission also brings other advantages, related to maintenance, speed regulation, hydraulic energy storage, etc. The article presents a proposal for a hydrostatic transmission for a low-power wind turbine (below 100 kW).*

Keywords: *Wind turbine, hydrostatic transmission, nacelle, mass, simulation, electric generator*

1. Introduction

In recent decades, the perspective of depletion of fossil fuel resources, their increasing price and the problems related to pollution from the combustion of these fuels have led to an increasing exploitation of renewable or "green" resources. Among these, wind energy and solar energy have stood out, their exploitation capacities increasing annually by significant percentages. In 2023, this increase was 36%, with installed capacity reaching 473 GW. In addition to reducing pollution, another positive aspect of the exploitation of renewable resources is the large number of people employed in the field; thus, in 2023, 13.7 million people were involved, an increase of 8% compared to the previous year. The exploitation of renewable energy sources contributes 13% to Total Final Energy Consumption, in 2023, the same percentage as in the previous year.
Regarding wind energy, Europe had a total installed capacity of 272 GW at the end of 2023, of which 18.3 GW were added in 2023. In Romania, these values are 3.1 GW and 72 MW respectively, with wind energy covering 14% of the country's electricity consumption [1, 2].
In terms of wind energy conversion means, horizontal axis wind turbines have proven to be the most suitable, both for onshore and offshore installation; in the latter category, the largest turbine commissioned in 2024 has a capacity of 26 MW. The nacelle of this turbine is located at a height of 185 m and weighs around 1000 tonnes; a significant part of this weight is the electric generator and the mechanical transmission between the wind rotor and the generator, as well as the auxiliary systems.
In recent years, in addition to the cost of materials used in wind turbines, environmental issues have become increasingly important; this concerns pollution associated with the manufacture of components, as well as their transport by sea or land and their installation at the intended location, all of which are proportional to the mass of the turbine [3].
This is why reducing the suspended mass in the nacelle becomes increasingly important as the capacity of wind turbines increases. Moving the generator and mechanical transmission to the base of the turbine reduces the total weight of the nacelle, but also the weight of the supporting tower and

the base in which it is mounted. According to [4], for a 3 MW turbine, replacing the transmission lightens the nacelle by approx. 35%, and the weight of the tower will be reduced by a percentage between 33 and 50%. Even if these values cannot be scaled for current turbines of higher power, it is obvious that the weight reductions, and implicitly the costs of manufacturing, transportation, etc., are significant [5, 6].

Even though in the past the issue of reducing the cost of wind turbines was not so current, concerns regarding the realization of hydrostatic transmissions for wind turbines can be found since the 1980s, increasing with the installed power. Thus, the first significant achievement is the SWT-3 turbine, with a power of 3 MW, produced by the Bendix Corporation, and put into operation in 1980. The hydrostatic transmission was realized with 14 fixed-capacity hydraulic pumps and 18 variable motors. Between the rotor and the hydraulic pumps, as well as between the hydraulic motors and the electric generator, speed amplifiers with gears were mounted.

The Norwegian company ChapDrive AS took a step forward by using an all-hydraulic transmission, without mechanical speed amplification. For this, it used a low speed hydraulic pump, fixed displacement, and a high speed hydraulic motor with variable displacement, which drives the generator. The turbine was developed in various power variants, with tests being carried out on models from 50 kW to a turbine with a power of 900 kW; the next step was the design of a variant with a power of 5 MW.

Interest in the field of hydrostatic transmissions for wind turbines can also be found in Germany, at RWTH Aachen, where a transmission testing and simulation platform has been developed [7].

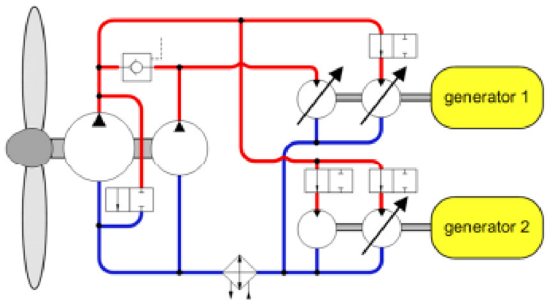

Fig. 1a. Hydrostatic transmission simulation platform for 1 MW wind turbines

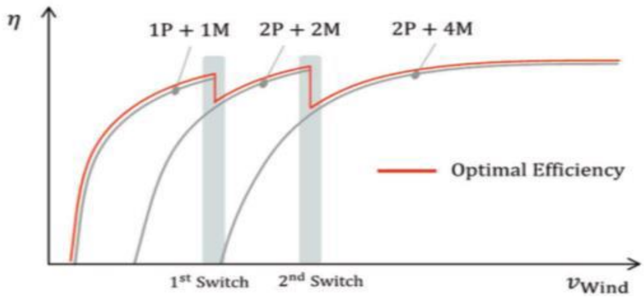

Fig. 1b. Overall system efficiency

The functional model consists of 2 fixed displacement hydrostatic pumps, one of which has a capacity 4 times greater than the other. 2 electric generators are driven by 2 hydraulic motors; of the 4 motors, 3 motors are fixed displacement and one has variable displacement. The latter is used alone at low wind speeds; at higher speeds the other drive motors are also introduced into the circuit.

2. Material and method

As shown, reducing the suspended mass has beneficial effects in several directions (economic, ecological, etc.). The importance of this solution increases as we consider larger turbines.

In any case, if the electric generator is to be placed on the ground, the energy of the wind rotor will have to be transmitted to the generator; the solution can be mechanical, hydraulic or a mix between the two types. As a rule, the purely mechanical transmission is used for low powers, while the hydrostatic transmission can also be used for high powers (even off-shore turbines, in the order of MW). It is also mandatory that a hydrostatic transmission has a component that allows the modification of the driving speed of the electric generator; most of the time, this component is a variable displacement motor (figure 2).

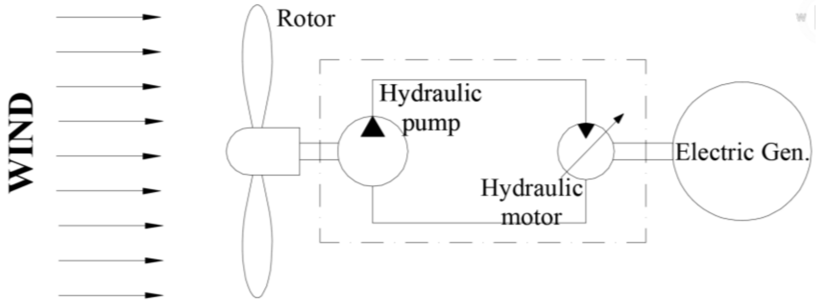

Fig. 2. Schematic diagram of a hydrostatic transmission for wind turbines

The Research Institute for Hydraulics and Pneumatics in Bucharest considered the creation of a mixed transmission, composed of 2 open-circuit hydrostatic transmissions and a mechanical transmission between them. The 2 hydrostatic transmissions are located in the nacelle, respectively on the ground, and the mechanical connection between them is made using a tubular shaft.
The first hydrostatic transmission, with the symbol HST1, is located in the turbine nacelle and acts as a speed amplifier; thus, the wind rotor drives an orbital hydraulic motor which in this case acts as a pump, with a displacement of 1000 cm^3/rev. The pump driven by the rotor transmits energy to a motor with a capacity of 34 cm^3/rev, both hydraulic machines having a fixed displacement. In this way, the speed of the wind rotor is amplified by approx. 30 times.
The hydraulic motor is coupled to a mechanical shaft, which transmits the rotational movement to the second hydraulic circuit (HST2); the shaft drives a fixed pump, with a displacement of 34 cm^3/rev. The pressurized fluid is transferred to a variable hydraulic motor, with a maximum capacity of 49 cm^3/rev, which drives the electric generator. By changing the displacement of the hydraulic motor, the constant generator drive speed is maintained.
The turbine simulated in AMESIM has a nominal power of 42 kW at a wind speed of 10 m/s and a corresponding speed of 100 rpm. For this power, a wind rotor with a diameter of 15 m is required, and the transmission shaft has a length of approx. 10 m.

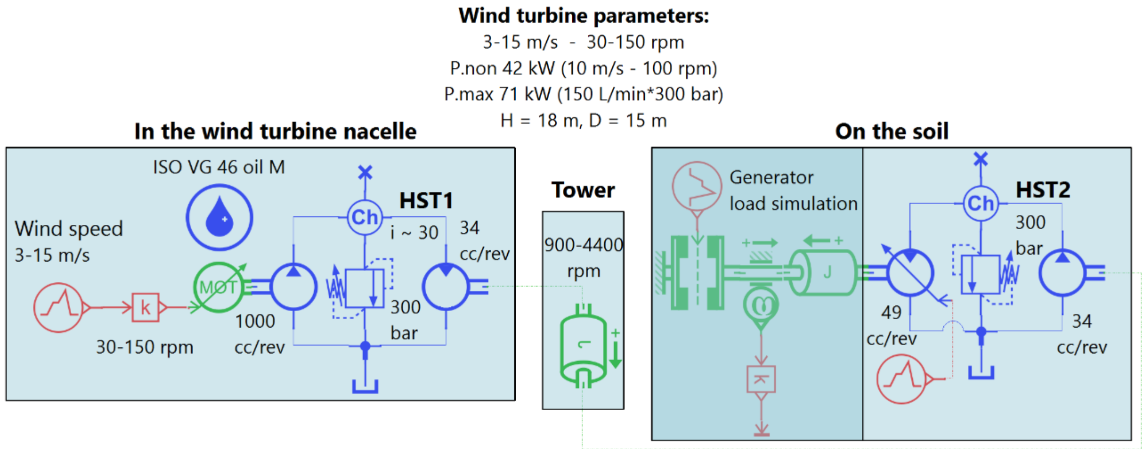

Fig. 3. Numerical simulation network of the wind turbine equipped with hydrostatic transmissions

3. Results & discussion

After running the simulation program of the turbine operation, having the wind speed as a variable parameter, the graphs in figures 4 and 5 resulted.
These graphs show the variation of the main parameters of the wind turbine depending on the wind speed. This parameter influences the power, which is proportional to the rotor speed, but also to the generator drive motor speed.

The turbine produces 42 kW at a wind speed of 10 m/s, which drives the turbine rotor at 100 rpm; at this speed, the variable hydraulic motor in HST2 has a speed of approx. 3000 rpm. The simulations were performed up to a wind speed of 15 m/s, at which the turbine has a power of 71 kW and a drive speed of the HST2 pump of 4400 rpm. At a wind speed of 15 m/s, the rotor rotates at 150 rpm.

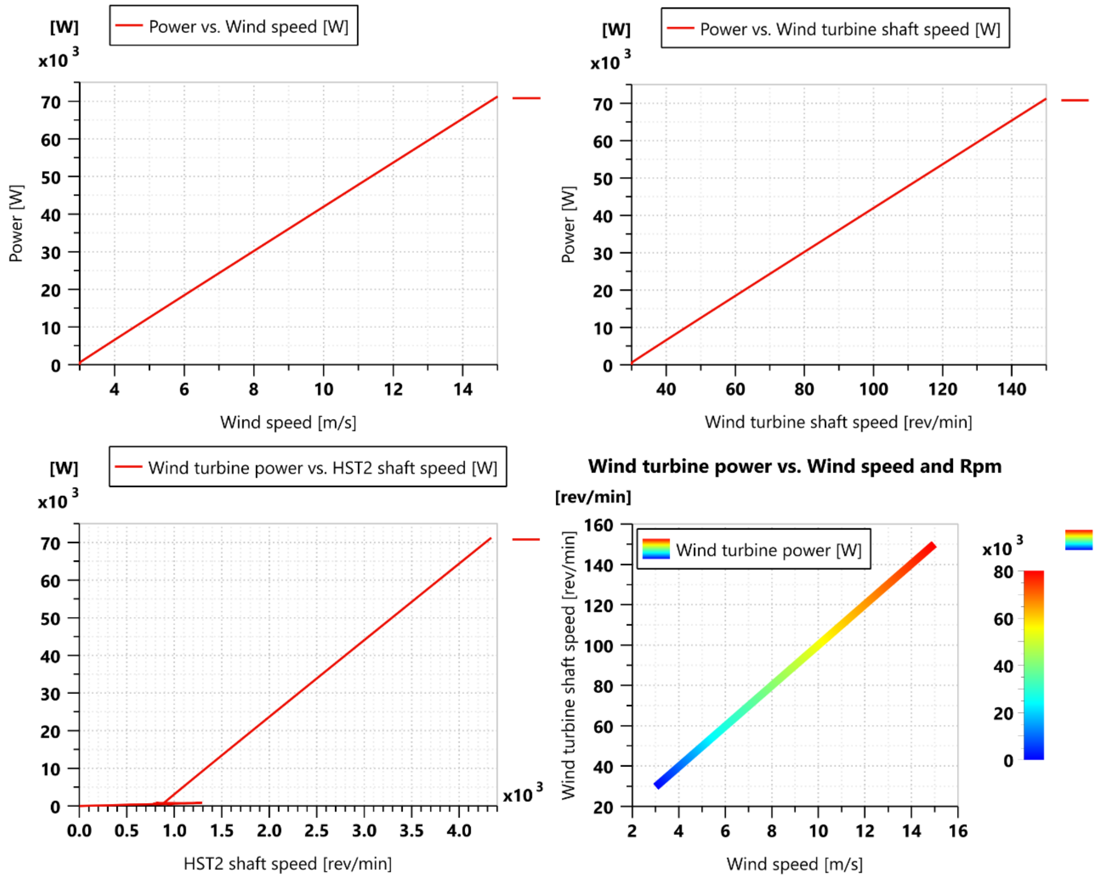

Fig. 4. Power as a function of wind speed, wind turbine shaft speed and speed of the hydraulic pump in the structure of HST2

At the electric generator level, it is of great importance that the drive speed and frequency are kept constant, at values of 3000 rpm and 50 Hz respectively. This is achieved by continuously changing the capacity of the hydraulic motor. The results for the 2 parameters are presented in figure 5.

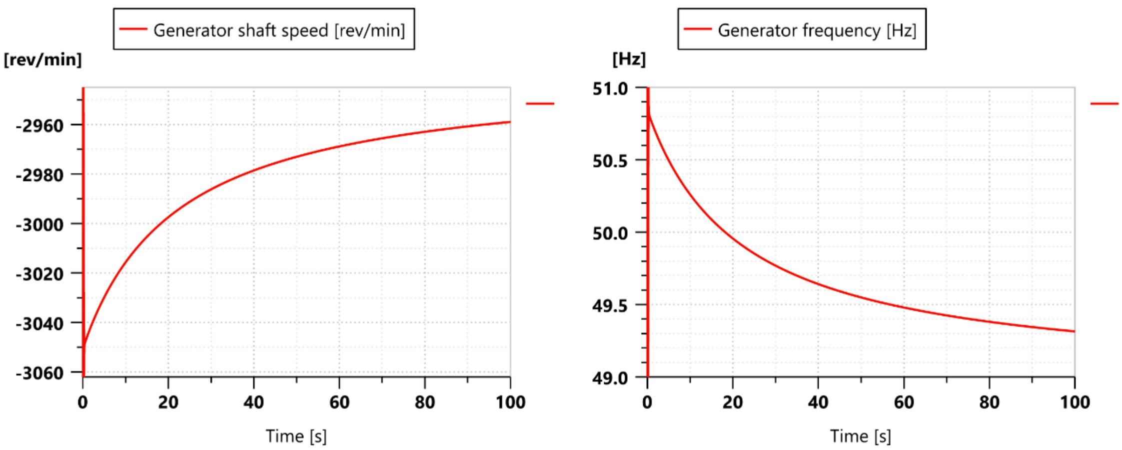

Fig. 5. Speed of the synchronous electric generator and its frequency

As can be seen from the first graph in the figure above, the generator speed varies by max. 60 rpm, which represents a deviation of less than 2%; as for the current frequency, it shows the same percentage variation around 50 Hz.

4. Conclusions

The use of hydraulic drives in applications for the production, transmission and storage of energy from renewable sources have application potential and are in continuous development.

There are various architecture solutions of hydrostatic transmissions and it must fulfil two important objectives: on the one hand, the management of large powers, up to over 10 MW at the present time, and on the other hand, the reduction of mass at the nacelle level.

The normally used mechanical power transmission can be easily replaced by a hydromechanical hybrid power transmission technology in wind power application.

In the proposed solution, the energy transmission is done mechanically-hydraulic; an open hydraulic circuit is placed in the turbine nacelle, which has the main role of amplifying the rotor speed, considered to be in the range of 30…150 rpm. The amplification ratio is 30. Thus, by means of a low-mass transmission shaft, the energy is transmitted to the second hydraulic circuit, which contains a variable hydraulic motor, which drives the electric generator, located on the ground, at a constant speed.

With this solution, both the generator drive speed and the frequency are maintained constant, with a deviation of less than 2%, which recommends the solution for implementation.

The proposed hydrostatic power transmission system for wind turbines has several advantages, such as reducing the suspended mass of the turbine, reducing the cost of the transmission system, and improving the general efficiency of the system.

Acknowledgments

The work was carried out through the Core Program within the National Research Development and Innovation Plan 2022-2027, carried out with the support of the Romanian Ministry of Research, Innovation and Digitalization (MCID), project no. PN 23-05.

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