Assessing Short-Term Storage Effects On Hydrostatic Wind Turbine In Presence Of Turbulent Wind

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ABSTRACT

One of the main challenges in wind turbines application is short-term storage of output power. Hydrostatic transmission (HST) systems, in addition to their advantages such as increasing the reliability of the system and ability to use high-efficiency synchronous generators, gives the system the chance to install the short-term storage in order to elevate quality and amount of the output power. The short-term storage in wind turbines is important because that significant amount of power in a wind profile lies in turbulence, which can be exploited by using a suitable short-term storage such as an accumulator. In this paper, the effects of employing accumulator on the hydrostatic power transmission system are investigated. First, the nonlinear dynamic model of the wind turbine system is obtained. Then the nonlinear dynamic equations are linearized around steady-state trajectory of the system. Control system is designed based on PID control method with switching capability over all operation regions. During various simulation scenarios with HST without the accumulator and with different accumulator size, it is proved that the employing accumulator in the wind turbine improves the quality and quantity of the output power. The results reveal that with right choice of the accumulator, output power of the wind turbine increases significantly.

KEYWORDS

Wind turbine, Short-term storage, Hydrostatic transmission, Accumulator, Switching

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1. Introduction

Nowadays, one area that has become of great concern is renewable energy and wind energy is the most competitive renewable energy resource in the world [1]. In conventional wind turbines, mechanical gearbox is one of the faultiest subsystems [2]. In order to tackle the mechanical gearbox challenges, hydrostatic variable speed transmission (HST) may avoid to use conventional mechanical gearbox and power electronic devices [3]. With a hydrostatic transmission, it is also easier to develop a short-term storage system by simply adding a hydraulic accumulator, since the power is transferred through the fluid [4].

In this paper, we will endeavor to deal with the challenge of developing short-term storage. First, the wind turbine embedded with hydrostatic transmission is modeled based on nonlinear mathematical equations for each component. Next, to obtain a control oriented linear system, the nonlinear mathematical model of the HST wind turbine is liberalized around desired operating trajectories. The control system is designed based on proportional-integral-derivative (PID) control approach with switching capability over all operation regions of the wind turbine. Finally, a set of simulations demonstrate capability of the HST wind turbine embedded with short-term storage in elevating the output performance of the wind turbine.

2. Methodology

The nonlinear state-space equation of HST wind turbine embedded with accumulator (presented in Figure1) as follows:

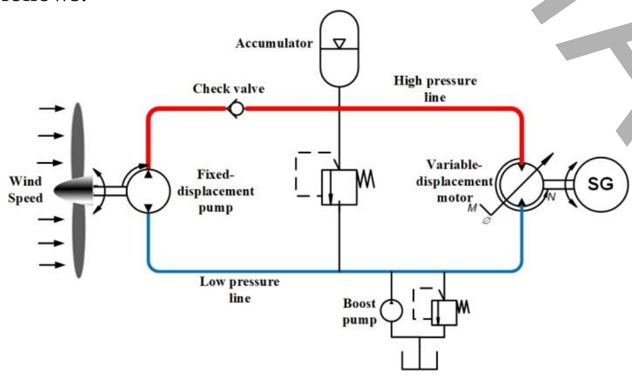

Figure 1. Schematics of hydrostatic wind turbine embedded with accumulator

$$\dot{x} = f(x,u,w) = Ax + Bu + B_1 w \qquad (1)$$
$$y = g(x) = Cx$$

Where x is state vector, u is control input, w is external disturbance and y is output of the system.

$$x = \begin{bmatrix} \omega_r & P_a & \omega_g & T_g & \beta \end{bmatrix}^T \qquad y = \begin{bmatrix} \omega_r & \omega_g & \beta \end{bmatrix}^T \qquad (2)$$
$$u = \begin{bmatrix} \alpha & u_g & u_\beta \end{bmatrix}^T, \qquad w = \begin{bmatrix} T_r & P_{lp} \end{bmatrix}^T$$

Where ω_r is rotor speed, P_a is accumulator pressure, ω_g is generator speed, T_g is loading torque of the generator, β is pitch angle, α denotes swash plate angle of the hydraulic motor, u_g is commanded torque of the generator, u_β is commanded pitch, T_r is aerodynamic torque of the low speed rotor and P_{lp} is low pressure line pressure.

After linearizing equation (2) around predefined desired trajectories, two PID control schemes with an appropriate switching law for partial load and full load operation regions are designed (Figure 2). Using Zeigler-Nichols algorithm two PID controllers are designed [5].

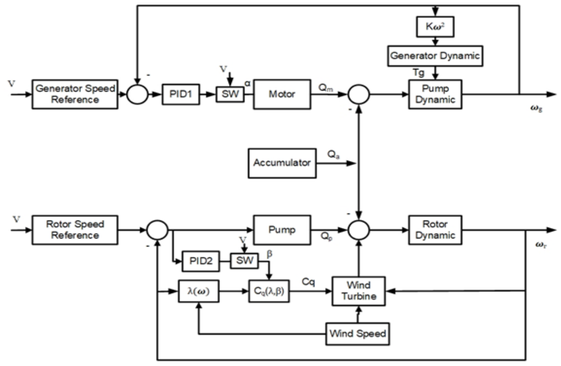

Figure 2. Block diagram of presented control method

3. Results and discussion

Through various simulation scenarios, proposed control method is implemented on HST wind turbine system. Simulation scenarios as follow:

1) HST wind turbine system without accumulator (Blue line)
2) HST wind turbine system with accumulator $V_0 = 21$liter $P_0 = 130$bar (green line)
3) HST wind turbine system with accumulator $V_0 = 41$liter $P_0 = 250$bar (red line)

Closed-loop results of three scenarios are presented in Figure. 3 to Figure.8

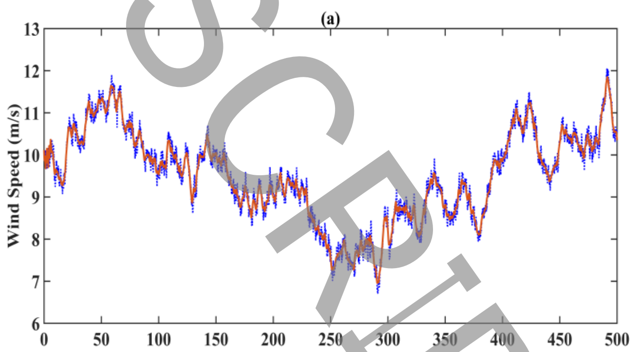

Figure 3. Simulated wind speed

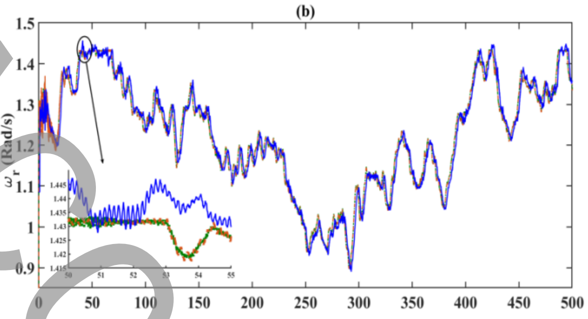

Figure 4. Rotational speed of rotor

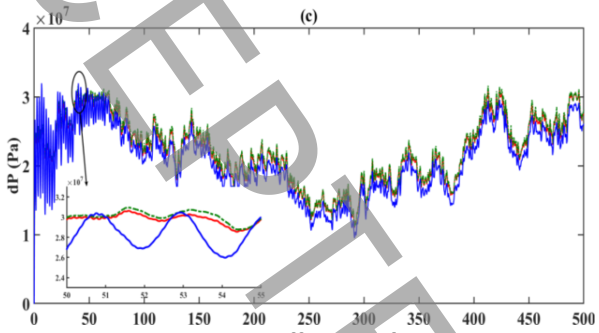

Figure 5. Pressure difference of HST system

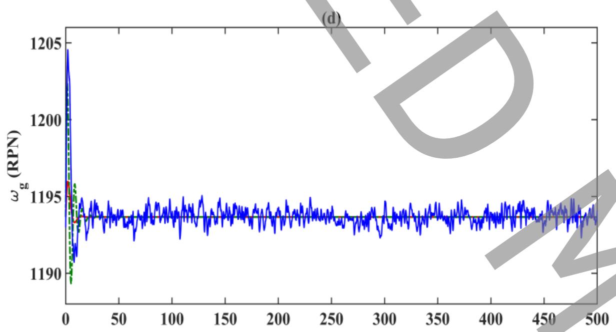

Figure 6.Rotational speed of generator

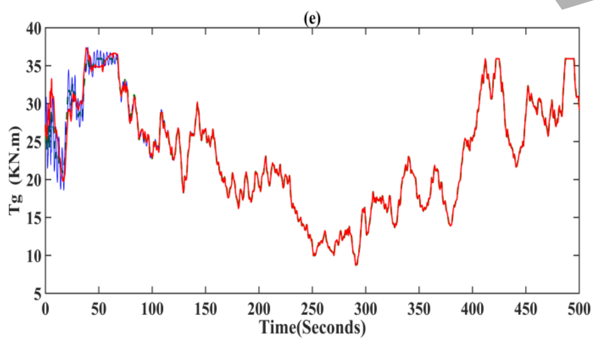

Figure 7. Loading torque of generator

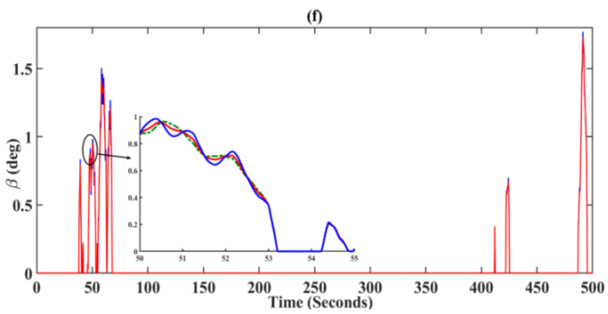

Figure 8. Pitch angle value

For the quantitative evaluation, the output power of aforementioned three scenarios is compared in Table1

Average output power in partial load region (MW)	**Scenarios**
3.24	Scenario 1
3.41	Scenario 2
3.48	Scenario 3

4. Conclusion

In the presented note, we have studied modeling and control of a hydrostatic WT embedded accumulator as short-term storage .First of all nonlinear model of the wind turbine is extracted. Then, in order to design appropriate switching PID control method, the nonlinear mathematical model is literalized around predefined trajectories. The proposed PID controllers are tuned using Zigler-Nichols algorithm. After simulating closed-loop system under three different scenarios, it is it is proved that the employing accumulator in the wind turbine improves the quality and quantity of the output power. The results reveal that with right choice of the accumulator, output power of the wind turbine increases significantly

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