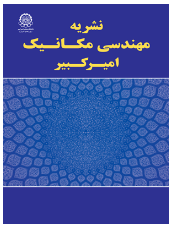

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Assessing short-term storage effects on hydrostatic wind turbine in presence of turbulent wind

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ABSTRACT: One of the main challenges in wind turbine application is short-term storage of output power. Hydrostatic transmission systems, in addition to their advantages such as increasing the reliability of the system and ability to use high-efficiency synchronous generators, give the system the chance to install the short-term storage 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 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 proportional-integral-derivative control method with switching capability overall operation regions. During various simulation scenarios with hydrostatic transmission without the accumulator and with different accumulator size, it is proved that 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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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 using 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 overall 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 Fig.1) as follows:

$$\begin{aligned} \dot{x} &= f(x,u,w) = Ax + Bu + B_1 w \\ y &= g(x) = Cx \end{aligned} \tag{1}$$

where is state vector, is control input, is external disturbance and is output of the system.

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

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

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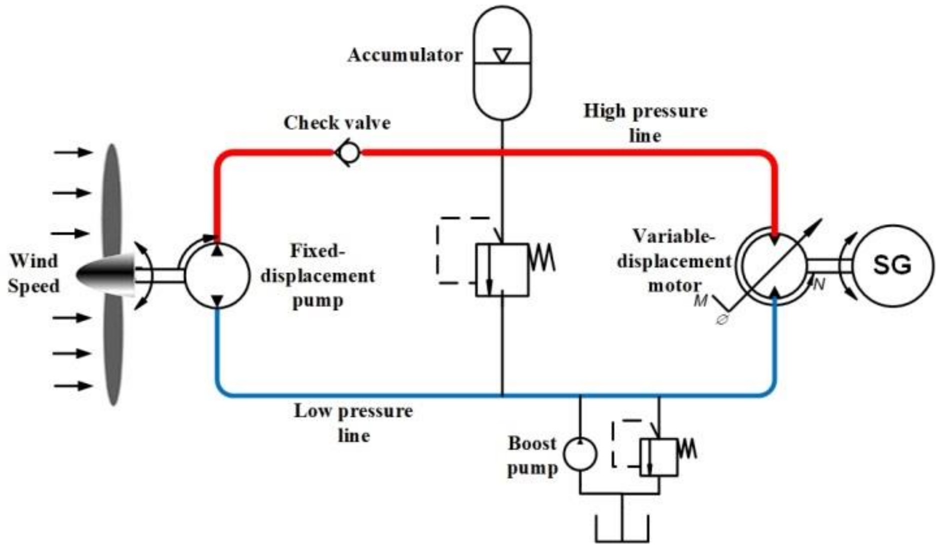

Fig. 1. Schematics of hydrostatic wind turbine embedded with accumulator

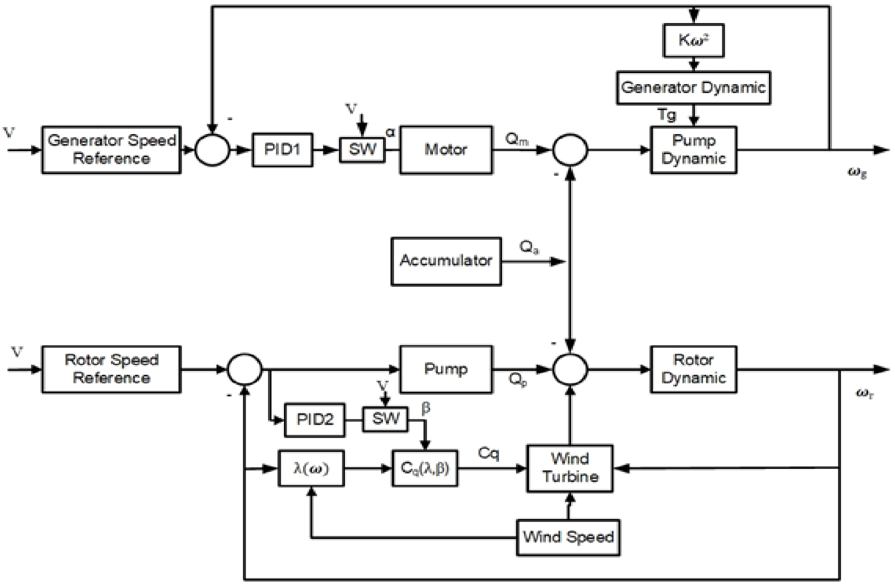

Fig. 2. Block diagram of presented control method

3. Results and Discussion

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

a) HST wind turbine system without accumulator (Blue line)

b) HST wind turbine system with accumulator $V_0 = 21\text{liter} \quad P_0 = 130\text{bar}$ (green line)

c) HST wind turbine system with accumulator $V_0 = 41\text{liter} \quad P_0 = 250\text{bar}$ (red line)

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

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

4. Conclusions

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 proved that the employing accumulator in the wind turbine improves the quality and quantity of the output power. The results reveal that with the right choice of the accumulator, output power of the wind turbine increases significantly.

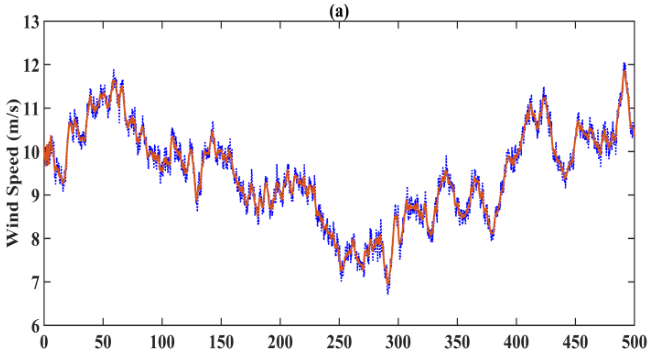

Fig. 3. Simulated wind speed

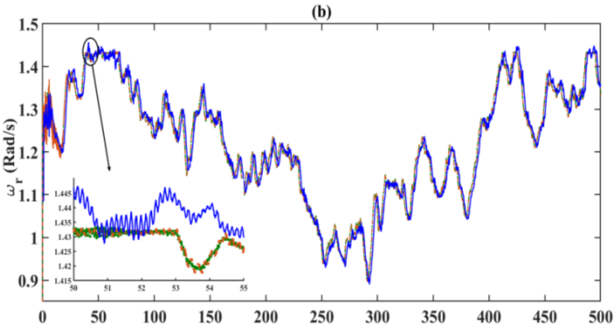

Fig. 4. Rotational speed of rotor

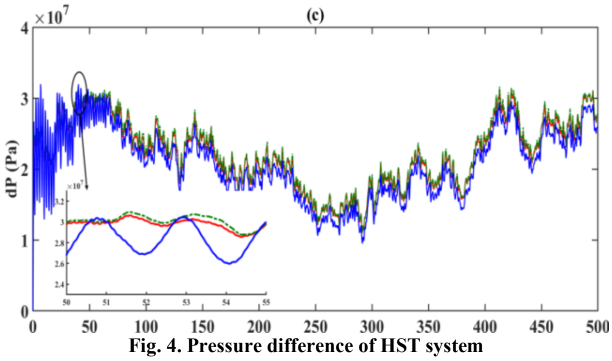

Fig. 5. Pressure difference of HST system

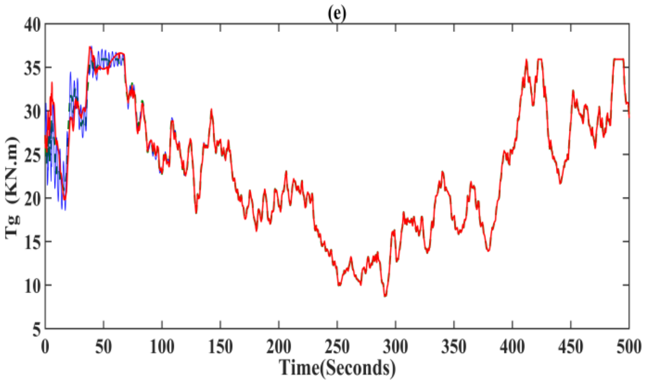

Fig. 7. Loading torque of generator

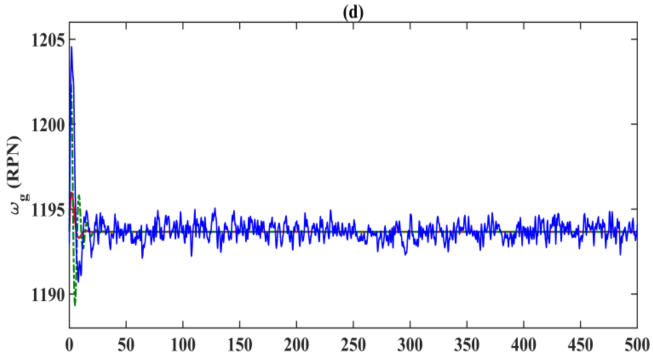

Fig. 6.Rotational speed of generator

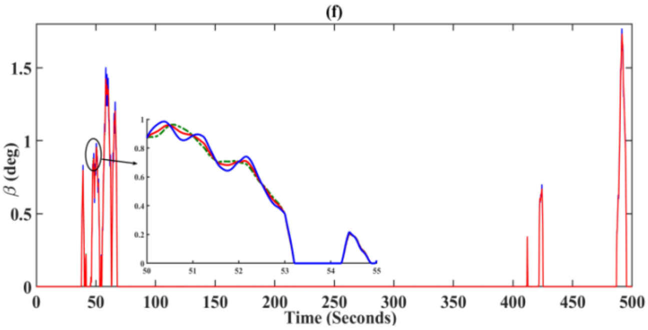

Fig. 8. Pitch angle value

Table 1 the output power of aforementioned three scenarios

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

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