

The Triangular Observer-Based Integral Sliding-Mode Wind System Energy Control

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Received: 13 April 2023 Accepted: 19 June 2023 Published: 26 June 2023

Abstract: We describe a fresh way to constructing a dependable controller utilizing a modified integrated sliding mode control technique in this research. Our proposed solution is intended to address the problem of attaining phase in systems with matching disturbances. As a starting point for demonstrating the usefulness of our technique, we propose replicating a wind turbine system. The inbuilt sliding mode control system is therefore used, which just requires the rotor speed as an accessible measurement. We use an asymptotic observer design that lowers observing errors over time to predict the unknown rotor acceleration required for the control law. The control law is based on Lyapunov stability analysis, which ensures the system's stability. We compare the performance of our proposed system to that of typical sliding mode control using simulation results in terms of settling time, tracking precision, energy usage, and input smoothness. Our findings show that the proposed technique outperforms classic sliding mode control across various performance parameters, showing its potential for developing a reliable controller in real applications.

Keywords: Integral sliding mode control, Lyapunov stability, Nonlinear control, Triangular observer, Wind turbine.

1. Introduction

Wind energy is an abundantly available source of electricity by converting the kinetic energy of moving air mass into electricity. The deployment of solar and wind is characterized as tributed/distributed local production, excluding huge offshore wind farms are considered as local when they are power plants having ratings in the range of more than 100 MW [1-3, 23].

Wind turbines (WTs) are progressing toward the trend of large size and huge capacity in order to fulfil the growing needs of wind power consumption. To enhance the overall performance of big WTs in this trend, numerous sophisticated yaw control solutions have been put out; however, their analysis and summaries are still missing [22].

Since the high rise in energy consumption and the threat of the depletion of natural resources, renewable energy production methods have drawn considerably greater attention, particularly in nations without access to natural energy resources. One of the major sources of clean, renewable energy for producing power is wind energy [4, 5].

It's believed that Sliding Mode Control (SMC) is one of the majorities of system performances, comprising disturbance and insensitivity to parameter changes rejection and have been implemented effectively in several fields.

Practical nonlinear plants, making the task of designing controls for nonlinear systems challenging [6, 10]. Thus, a variety of nonlinear control techniques, including sliding mode control and integral sliding mode control, have been developed for

nonlinear systems to get around the challenge of designing a controller for a real system.

Sliding mode control is a robust control technology that is increasingly used in wind turbine control. It is intended to handle the uncertainties and disturbances associated with wind energy conversion systems, making it an appropriate alternative for wind turbine control [7-9]. A sliding surface is defined as a function of the system states and desired references in sliding mode control, and the control rule is designed to drive the system states onto this sliding surface. The basic concept is to drive the system to slide down the surface towards the desired operating point, resulting in fast and accurate control. Sliding mode control for wind turbines has various advantages, including resistance to parameter changes, changes in wind speed, and other environmental disturbances.

Sliding mode control (SMC), a nonlinear control technique, induces a nonlinear system to "slide" over a cross-section of its typical behaviour by delivering a discontinuous control signal [10, 11].

Integral sliding mode control (ISMC) is a sophisticated control technique that has been developed to address the challenges associated with designing controllers for nonlinear systems, such as practical nonlinear plants. Unlike traditional sliding mode control, ISMC allows the system trajectory to start from the sliding plane, eliminating the arrival phase and promising robustness across the entire state space. ISMC is a combination of sliding mode control with another controller, and was initially developed with the goal of ensuring a sliding mode response from the start of the system's reaction or providing compensation for matching uncertainty response throughout the system [12, 15]. This makes ISMC a powerful approach for controlling nonlinear systems with matched disturbances, as it can effectively handle uncertainties and disturbances in the system dynamics. ISMC has been successfully applied in various fields, including renewable energy systems like wind energy, to improve system performance in terms of tracking accuracy, disturbance rejection, and robustness against parameter changes. In the context of wind energy systems, ISMC has shown promising results in optimizing the performance of large wind turbines and enhancing the overall efficiency and reliability of wind energy generation. The use of ISMC in wind energy systems is an active area of research, and ongoing studies continue to explore its potential for further advancements in renewable energy production.

The integral sliding mode control (ISMC) is a technique which was first proposed in [13, 14] as a solution to the reaching phase problem for systems with matched disturbances. It can be considered a technique for combining the use of the sliding mode controller with another controller.

When ISMC was first developed, the main goal was to compel a sliding mode from the start of the system's reaction, or an ISMC-based controller can give the entire system compensation for matching uncertainty response [16, 17].

The triangular observer is a popular state estimation approach in control systems. It is a special sort of observer, also known as an extended state observer, that is well suited for estimating the states of nonlinear systems with unknown or uncertain dynamics [22]. The triangular observer is based on the concept of a system's "triangular form," in which the state variables are represented as a combination of their original and derivative values. The observer estimates the system states using the system's input-output data and an estimated input. The key concept is to design the observer dynamics so that the estimation error converges to zero, resulting in accurate state estimation. The capacity of triangular observers to deliver resilient and accurate state estimates even in the presence of model uncertainties and disruptions is well established. They've found use in a variety of fields, including robotics, power systems, and automotive systems, where precise state estimate is critical for control and monitoring. The triangular observer is a potent tool for nonlinear system state estimation, contributing to improved system performance, fault detection, and control.

The system's motion is same in dimension to the state space, in contrast to traditional sliding mode control. In integral sliding mode control (ISMC), the system trajectory starts usually from the planning plane. Hence eliminates the arrival phase and promises robustness across the state space.

In this work, the first section covers the modelling of the wind energy system [23, 20] then we present the suggested strategy then we applied it on our system, and we present some simulations of the sliding mode control and the integral to make a comparison between the two modes of sliding control. Finally, a conclusion is reached from the results.

2. Wind Turbine Modeling

The variable speed wind turbine's aerodynamic torque is given by [8, 23]:

$$T_a = \frac{1}{2} \rho \pi R^3 \frac{C_p(\lambda, \beta)}{\lambda(t)} v(t)^2, \quad (1)$$

where ρ is the density of air, R is the rotor radius, V is the wind speed, C_p is the power coefficient and λ is defined as:

$$\lambda(t) = R \cdot \dot{w}_t / v(t) \quad (2)$$

The rotor's dynamics is determined by:

$$J_r \dot{w}_t = T_a - T_{ls} - k_r w_t, \quad (3)$$

where J_r , k_r and w_t are the sequentially, the rotor's inertia, external damping, and rotational speed.

The speed w_g of the generator is provided by the following expression:

$$J_g \dot{w}_g = T_{hs} - k_g w_g - T_{em}, \quad (4)$$

where J_g , k_g are the generator inertia and friction coefficient and T_{em} is the control law of the system.

Expecting a perfect transmission, we define n_g :

$$n_g = \frac{T_{ls}}{T_{hs}} \quad (5)$$

3. Integral Sliding Mode Control

The maximum point on the power coefficient curve corresponds to the ideal amount of wind energy which corresponds to w_{topt} [23, 22], where w_{topt} is given by:

$$y_r = w_{topt} = \frac{v(t) \cdot \lambda_{opt}}{R} \quad (6)$$

The system in (Fig. 1) is represented by (7) with disturbances:

$$\begin{cases} \dot{w}_t = w_g \\ \dot{w}_g = f(x) * w_g + g \cdot u(x, t) + \frac{1}{10} * \frac{K_g}{J_g} randn \\ y_1 = w_t \end{cases} \quad (7)$$

The control law $u=T_{em}$, $y=w_t$.

The errors of the system are provided by [23]:

$$e_1 = w_{topt} - w_t, e_2 = w_{topt} - \dot{w}_t \quad (8)$$

The sliding surface is defined as:

$$\sigma(t) = \lambda e_1(t) + e_2(t) + ki * \int_0^\infty e_1(t) dt \quad (9)$$

Such as ki is the sliding gain.

Assuming the function of stability given by [23]

$$e_1 = w_{topt} - w_t, e_2 = w_{topt} - \dot{w}_t \quad (10)$$

By using the following equation's derivative, we have

$$\dot{V} = \sigma \dot{\sigma} = \sigma(\lambda(\dot{w}_{topt} - \dot{w}_t) + ki * e_1(t)) \quad (11)$$

The condition of stability

$$\dot{V} \leq 0 \quad (12)$$

This condition satisfies the following requirement [18]

$$\lambda(\dot{w}_{topt} - \dot{w}_t) + ki * e_1 = \begin{cases} < 0 & \text{for } \sigma > 0 \\ = 0 & \text{for } \sigma = 0 \\ > 0 & \text{for } \sigma < 0 \end{cases} \quad (13)$$

K is the designer's chosen sliding control positive gain [19].

$$T_{em} = J_g \left(-\lambda e_2(t) - w_{topt} + \frac{1}{J_g} (T_{hs} - kgw_g) kie_1(t) \right) - ksign(\sigma). \quad (14)$$

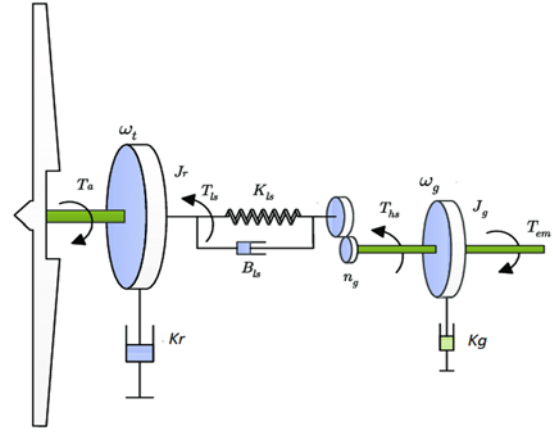


Fig. 1. The representation of the two-mass model wind turbine (10 m/s).

4. Triangular Observer Structure

For the system model stated in (7), the triangle observer that causes the observing errors to go to zero after a finite length of time can be expressed as follows [6][23]:

$$\begin{cases} \dot{\hat{w}}_t = \hat{w}_g + \lambda_1 sign(w_t - \hat{w}_t) \\ \dot{\hat{w}}_g = \hat{w}_g + \lambda_2 sign(\tilde{w}_g - \hat{w}_g) \end{cases}$$

where

$$\tilde{w}_g = \hat{w}_g + \lambda_1 sign_1(w_t - \hat{w}_t)$$

and

$$\tilde{w}_t = w_t$$

Such as $sign_i$ is characterized by:

$$sign_i(\cdot) = \begin{cases} 0 & \text{if } \tilde{x}_j - \hat{x}_j \neq 0 \\ j \in [1, i] \\ sign(\cdot) & \text{elsewhere} \end{cases}$$

5. Simulation Results

The Fig. 2 depicts the wind speed used in our study (10 m/s), the second depicts the two curves, one for the rotor speed and the other for the target rotor speed, and the third depicts the error between the two rotor speeds, the normal and the desired. The Fig. 6 describes an asymptotic observer triangular; that causes the observing errors to go toward zero over a finite period of time which shown in Fig. 7; to roughly estimate the unknown rotor acceleration needed to build the control law. Fig. 6 depicts the difference between the generator speed and the observed state.

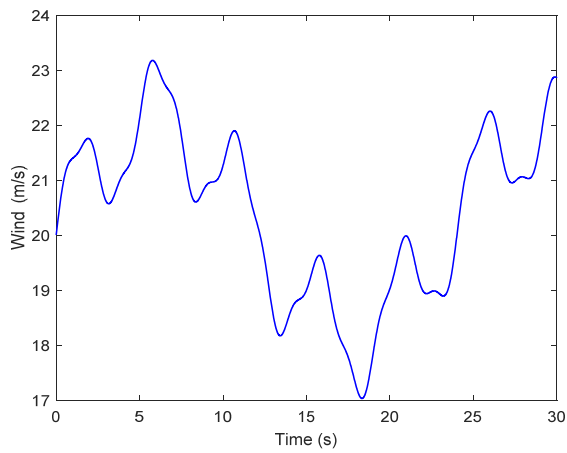


Fig. 2. The representation of the wind for (10 m/s).

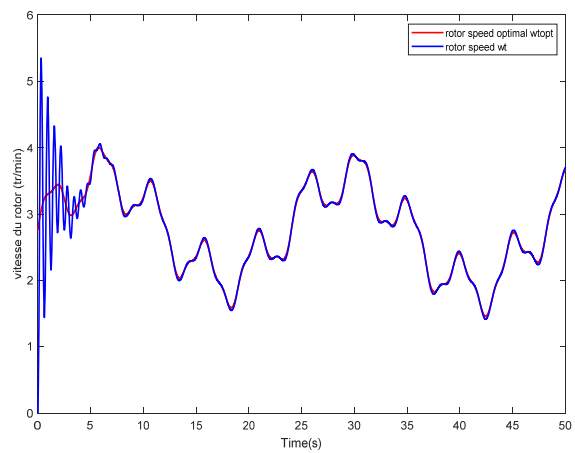


Fig. 3. Responses of the calculate and desired (optimal) rotor speed.

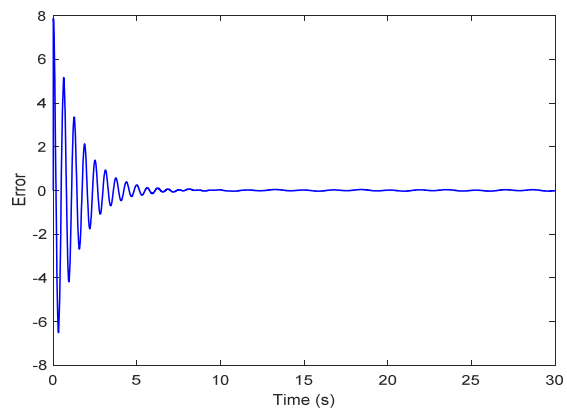


Fig. 4. Responses of tracking error between the rotor speed and the rotor speed desired.

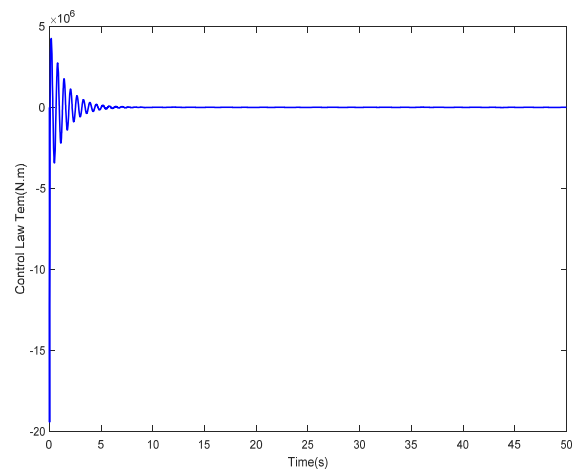


Fig. 5. The response of the control law with integral sliding mode control.

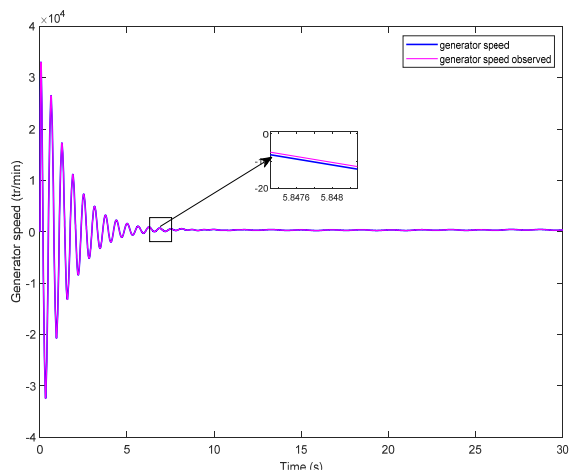


Fig. 6. The generator speed and the generator speed observed.

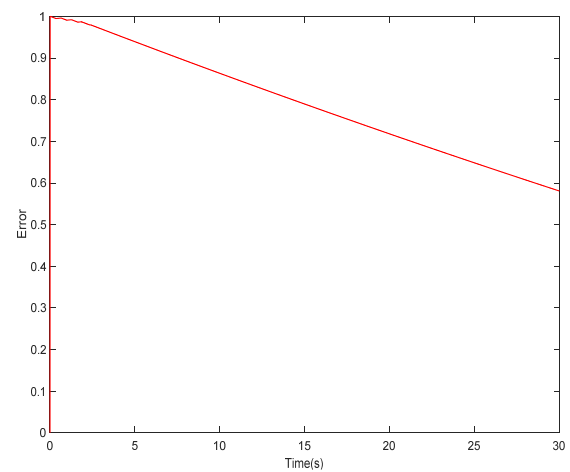


Fig. 7. The observatory error.

6. Conclusion

In this article, we explored the operating mode for the two-mass model system that is connected to the

integral sliding mode control (ISMC). The simulation results demonstrate the distinction between the two strategies. The Lyapunov technique ensures the stability of the system. In this optics, we can make and

search for approximations to key parameters and gains in order to improve our system's performance and efficiency.

7. References

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