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Modeling and robust control of a twin wind turbines structure

I. Guenoune [a,b], F. Plestan [a,*], A. Chermitti [b], C. Evangelista [c]

[a] École Centrale de Nantes-LS2N, Nantes, France
[b] Université de Tlemcen-LAT, Tlemcen, Algeria
[c] LEICI, UNLP-CONICET, La Plata, Argentina

A R T I C L E I N F O

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A B S T R A C T

The control of a new structure of twin wind turbines (TWT) is presented in this paper. This new concept includes two identical wind turbines ridden on the same tower, which can pivot face the wind with no additional actuator. The motion of the arms carrying the TWT is free. The control law based on sliding mode controller is designed to track the maximum power, by controlling the rotor speed of the TWT and the yaw rotation but without yaw actuator. Finally, performances of the proposed control strategy are compared to standard proportional integral controller, for several scenarios (time varying direction or magnitude of the wind, error on the inertia of the system, . . .).

1. Introduction

An original new structure of twin wind turbines is presented in this work. This concept named SEREO and patented by Herskovits, Laffitte, Thome, and Tobie (2012) (see Fig. 1) includes two identical wind turbines ridden on the same tower, which can pivot in front of the wind.

The original feature of SEREO versus standard twin turbines is due to the fact that the rotation of the arms carrying the two wind turbines is free: indeed, no additional yaw driving motor is required to follow the wind direction which is really a novelty. The challenge is to design a control structure to force the system against the wind while ensuring optimal energy production. The advantages of such structure are

- Given that there is no yaw actuation, failures risks are reduced, as well as maintenance ;
- Furthermore, on a same tower, two turbines are available. For a given nominal power for the whole system, especially for the large power turbines (>10 MW), it is more interesting by a weight point-of-view to have two turbines, than only a single one.

However, as previously mentioned, it is necessary to design an appropriate control strategy to align the turbines face the wind. Concerning the electrical part of the system, the two wind turbines are associated with two permanent magnet synchronous generators.

In order to reach a high efficiency, two objectives have to be managed: the first one consists in controlling the position of the wind turbine with respect to the wind direction whereas the second controller is devoted to the electrical generator. The rotor speed of the wind turbine is controlled by maintaining the tip speed ratio at its optimum value (Corradini, Ippoliti, & Orlando, 2013; Huang, Li, Ding, Jin, & Ma, 2015a; Saravanakumar & Jena, 2015). For this objective, various control strategy have been introduced, such as direct torque control (DTC) and oriented field control (Chinchilla, Arnaltes, & Burgos, 2006; Zhang, Zhao, Qiao, & Qu, 2014). It means that the angular velocity of the wind turbine has to be controlled with respect to the velocity and the direction of the wind. In fact, the wind turbine is the most efficient if it is face the wind. In the framework of the power maximization by following the wind direction, it is worth mentioning (Mesemanolis & Mademlis, 2014), where the MPPT (Maximum Power Point Tracking) technique is combined with the active yaw control. The misalignment angle between the nacelle and the wind direction is estimated from the optimum and real mechanical power. It means that no sensor is required for the wind direction. The yaw control can be also used to protect the wind turbine against the excess power at high wind speed (Shariatpanah, Fadaeinedjad, & Rashidinejad, 2013).

For SEREO concept, the difficulty is that there is no yaw actuator. It is shown in the sequel that, viewed that there are two wind turbines, a difference between the drag forces of the turbines is created to unbalance the yaw trim. The control of the yaw angle allows to maintain this structure in front of the wind. Indeed, by varying the pitch angle of the two wind turbines, a different of the aerodynamic forces is created

* Corresponding author.
E-mail address: franck.plestan@ec-nantes.fr (F. Plestan).

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Fig. 1. SEREO structure (Herskovits et al., 2012) composed of twin wind turbines.

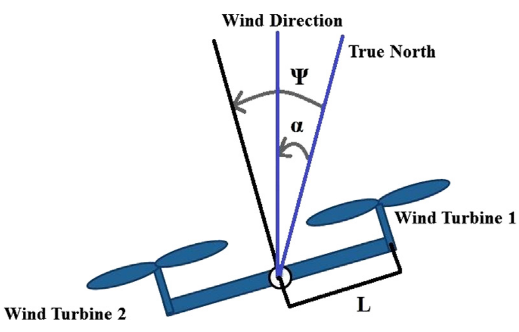

Fig. 2. Simplified model of the twin wind turbines (view from the top).

between the two rotors. Thus, the torque resulting from this difference enables to drive the yaw rotation of the structure around the vertical axis.

The SEREO system including mechanical and electrical parts, is a nonlinear system where it is greatly disturbed (wind variations, parametric uncertainties, …). Furthermore, the variable speed-variable pitch wind turbines are expected to operate in large scale of the wind velocity (Huang et al., 2015a; Tan, Thanh, & Dong, 2015). Due to these features, it is crucial to develop control laws which are robust with respect to uncertainties and perturbations, and which are efficient over a large operating domain. In the framework of the control design, the standard proportional integral PI controller is widely used in industrial context for different applications, and also for wind turbines (Chen, Chen, & Gong, 2013; Ikni, Camara, Camara, Dakyo, & Gualous, 2014; Zaragoza, Pou, Arias, Spiteri, Robles, et al., 2011). However, the PI controller is considered as a linear controller; therefore, an accurate knowledge of the system is required to ensure a good performance (Corradini et al., 2013) and the operating domain of the controller is quite limited. It means that, outside this domain, the control strategy is less efficient in terms of accuracy, disturbance rejection and parametric variations.

Several nonlinear control strategies have been used in order to overcome the drawbacks of robustness and limited operating domain. Thus, one can cite fuzzy-sliding mode control (Yan, Lin, Feng, Guo, Huang, et al., 2012) or adaptive neural network (Jafarnejadsani, Pieper, & Ehlers, 2013) which are quite efficient but are not easy to tune and formally implement. Concerning robust nonlinear control, integral sliding mode control has been used in Saravanakumar and Jena (2015) to control the wind turbines in three different regions (optimizing the power, limiting the power, and transient region for loads transient reducing).

The choice in the current work has been to develop sliding mode based control. This approach (Shtessel, Edwards, Fridman, & Levant, 2014; Utkin, Guldner, & Shi, 1999) is known to be robust versus parametric uncertainties and perturbations, quite easy to tune and has been used in numerous fields of application (Fridman, Barbot, & Plestan, 2016; Girin, Plestan, Brun, & Glumineau, 2009; Utkin, 1993; Utkin et al., 1999) including wind turbines area (Beltran, Ahmed-Ali, & Benbouzid, 2008, 2009).

The main objective of this work is then to propose, for the first time, a control architecture for a twin turbines structure without yaw actuation in order to optimize the power production. The main contributions are

- Nonlinear model of the SEREO twin wind turbines structure (dynamics of the yaw of the structure, the rotation velocities of turbines, and the direct/quadratic currents of the generator),
- Control of the both mechanical and electrical parts of SEREO structure, based on sliding mode approach,
- Evaluation of the closed-loop system performances under different scenarios (structure face the wind, structure not face the wind, parametric uncertainties, …),

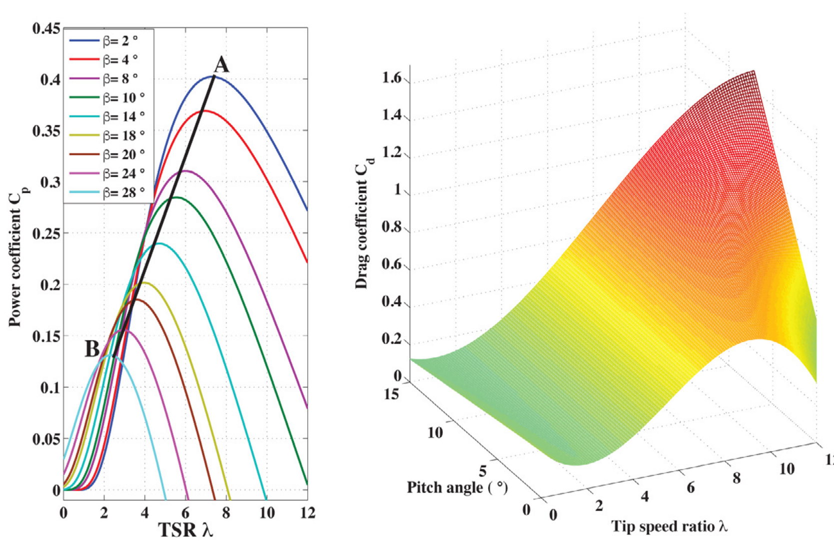

Fig. 3. Left (a)—Power coefficient C_p versus the tip-speed ratio λ, for different values of pitch angle. Right (b)—Drag coefficient C_d versus the tip-speed ratio λ and the pitch angle β. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)