Journal of Control & Instrumentation
Volume 1, Issue 1-3 Compilation 2011

A Sliding Mode Control with a PID Sliding Surface for Power Output Maximizing of a Wind Turbine

Ahmed Rhif
Department of Electronics Engineering,
High Institute of Applied Sciences and Technologies, Sousse, Tunisia
(Institut Supérieur des Sciences Appliquées et de Technologie de Sousse)

ABSTRACT

The wind energy has many advantages, it does not pollute and it is an inexhaustible source. However, the cost of this energy is still too high to compete with traditional fossil fuels, especially on the less windy sites. The performance of a wind turbine depends mainly on three parameters: the power of the wind, the power curve of the turbine and the generator's ability to respond to the wind fluctuations. This article proposes a robust control of a double-fed induction generator of wind turbine to optimize its production that means the energy quality and efficiency. The proposed control reposes in the sliding mode approach using a PID sliding surface, which contributes to the minimization of the static error and the number of the derivative functions. Simulation results show good performances of this control.

Keywords: *Sliding mode control, chattering phenomenon, PID controller, wind turbine*

Author for Correspondence E-mail: ahmed.rhif@gmail.com, Tel: 0021621160314

INTRODUCTION

Today, renewable energy arouses the interest of several research teams because of the expanded development of wind turbines, which represent a major investment in technological research. The systems that produce electricity from wind can be an alternative to various technological and economic inexhaustible energy sources. Moreover, the growth of the global wind industry is around 30% per year since the early 2000.

The advantage of a wind turbine is justified by the possibility to recover the kinetic energy present in the wind. This energy is converted into mechanical energy, which can be exploited in two main ways:

- Directly to drive a mechanical device such as a pumping system
- To drive an electric generator

In the case of power generation, two types of configurations could be distinguished:

- The energy is stored in batteries.
- Energy is used directly on a distribution network.

We note then the outspread of the electrical applications of the wind energy used both with the traditional means of power production (thermal power plants or nuclear) for areas with existing connected distribution network and also for not connected sites to a traditional network distribution. However, the cost of wind energy is still too high to compete with traditional sources.

A lot of research on the control of wind turbines has been carried out. Thanks to this research, the latest generation of wind turbines now operates with variable speed and has a pitch control. We can now improve the turbine production by changing the speed and pitch angle of each blade [1–3].

In this paper, the wind turbine studied is a three-bladed horizontal axis with pitch control using an asynchronous double-fed generator. The purpose of this study is to propose a robust control for the generator, which can optimize the production of the wind turbine. This paper is organized in four parts. First, we begin by modelling the process. Second, we present the sliding mode control (SMC). After that, we introduce the SMC with PID sliding surface (SMC-PID). Finally, we present the experimental results.

PROCESS MODELING

These wind turbine (Fig. 1) machines are the direct descendants of the windmills on which the wings, made of sail stretched over a structure usually made of wood, were replaced by strong elements resembling the aircraft wings. The lift of the wings placed in the wind is used to generate torque for driving a mechanical device such as an electric generator or a pump. These machines generally have a number of blades between 1 and 3 and can develop high power (several megawatts).

The double-feed asynchronous generator is typically modeled in the Park benchmark in a (d-q) referential "direct-quadrature transformation," giving rise to the following equations (1, 2 and 3) [4, 5].

The mechanical equations are written in (1) and (2).

$$J\frac{d\omega}{dt} = p\frac{L_m}{L}\left(i_{qs}\phi_{dr} - i_{ds}\phi_{qr}\right) - C_l - f_v\omega \qquad (1)$$

$$T_e = p\frac{L_m}{L}\left(i_{qs}\phi_{dr} - i_{ds}\phi_{qr}\right) \qquad (2)$$

with ω the rotor angular velocity, J the inertia, p the pole number, C_l the torque and f_v the friction coefficient.

Now, we can write the electromagnetic equations:

$$\begin{cases} \dfrac{d\phi_{dr}}{dt} = -b\phi_{dr} + ai_{ds} - \omega p\phi_{qr} \\ \dfrac{d\phi_{qr}}{dt} = -b\phi_{qr} + ai_{qs} - \omega p\phi_{dr} \\ \dfrac{di_{ds}}{dt} = -\gamma_4 V_{ds} - \gamma_1 i_{ds} - \gamma_2\phi_{dr} + \gamma_3\omega\phi_{qr} \\ \dfrac{di_{ds}}{dt} = -\gamma_4 V_{qs} - \gamma_1 i_{qs} - \gamma_2\phi_{qr} - \gamma_3\omega\phi_{dr} \end{cases} \qquad (3)$$

with

$$\sigma = 1 - \frac{L_m^2}{L_s L_r} \qquad \gamma_1 = \frac{R_s}{\sigma L_s} + \frac{R_r L_m^2}{\sigma L_s L_r^2}$$

$$\gamma_2 = \frac{R_r L_m}{\sigma L_s L_r^2} \qquad \gamma_3 = \frac{L_m}{\sigma L_s L_r} p$$

$$\gamma_4 = \frac{1}{\sigma L_s} \qquad a = \frac{R_r}{L_r} L_m$$

$$b = \frac{R_r}{L_r}$$

where, ϕ_{dr}, ϕ_{qr} are the rotor flux and i_{ds}, i_{qs} are the stator current.

The state function of the generator could be written as follows:

$$\begin{cases} \dot{x}_f = ax_c + A_f(\omega)x_f \\ \dot{x}_c = -\gamma_1 x_c + B_c(\omega)x_f + \gamma_4 u \end{cases} \quad (4)$$

with,

$$A_f(\omega) = \begin{pmatrix} -b & -p\omega \\ p\omega & -b \end{pmatrix}$$

and

$$B_c(\omega) = \begin{pmatrix} -\gamma_2 & \gamma_3\omega \\ -\gamma_3\omega & \gamma_2 \end{pmatrix}$$

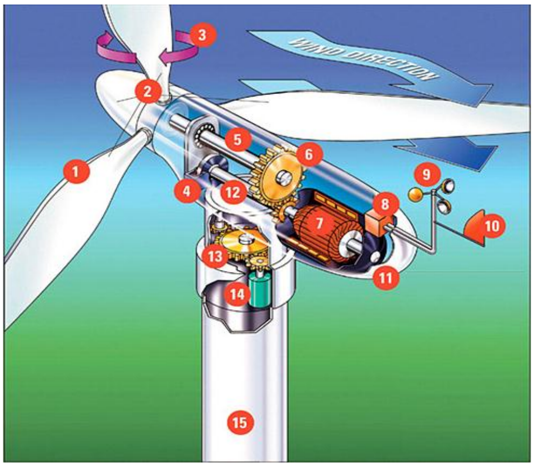

Fig.1 Wind Turbine Structure.

1. Blades
2. Rotor
3. Pitch
4. Brake
5. Low-speed shaft
6. Gear box
7. Generator
8. Controller
9. Anemometer
10. Wind vane
11. Nacelle
12. High speed shaft
13. Yaw drive
14. Yaw motor
15. Tower

PROCESS CONTROL DESIGN

The SMC proved good effectiveness in the electromechanical devices control and for tracking operation. In fact, the SMC consist in bringing back the system state on the sliding surface where it will slide along it to the desired state. However, this approach needs a high level of discontinuous control which makes harmful effects on the actuators. This problem is known as the chattering phenomenon. As solution to this is inconvenient, we suggest the high-order SMC which consists in the sliding variable derivative computing. This method allows the rejection of the chattering phenomenon while preserving the robustness of the approach. In the case of second order sliding mode control, the following relation (5) and (6) must be verified [6–9].

$$s(x) = \dot{s}(x) = 0 \quad (5)$$

$$\dot{V} = \frac{1}{2}\frac{\partial}{\partial t}\left(s^2\right) = s\,\dot{s} \le -\eta|s| \quad (6)$$

with $\eta > 0$ and V the Lyaponov quadratic function.

The torque reference from the maximum power point tracking (MPPT) block has two challenges: maximizing the power and the management operation of the wind area. The ratio of power extracted from the wind and the total wind power available theoretically has a maximum defined by the Betz limit. This limit is actually never reached and each turbine is defined by its own power coefficient as a function of the relative velocity representing the ratio between the speed of the turbine blade and the wind speed. The control of the double-feed asynchronous generator of the turbine must be a compromise between maintaining the optimum performance at all times and to limit the torque oscillations engendered by this maximizing. The set of reactive power will remain null in order to keep a power factor on the stator side [10–14].

To design the sliding mode control, we will choose a general state function which makes the study more general and liable for all applications.

Consider the state system (7).

$$\begin{cases} \dot{X} = Ax + Bu \\ Y = Cx \end{cases} \quad (7)$$

The sliding surface chosen is as follows:

$$s = C\hat{x} \quad (8)$$

$$C = (c_1 \cdots c_n); \quad c_i > 0, i = 1,...,n$$

with $\hat{x} = x_d - x_r$

To carry out the system on the sliding surface *s*, we have to select a discontinuous control which commutates between two extreme values: $u_s = -ksign(s)$, with $k > 0$. When the system reaches the surface, the process control *u* is equal to the equivalent control u_{eq} (9).

$$\dot{s} = C\dot{x} = CAx + CBu_{eq}$$

$$\Leftrightarrow u_{eq} = -(CB)^{-1} CAx \quad (9)$$

We conclude that the global control of the system considering the two phases (reaching the sliding surface and the sliding phase to the equilibrium state) is represented by (10).

$$u = -(CB)^{-1} CAx - ksign(s) \quad (10)$$

To ensure the system stability carried out by this control, we consider the Lyapunov candidate function $v = \frac{1}{2} s^2, \dot{v} = s\dot{s}$, then we have to prove that $\dot{v} < 0$.

$$\dot{s} = C\dot{x} = CAx + CBu = -CBksign(s)$$

to ensure $\dot{v} < 0$, we must have $CBk > 0$.

In this way, using the PID controller, the sliding surface will be represented as written below (11) [15–17].

$$s = \alpha_1 (x_d - x_r) + \alpha_2 \frac{d(x_d - x_r)}{dt} + \alpha_3 \int_0^t (x_d - x_r) dt \quad (11)$$

then,

$$\dot{s} = \alpha_1 \frac{d(x_d - x_r)}{dt} + \alpha_2 \frac{d^2(x_d - x_r)}{dt^2} + \alpha_3 (x_d - x_r)$$

To reduce the chattering phenomenon, we will use the saturation function which gives:

$$u = \lambda sat\left(\frac{s}{\Omega}\right) \quad (12)$$

where,

$$u = \begin{cases} \lambda sign(s) \ \ if \ \ |s| \geq \Omega \\ \lambda\left(\frac{s}{\Omega}\right) \ \ if \ \ |s| \leq \Omega \end{cases} \quad (13)$$

with λ and $\Omega > 0$, Ω defines the boundary layer thickness.

SIMULATION RESULTS AND DISCUSSION

Simulation results are illustrated in Figures 2 to 8. In this simulation, we consider that the process is controlled only with the discontinuous control $u = u_s$. Simulation is accomplished thanks to the software MATLAB V6.5.

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Figure 2 shows that with a first order sliding mode control (SMC1), we cannot reach the torque's desired value and the control level $(u = \pm 3)$ and its switching frequency are high (Fig. 3). In addition, we notice that the reaching phase presents commutations known as chattering phenomenon. However, the second order sliding mode control (SMC2) reduces considerably the chattering phenomenon (Fig. 4) but the level of the control is always high $(u = \pm 3)$ and its commutation frequency is even higher (Fig. 5). As a solution to this problem, we apply the PID-SMC1 with sliding surface defined in Eq. (11). To reach the sliding surface and to converge to zeros, we choose $\phi = 2$ and $\lambda = 1$. The simulation results of this approach are given in Figures 6 to 8. We notice that the system error converges to zero (Fig. 6) and that we have reduced considerably the chattering effect relatively to the two last approaches simulated in this paper. Other ways, we notice that the control level (Fig. 7) has a little commutation in the beginning of the system evolution, then it stabilizes in $(u = 0.2)$ after a period of time (~ 50 s).

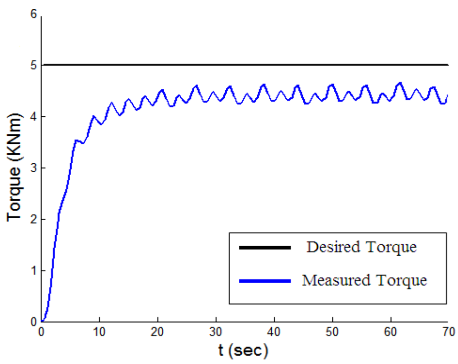

Fig. 2 Torque Evolutions by SMC1.

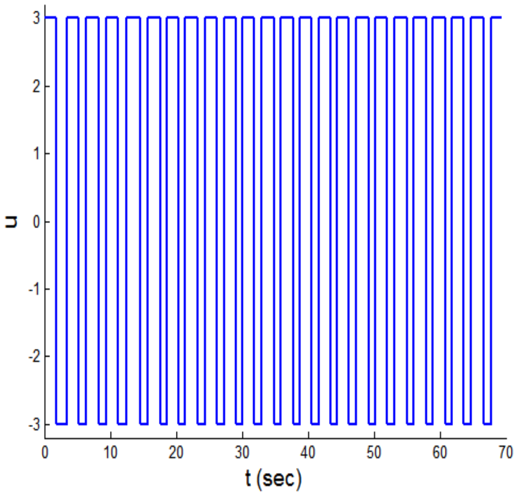

Fig. 3 Control Evolutions by SMC1.

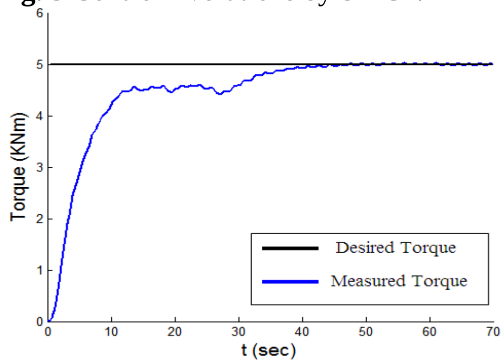

Fig. 4 Torque Evolutions by SMC2.

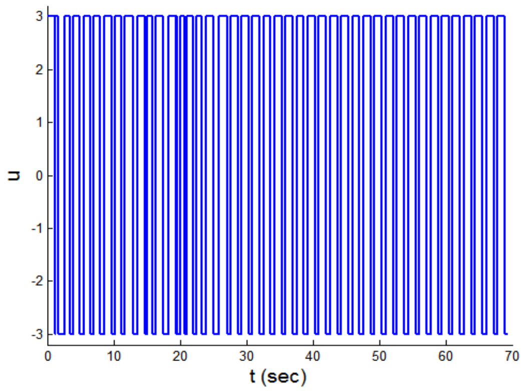

Fig. 5 Control Evolutions by SMC2.

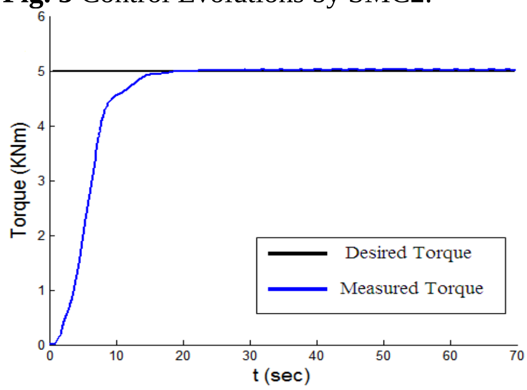

Fig. 6 Torque Evolutions by PID-SMC1.

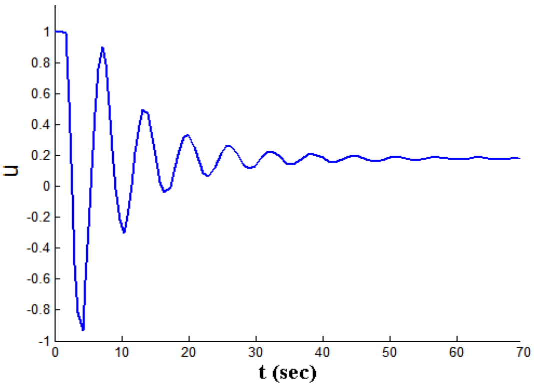

Fig. 7 Control Evolutions by PID-SMC1.

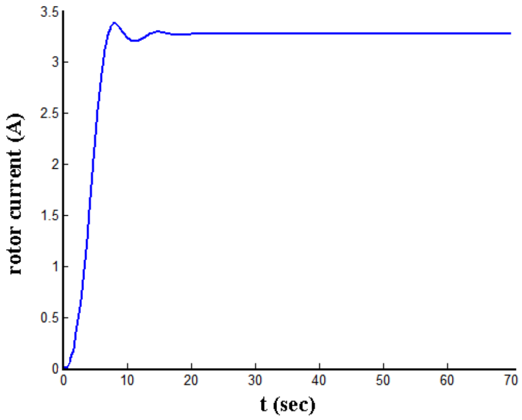

Fig. 8 Current Evolutions by PID-SMC1.

CONCLUSIONS

In this work, wind turbine controllers have been presented, detailed and justified by simulation results. We approached the synthesis method of a control law by sliding mode using a nonlinear sliding surface. In the first time, we presented the class and the properties of this sliding surface adopted. Then, a sliding mode control using the sliding surface developed together with stability studies were elaborated. After that, second order sliding mode control was developed and tested. Finally, to reduce the static error, a PID sliding surface was developed and simulated. This last approach shows very effective qualities of control and robustness especially in term of the control-level reduction and the sliding mode discontinuous control minimization.

REFERENCES

1. S. Singaravelu, S. Velusami. *Energy Conversion and Management*. 2006. 1–16p.
2. V. Spudic, M. Jelavic, M. Baotic. *AUTOMATIKA*. 52. 2011. 82–94p.
3. B. H. Chowdhury and S. Chellapilla. *Energy Conversion and Management*. 2005. 786–800p.
4. J. A. Baroudi, V. Dinavahi, A. M. Knight. *Renewable Energy*. 2007. 2369–2385p.
5. B. Boukhezzara, L. Lupua, H. Siguerdidjanea et al. *Renewable Energy*. 2007. 1273–1287p.
6. A. Rhif, Z. Kardous, N. Ben Hadj Braiek. *Eighth International Multi-Conference on Systems, Signals & Devices*. Sousse, Tunisia. March 2011.
7. A. Rhif. *IETE Technical Review*. 28. 2011. 479–485.
8. A. Rhif. *IETE Technical Review*. 28. 2011. 486–493.
9. A. Alaybeyoglu, K. Ericiyes, A.Kantarci. et al. *IETE Technical Review*. 2010. 27. 46–53.
10. N. Petrellis, N. Konofaos, G. Ph. Alexiou. *IETE Technical Review*. 2010. 27. 36–45.
11. C. Hua and C. Shen. *IEEE Applied Power Electronics Conference and Exposition*. USA. February, 1998. 15–19.

12. I. Erceg, G. Erceg, D. Sumina. *AUTOMATIKA*. 52. 2011. 95–106.
13. A. Rhif. *International Journal of Instrumentation and Control Systems*. 2012. 2. 25–33p.
14. F. Boudjema and J.L. Abatut. *IEEE Conference of Industrial Electronics Society*. 1990. 938–943p.
15. İ. Eker. *ISA Transaction*. Turkey. 2005. 45. 109–118.
16. Z. Li and Q. Shui-sheng. *Journal of Electronic Science and Technology of China*. 2005. 3. 140–143p.
17. A.Rhif. *International Journal of Information Technology, Control and Automation*. 2. 2012. 1–13p.

