INTERNATIONAL JOURNAL of ENGINEERING SCIENCE AND APPLICATION
L. Amira et al., Vol.4, No.4, December 2020

Strategy of Sliding Mode Control Wind Energy Conversion System

Lakhdara Amira *, Bahi Tahar **‡, Moussaoui Abdelkrim ***

* Department of Electrical and automatic Engineering_LGEG, 8 may 1945 Guelma University, Guelma 24000, Algeria

**Department of Electrical LASA laboratory, Badji Mokhtar Mokhtar University, Annaba 23000, Algeria

***Department of Electrical and automatic Engineering_LGEG, 8 may 1945 Guelma University, Guelma 24000, Algeria

(lakhdara.amira@univ-guelma.dz, tbahi@hotmail.fr, moussaoui.abdelkrim@univ-guelma.dz)

Lakhdara Amira; Bahi Tahar; Moussaoui Abdelkrim, Guelma 24000; Annaba 23000 , Tel: +90 312 123 4567, Fax: +90 312 123 4567, lakhdara.amira@univ-guelma.dz

Received: 29.09.2020 Accepted:26.12.2020

Abstract- Due to the ever-growing demand for electrical energy and taking into count environmental constraints, the production of electricity from wind energy is nowadays of an imperative and remarkable interest. Indeed, the installations of wind energy conversion system continue to spread thanks to their possibility of operating at variable speed, thus causing the improvement of the efficiency of the conversion. This motivated us to study a wind power conversion structure based on a dual power generator, the rotation speed of which is provided by a sliding mode controller. The goal of this work consists of modeling, simulation under the MatLab / Simulink environment and the analysis and evaluation of the performance of such a wind energy conversion system under the effect of the variation of the wind speed. . The results obtained show a clear improvement in performance and better quality of the energy produced.

Keywords - Wind Conversion System, Doubly Fed Induction Generator, Sliding Mode Control, Performances, Simulations.

1. Introduction.

The field of electrical energy production throughout the world remains dominated by the use of fossil resources: coal, natural gas, petroleum, uranium, etc.... [1]. In addition, the requirements to ensure the comfort of the population and the ever increasing need of industrial systems in terms of electrical energy have forced electricity producers to use a large amount of fossil fuels [2]. This screen-imposed electricity production technology has proven to be the indisputable cause of greenhouse gas emissions and is therefore the main consequence of atmospheric pollution. The first universal climate agreement was approved on December 12, 2015 [3].

Following this observation, the most appropriate solution to face the problem of pollution due to the excessive consumption of fossil fuels and this while ensuring the energy demand of consumers, significant encouragement from decision-makers in the most industrialized countries has been launched in terms of the challenge to produce electricity from renewable energies to replace fossil fuels [4].

To this end, the majority of countries around the world have set objectives to be achieved consisting of producing a particular quality of electrical energy for a given future period. For example, Algeria intends to position itself as a main player in the production of 15,000 MW of electricity by 2035, including 4,000 MW by 2024 and this from renewable resources [5].

The renewable energies (RE) are in abundance and potential on the planet. Otherwise RE do not emit greenhouse gases therefore their use is a solution to prevent environmental degradation. However, the adoption of a particular renewable resource (solar, wind, geothermal, etc...) is mainly linked to the geographical situation of each country.

In this work, we are interested in wind energy conversion system (WECS). Wind power is among the most widely used RE technologies around the world where the wind is used to produce electricity using the kinetic energy produced by air in motion. The efficiency of WECS depends mainly on the wind speed. However, due to the random nature of the wind speed it is necessary to alleviate this problem by using adequate controls to extract the maximum power in all possible atmospheric conditions. Thus the majority of WECS requires variable speed operation of the generator which could be an Induction Generator (IG), Permanent Magnet Synchronous Generator (PMSG) and Dual Feed Induction Generator (DFIG) [6, 7].

However, the most relevant configuration of the WECS is that based on a GADA equipped with a powerful control to produce the quantities of the desired active and reactive power and a frequency adapted to the load and essentially to that of the network, in the case of an installation connected to the distribution network [8].

Indeed, the wind turbine performance equipped with the double feed induction generator with adjustable speed is improving the system efficiency compared to WECS with fixed speed generator [9, 10]. For this purpose, in this paper the speed sliding mode controller is proposed in order to track the optimal reference whatever the wind speed and the vector oriented control (VOC) is used to simplify the dynamic mode of the DFIG.

In addition, considering the configuration of the WECS, the stator of the DFIG is directly coupled to the network with a constant frequency when its rotor is connected to the same distribution network but through power converters, where the regulation of the DFIG rotor speed with SMC for maximum wind power capture and the power captured is converted into electrical power by the generator.

This adjustment method consists in determining first the surface of adequate slip, as well as the equivalent and nonlinear value for each quantity to be regulated [10, 11].

The content of this article is structured in three (3) parts which are presented as follows:

In the first part we present the description of the system, and the modelling of the parts constituting this studied wind conversion system, each element of the chain is defined and its mathematical model is developed. The second part is devoted to the simulation results and their analysis and discussion. Finally a conclusion which sums up the work done is given in the fourth part.

2. Modelisation of the System

The conversion system to be studied consists mainly on three (03) parts: a mechanical part, an electrical part and the control system [10].

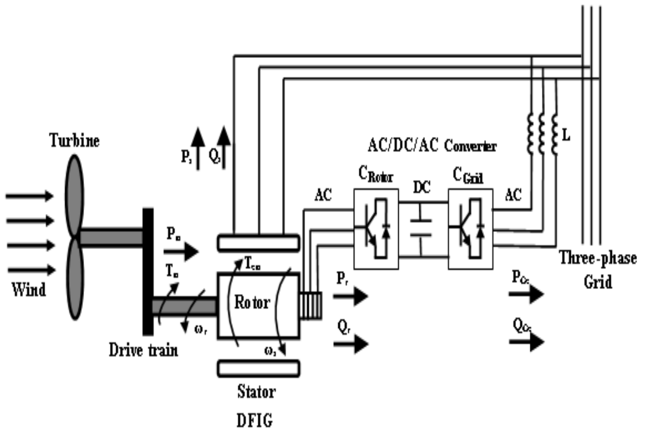

Fig. 1. Configuration of the proposed WECS

2.1. Mechanical part

The mechanical part contains the wind turbine and a multiplier [12].

The wind turbine is a device that transforms wind energy into mechanical energy. The mechanical power Pm available on the shaft of a wind turbine can be expressed by:

$$P_e = \frac{1}{2}\rho * A * V_w^3 \tag{1}$$

$$C_p = \frac{P_m}{P_e} \Rightarrow P_m = C_p . P_e \tag{2}$$

By replacing Eq (2) in Eq (1), we get:

$$P_m = \frac{1}{2} C_p(\lambda,\beta) * \rho * A * V_w^3 \tag{3}$$

$$A = \pi . R^2 \tag{4}$$

P_e: wind power; P_m: mechanical Power; ρ : air density; V_w : wind speed (m /s); A: swept area; R : radius of the wind generator; C_p: power coefficient.

Where,

$$C_p(\lambda,\beta) = 0.5176 \left((\frac{116}{\lambda_I} - 0.4\beta - 5) e^{\frac{-21}{\lambda_i}} + 0.0068\lambda \right) \tag{5}$$

With:

$$\lambda = \frac{\omega_m . R}{V_w} \tag{6}$$

and,

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{7}$$

With,

β: wedge angle; λ : Specific speed; ω_m: mechanical speed.

The torque produced by the turbine is:

$$C_t = \frac{P_m}{\omega_t} \tag{8}$$

ω_t: turbine speed.
The optimal power is given by this relation:

$$P_{opt} = \frac{1}{2} C_p^{opt} (\lambda_{opt}, \beta) * \rho * A * V_w^3 \tag{9}$$

The speed multiplier is used to increase the speed of rotation between the primary and the secondary shaft which drives the electric generator. Its role is to transform the mechanical speed of the turbine into the speed of the generator, and the aerodynamic torque into the torque of the multiplier according to the following mathematical formulas:

$$G = \frac{\omega_m}{\omega_t} \tag{10}$$

$$G = \frac{C_{aero}}{C_g} \tag{11}$$

C_{aero}: turbine torque; C_g: multiplier torque.

The fundamental equation of dynamics makes it possible to determine the evolution of the mechanical speed from the total mechanical torque (C_{mec}) applied to the rotor:

$$C_{mec} = J \frac{d\omega_m}{dt} \tag{12}$$

J: the total inertia returned to the generator shaft, comprising the inertia of the turbine, generator, two shafts, and multiplier.
The mechanical torque deduced from this simplified representation is the sum of all the torques applied to the rotor:

$$C_{mec} = C_g - C_{em} - C_f \tag{13}$$

C_{em}: electromagnetic torque developed by the generator; C_g : torque resulting from the multiplier; C_f: resistant torque due to friction.

$$C_f = K_f . \omega_m \tag{14}$$

2.2. Electrical part

The electrical part contains a dual power generator and power converters.

The DFIG has a three-phase stator identical to that of conventional asynchronous machines and a rotor also containing a three-phase winding accessible by three rings fitted with sliding contacts. Its stator is directly connected to the electrical network. On the other hand, its rotor is connected to the same electrical network, but through static power converters [13, 14]. The equivalent circuit of the DFIG is:

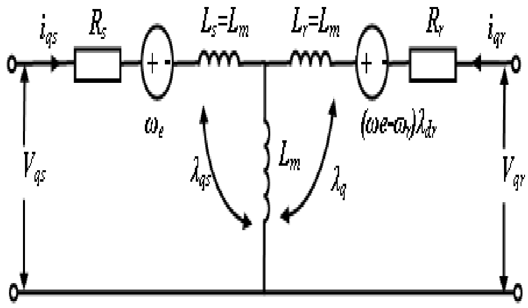

Fig. 2. DFIG electrical model

To reduce the complexity of the equations we use the matrix P(θ) for a transformation d-q

$$P(\theta) = \frac{2}{3} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \tag{15}$$

- Voltage equations

$$\begin{cases} V_{qs} = R_s I_{qs} + \frac{d\varphi_{qs}}{dt} + (\omega_e \varphi_{ds}) \\ V_{ds} = R_s I_{ds} + \frac{d\varphi_{ds}}{dt} - (\omega_e \varphi_{qs}) \end{cases} \tag{16}$$

$$\begin{cases} V_{qr} = R_r I_{qr} + \frac{d\varphi_{qr}}{dt} + (\omega_e - \omega_r) \varphi_{dr} \\ V_{dr} = R_r I_{dr} + \frac{d\varphi_{dr}}{dt} - (\omega_e - \omega_r) \varphi_{qr} \end{cases} \tag{17}$$

- Powers equations

$$\begin{cases} P_s = \frac{3}{2}(V_{ds}I_{ds} + V_{qs}I_{qs}) \\ Q_s = \frac{3}{2}(V_{qs}I_{ds} - V_{ds}I_{ds}) \end{cases} \tag{18}$$

- Torque equation

$$T_e = \frac{-3P}{4}(\varphi_{ds}I_{qs} - \varphi_{qs}I_{ds}) \tag{19}$$

- Flux equations

$$\begin{cases} \varphi_{ds} = (L_{is} + L_m)I_{ds} + L_m I_{dr} \\ \varphi_{qs} = (L_{is} + L_m)I_{qs} + L_m I_{qr} \end{cases} \tag{20}$$

$$\begin{cases} \varphi_{dr} = (L_{ir} + L_m)I_{dr} + L_m I_{ds} \\ \varphi_{qr} = (L_{ir} + L_m)I_{qr} + L_m I_{qs} \end{cases} \tag{21}$$

In this structure, two converters; the rotor side converter and the line side converter, are voltage converters that use controlled switching power electronics (IGBT).

The three-phase rotor is connected to the rectifier by slip rings and brushes, and the three-phase stator is directly connected to the network.

The power captured by the wind turbine is converted into electrical energy by the DFIG and it is transmitted to the network by the stator and the rotor windings.

The control signals of the inverter switches are obtained from the pulse with modulation (PWM) command, its principle is the intersection of the sinusoidal reference signal with a triangular signal.

2.3. Control system

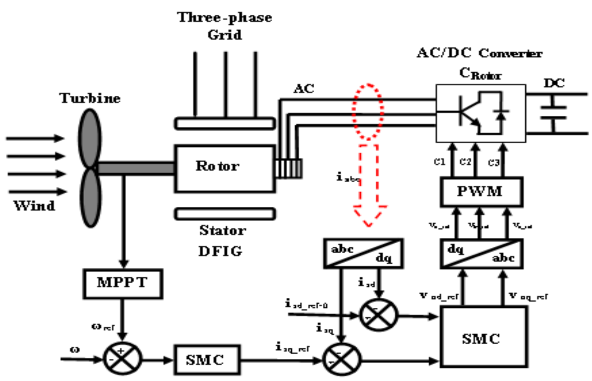

Fig. 3. The control system

The disturbance of the wind chain due to the random available wind forces us to apply an MPPT control to extract the maximum power generated [15].

The second type of control is applied to control the speed; it is based on the SMC [16, 17].

To design a SMC speed, we consider the following system:

$$\frac{d\omega}{dt} = \frac{1}{J}(T_m - T_{em} - f.\omega) \tag{22}$$

The existence rule of the SMC is S = 0 to ensure that the system reaches the surface of the slip.

$$\begin{cases} \lim\limits_{s \to 0^-} \dot{S} \rangle 0 \\ \lim\limits_{s \to 0^+} \dot{S} \langle 0 \end{cases} \tag{23}$$

The Lyapunov function is a very used method to study the existence of SMC

$$V(S(\omega)) = \frac{1}{2}S^2(\omega) \tag{24}$$

$$\dot{V}(S(\omega)) = S(\omega).\dot{S}(\omega) \tag{25}$$

With:

$$\dot{S}(\omega) = \dot{\omega}^* - \dot{\omega} \tag{26}$$

By replacing (22) in the (25)

$$\dot{S}(\omega) = \dot{\omega}^* + \frac{1}{J}(T_{em} + f.\omega - T_m) \tag{27}$$

We have,

$$T_e = T_{emeq} + T_{emn} \tag{28}$$

T_{emeq}: equivalent element; T_{emn}: discrete element.

Then (27) becomes:

$$\dot{S}(\omega) = \dot{\omega}^* + \frac{1}{J}((T_{emeq} + T_{emn}) + f.\omega - T_m) \tag{29}$$

When the system reaches the surface S accordingly it satisfies the linear differential equation $S(\omega) = 0$,

$\dot{S}(\omega) = 0$ and $T_{emn} = 0$, we obtain:

$$T_{emeq} = -J\dot{\omega}^* - f.\omega + T_m \tag{30}$$

Replacing expression Eq (30) in Eq (29) we obtain:

$$\dot{S}(\omega) = \frac{1}{J}(T_{emn}) \tag{31}$$

To ensure Lyapunov convergence:

$$T_{emn} = -K.sign(S(\omega)) \quad with \quad (K \succ 0) \tag{32}$$

3. Simulation Results

The WECS operational analysis is examined under two (2) different wind profiles: The first profile is formed, mainly, by two (2) constant wind levels of respective values 7m/s and 9.5m/s; and two intervals where the speed increases progressively between the instants 1.5s and 2.5s on the other hand in the last part of the profiles, the speed decreases from 9.5m/s to 6m/s. Concerning the second profile under which the WECS is requested, the wind speed changes randomly "Fig.4". The quantities recorded for each of these profiles, in particular, the power coefficient, turbine power, DFIM speed, stator current, finally passive and reactive speed are shown in fig Fig.4 and Fig.5, respectively. We notice that the power coefficient changes depending on the evolution of the wind profile so that the maximum power is extracted (see the figure just below). In addition, the DFIG speed perfectly follows the changes in the speed reference levels during each interval proving that the sliding mode setting undoubtedly ensures good performance.

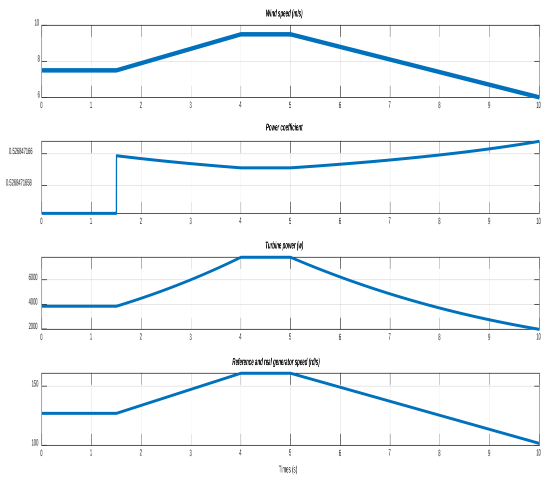

Fig. 4. Turbine side quantities for a variable wind by steps

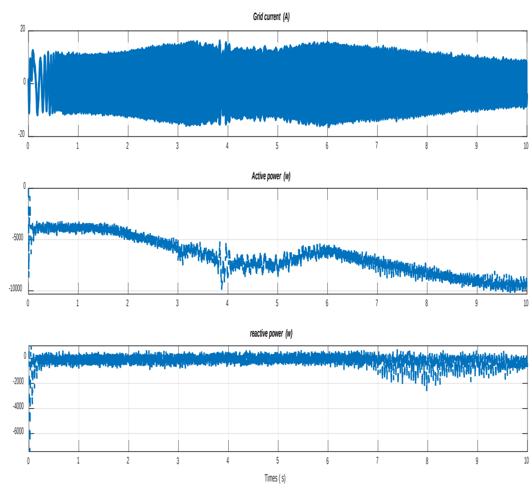

Fig. 5. Network side quantities for a variable wind by steps

Concerning the quantities on the network side, in particular, the stator currents and the active and reactive powers recorded under the two profiles of the wind speed, they are shown in Fig.6 and Fig.7, respectively. It can be seen that the stator currents have the same frequency as the network to which they are connected; the active and reactive powers follow their reference values. Indeed, the passive power reference is imposed by the control system and the reactive power is imposed as zero *($Q_{ref} = 0$)* to ensure a unitary power factor of the installation.

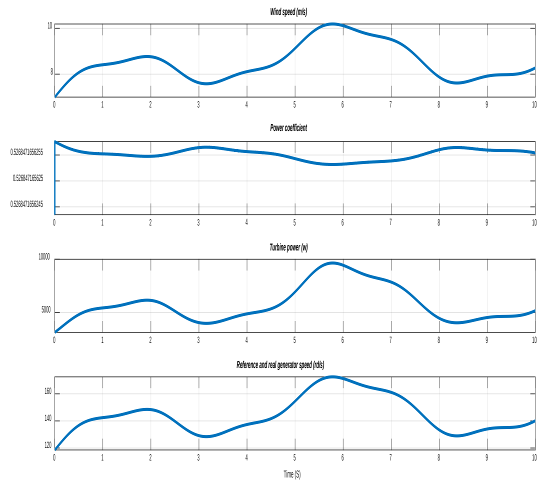

Fig. 6. Size of the network side for random wind

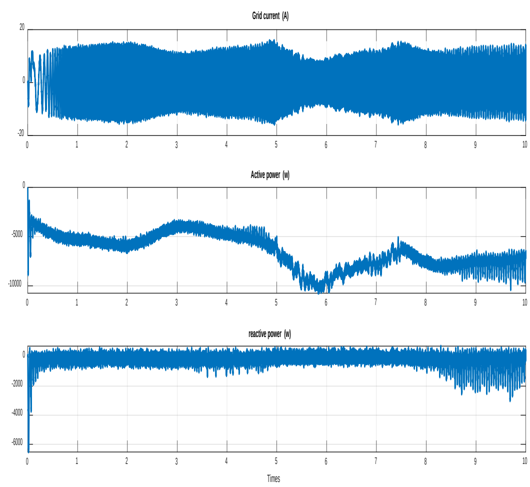

Fig. 7. Network side quantities for random wind

4. Conclusion

The modelling aspect of a WECS system as well as the speed control of the DFIG with connection to the network characterizes the work carried out in this paper. The speed control by a variable structure controller, in particular the sliding mode, proved to be very efficient under the effect of the two wind profiles considered (variation in stages and of a random nature). The analysis of the results obtained by simulation is very conclusive and therefore the proposed structure is very promising.

References

[1] D. Jha, T. Amarmath, P. Swetapadma, Behera R.R., “A Review on wind energy conversion system and Enabling Technology‖, (CEPES) ”, Maulana Azad National Institute of Technology, Bhopal, India. Dec. 14-16, 2016.

[2] A. Habibi, N. Mousavi, M. Mohammadi, S. Farahmand, “The Performance of Types of Fuel Cell: Energy Generation”, International Journal of Engineering Science and Application 3 / 3 (September 2019): 142-150.

[3] Site update May 15, 2017, content published under the Valls II government from August 26, 2014 to January 11, 2016

[4] Worldwide energy report, Conf. World wind energy Renew. Energy Exhib., WWEA, Cairo, pp.6-8, 20102.

[5] http://www.aps.dz/en Sunday, 09 February 2020 18:52

[6] Y. Xia, H. Kh. Ahmed, B. Williams, “Wind Turbine Power Coefficient Analysis of a New Maximum Power Point Tracking Technique”, IEEE Transactions on Industrial Electronics, VOL. 60, NO. 3, pp. 1122-1132, March 2013.

[7] I. Mohame, A. Yousef, K. Hasaneen, M. Nashed, Galal H. Hamed, “International Standalone Wind Energy Conversion System Control Using New Maximum Power Point Tracking Technique”, Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 9, Issue 2, February 2019).

[8] M. Hallouz, N. Kabache, S. Moulahoum, S. Kouadria, “Neural Network Based Field Oriented Control for Doubly-Fed Induction Generator”, International Journal of Smart Grid , Vol.2, No.3, 2018.

[9] H. Benbouhenni, Z. Boudjema, Abd.k. Belaidi, “A Direct Power Control of the Doubly Fed Induction Generator Based on the Three-Level NSVPWM Technique”, International Journal of Smart Grid , Vol.3, No.4, December 2019.

[10] A. Lakhdara, T. Bahi and Abd. Moussaoui, “Sliding Mode Control of Doubly-fed Induction Generator in Wind Energy Conversion System”, 2020 8th International Conference on Smart Grid (icSmartGrid), Paris, France, 2020, pp. 96-100, doi: 10.1109/icSmartGrid49881.2020.9144778.

[11] M. Zadehbagheri, R. Ildarabadi, M. Baghaei Nejad, “Sliding Mode Control of a Doubly- fed Induction Generator(DFIG) for Wind Energy Conversion System”, International Journal of Scientific & Engineering Research, Volume 4, Issue 11, November - 2013 ISSN 2229-5518

[12] A. Boyette, “Control and command of an doubly fed induction generator power supply with storage system for wind power generation,” PHD Thesis, Henri Poincaré University , France, 2006.

[13] S. Niranjan, Y. K. Chauhan, “Performance Analysis of Doubly Fed Induction Generator Coupled With Wind Turbine,” Themed Section: Engineering and Technology, © 2015 IJSRSET, Volume 1, Issue 3 ,Print ISSN : 2395-1990 | Online ISSN : 2394-4099, Gautam Buddha University, Greater Noida, India.

[14] I. Ngom, A. Bmboup, A. Dieng, N. Diaw, “Efficient Control of Doubly Fed Induction Generator Wind Turbine Implementation in Matlab Simulink,” Journal of Engineering Research and Application, Vol. 8, , pp 06-12, Issue 7 (Part -I) July 2018.

[15] I. M. Abdelqawe, “International Standalone Wind Energy Conversion System Control Using New Maximum Power Point Tracking Technique,” Journal of Emerging Technology and Advanced Engineering , Volume 9, Issue 2, February 2019. .

[16] Harnan, R. J. Mantz, “Dynamical variable structure controller for power regulation of wind energy conversion systems,” IEEE T. Energy Conver., vol.19, pp.756-763, 2004.

[17] V. Utkin, “Sliding mode control design principles and applications to electric drives,” IEEE T. Ind. Electron., vol.40, pp.26-36, 1993.