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A Study of the Performance of Generators Used in Wind Systems

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Abstract

The world's energy consumption is ever on the increase, raising crucial questions about the problem of global warming due to the release of greenhouse effect gases (GHG), on the one hand, and to the exhaustion of fossil resources, on the other one. Such realisation ought to result in an environment conscious economic development. Wind power is one of the most promising renewable energies. Within this context, this paper constitutes a study about the various configurations and performances of the most used generators in wind systems.

Keywords: *Various generators, Wind energy conversion system, Regulation of a windmill*

1. Introduction

The oil crisis of 1974, the exhaustion of fossil energies in the near future and the search for permanent growth that is environment conscious, as emphasized by the World Climate Conference agreement of Kyoto on December 1997, have contributed to the development of renewable energies. One particular case of such energies is wind energy which is emerging as a consequence of both environmental problems and technological advances in aero generators, the technology of which has considerably evolved in the last 20 years bringing about specialization in various types of windmills.

A classification approach to the various generators used in the wind systems will be presented while describing the major configurations of the fixed speed systems and the variable speed ones. The mathematical models of the asynchronous cage winding generator, twin supplied generator, twin star generator and permanent magnets asynchronous generator will be dealt with in details. The advantages and disadvantages of these different types will be displayed in a recap chart.

2. Constituents and Technological Aspects of Windmills

We may classify windmills according to the geometrical disposition of the shaft on which the propeller is mounted. There are two major types of turbines [15]:

- Horizontal axis turbines
- Vertical axis turbines

Most of the currently used windmills are of the horizontal axis type. They are aerodynamically more efficient; they start in an autonomous way and have fewer ground cluttering problems.

The number of blades ranges between 1 and 3; the three blade rotor is by far the most widespread because it fairly well combines low cost with less vibrating behaviour and less visual pollution and noise.

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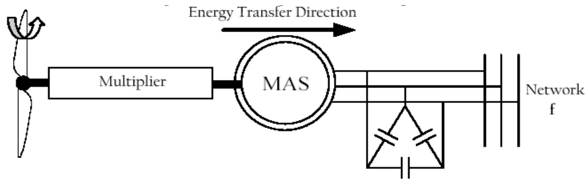
Vertical axis windmills are still at the stage of experiment; two structures have reached an industrialization stage, namely Savonius and Darrieus rotors. Although some industrial projects have been achieved, vertical axis windmills remain, nonetheless, less common and rarely used.

3. Various generators used in wind systems

3.1. Asynchronous Cage Winding Generator

Contrary to other traditional means for the production of electricity in which the synchronous alternator is widely used, now it is the worldwide us cage winding generator alternator which equips the majority of windmills installed worldwide. Since it is quite reversible, this machine is very resistant and seldom breaks down. Its low cost and its working without a collector stick system make of it quite an adequate means for using wind. The couple/speed features of a twin pole pairs asynchronous machine are provided in Figure 1 [2, 14].

For a stable functioning of the device, the generator must keep a rotation speed that is close to synchronism (g = 0 point); in case the feature is as it is below, the speed of the generator must be kept between 1500 and 1600 turn/min.



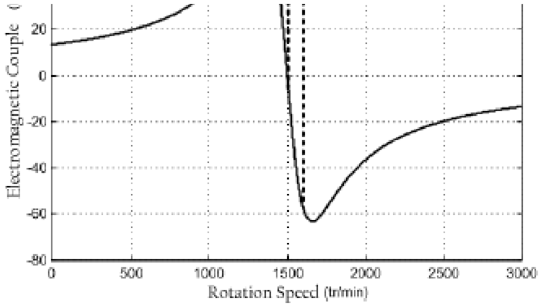


Figure 1. Couple/Speed Feature of a Twin Pole Pair Asynchronous Machine

Figure 2. Direct Connection of a MAS to the Network [2]

The simplest and most used device consists in inserting a speed multiplier between the turbine and the asynchronous machine and directly connecting the stator of the latter to the network, Figure 2.

Most wind applications, about 85%, are with fixed rotation speed and direct connection to the network.

As the machine has a fixed number of pole pairs, it must work at a very limited speed range (a shift that is inferior to 2%). As frequency is imposed by the network, if the shift becomes too significant, the machine's statoric currents increase and may become destructive. The simplicity of the configuration, no interface between the network and the stator and no slipping contact, limit the machine's maintenance.

This type of machine consumes reactive energy for its rotor's magnetization, which deteriorates the power factor of the network. This is their major drawback, and as a solution condenser batteries may be added.

This fixed speed operating system, despite its simplicity, does not make use of all the available power for high wind speeds. It is also noisy because of the blades' orientation system which is often in action in order to solve the problem of wind speed variation. To increase the efficiency of this system, some manufacturers use the twin star asynchronous machine Figure 3.

This system remains at a fixed speed but with two functioning points. A low power star with a big number of pole pairs for small wind speeds, and a high power one with a small number of pole pairs for higher wind speeds. The presence of a second star increases the windmill cost as well as its weight and the cluttering of the overall device [2].

Another solution consists in using a frequency switch, but it is a costly solution as it requires a speed multiplier and a frequency switch. The pricing disadvantage has not allowed developing this important configuration as it is rarely used despite the fact that it permits working with a variable speed Figure 4.

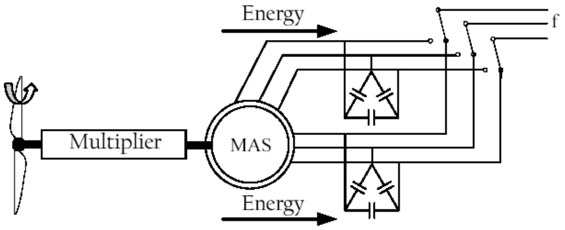


Figure 3. Twin Star Asynchronous Machine [2]

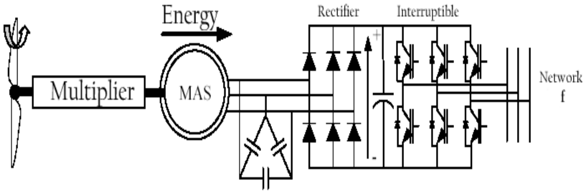


Figure 4.Variable Frequency Cage Winding Asynchronous Machine [2]

3.2. Double Supply Asynchronous Machine (DSAM)

The DSAM is a little bit more complex than the cage winding asynchronous machine with which it shares the need for a speed multiplier; its resistance is diminished by the stick ring system, but its advantageous working with variable speed led to a lot of manufacturers using this kind of machine [1, 11, 13].

The generator's stator is directly coupled to the network, and the rotor's electronic setting ensures the sliding variation. The rotor chain permits, in this way, all the device to function at a variable speed. This configuration allows a limited speed variation at approximately 10% around the speed of synchronism by changing the rotor's resistance. In addition to the limited speed variation range, the disadvantage of this solution is the reduction of the rotor power in the resistant elements Figure 5.

Another very interesting solution permits obtaining a rotation speed variation of about 30% round the speed of synchronism. This consists in coupling the generator's rotor with the network using a rectifier, then an interruptible power supply Figure 6.

3.3. Synchronous Generators

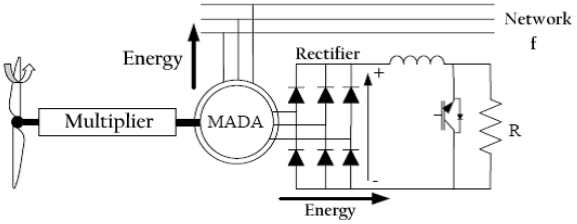


Figure 5. Speed Variation by Setting the Rotor's Resistance [2]

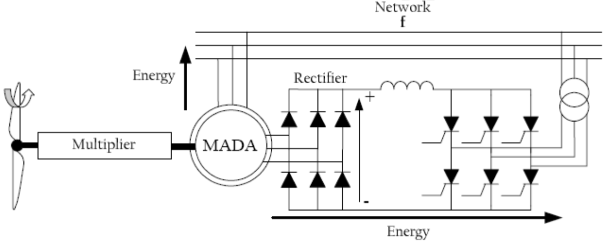


Figure 6. Rotation Speed Regulation by Rotor Chain [2]

The asynchronous machines have the disadvantage of imposing a speed multiplier and an insufficient couple for a direct mechanical coupling on the windmill wings. Conversely, synchronous machines are known to offer important couples; they may, therefore, be used by direct traction on wind turbines.

This type of systems has its disadvantages too. They require regular maintenance of the rings and sticks. Direct coupling on the network is prohibited, given that it is too much rigid. Hence, power electronics is a must for all applications using this type of machines with variable speed.

In a classical synchronous machine used as an alternator, the field that is created by the rotor must turn at the same speed as the statoric field. Consequently, if the alternator is coupled with the network, its rotation speed must strictly be a sub multiple of the statoric currents pulse. In order to synchronize the machine with the network, we place a power electronics interface between the machine's stator and the network; this permits functioning at a variable speed [2].

Coupling these machines with electronics power renders them economically more and more efficient and, therefore, a serious competitor for the twin supplied asynchronous generators.

Some variants of these synchronous machines may work at low rotation speeds and may be directly coupled with the aero turbine. They allow, in this way, to spare the user the multiplier which is a costly element in most of the aerogenerators and requires a substantial work of maintenance [5].

The systems of this type have a malfunction rate deemed weak thanks to the suppression of certain sources of defects: No speed multiplier and no system of rings and sticks for magnet generators Figure 7. The costs of maintenance are, therefore, reduced, which is very interesting in wind applications.

The following is an example of a classical connection interface of a synchronous machine to a network. The connected convertor to the machine's stator is a simple rectifier followed by a chopper elevator which allows supplying the MLI interruptible with enough voltage for weak rotation speeds. The presence of an interruptible allows controlling the power factor concerning the network. These convertors are, however, sized for the entire nominal power of the machine and cause the loss of up to 3% of this power Figure 8.

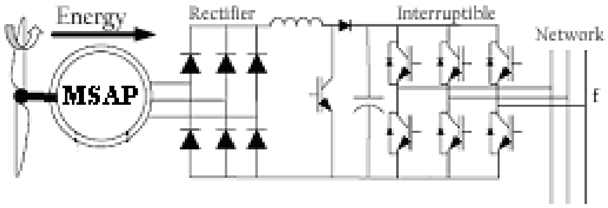


Figure 7. Permanent Synchronous Magnet Machine with Direct Traction

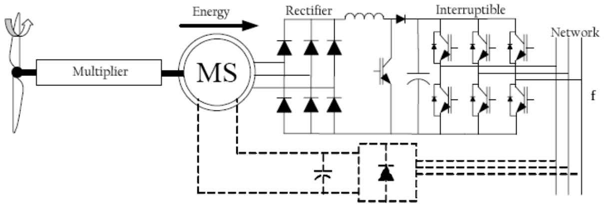


Figure 8. Synchronous Machine Connected to the Network with an MLI Rectifier-chopper-uninterruptible [2]

4. Power Mechanical Regulation of a windmill

A windmill is conceived and sized in order to produce a Pn nominal power on the basis of a Vn nominal wind speed. Beyond such speed, the turbine must modify its aerodynamic parameters so that the power it recovers should not exceed the nominal power for which the windmill was conceived.

Let Vd: The initial wind speed at which the windmill starts producing energy.

Vm: Maximal wind speed beyond which the windmill must be stopped for safety and functioning reasons [3].

Therefore, the power feature, according to the wind speed, includes four zones Figure 9.

a) Zone I : The turbine does not provide any power yet.

b) Zone II : The provided power is in accordance with the wind speed.

c) Zone III : The rotation speed is kept constant using a regulating device and at which point the provided power is practically equal to Pn.

d) Zone IV : Where the functioning safety system stops rotation and energy transfer.

Most of the aerogenerators use two aerodynamic control principles in order to limit the extracted power from the generator's nominal value [5].

The pitch system or step system or variable stalling system is an active technique that is costly enough and which consists in mechanically setting the blades' angular position on the axis. It is, therefore, a technique which is used in the variable speed systems with an average or high power [10].

The stall system or the aerodynamic uncoupling one is more resistant because it is the form of the blades which leads to a loss of lift beyond a certain wind speed. It is therefore a passive solution [4].

Certain manufacturers have developed hybrid systems. Active stall or aerodynamic stalling is progressively obtained thanks to a minimal orientation of the blades which requires more economical setting means.

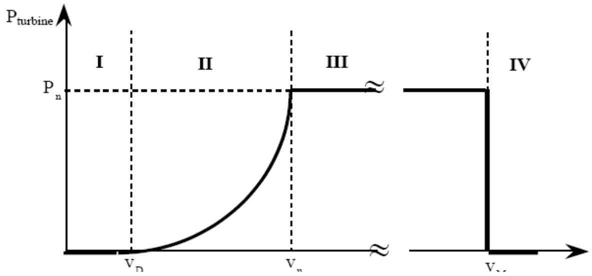


Figure 9. Power Feature Following the Wind Speed

5. Establishing the Patterns of Various Generators

5.1. Cage Winding Asynchronous Generator

The equations system of the generator following the dq axes in Park's point of reference linked to the turning field is given in [8, 17, 19]:

$$\begin{cases} -v_{ds} = r_s i_{ds} - \omega_s \varphi_{qs} + p\varphi_{ds} \\ -v_{qs} = r_s i_{qs} + \omega_s \varphi_{ds} + p\varphi_{qs} \\ v_{dr} = 0 = r_r i_{dr} - \omega_{gl} \varphi_{qr} + p\varphi_{dr} \\ v_{qr} = 0 = r_r i_{qr} + \omega_{gl} \varphi_{dr} + p\varphi_{qr} \end{cases} \text{avec} \begin{cases} \varphi_{ds} = L_s i_{ds} + M i_{dr} \\ \varphi_{qs} = L_s i_{qs} + M i_{qr} \\ \varphi_{dr} = L_r i_{dr} + M i_{ds} \\ \varphi_{qr} = L_r i_{qr} + M i_{qs} \end{cases} \quad (1)$$

r_s, L_s an r_r, L_r respectively represent statoric and rotor resistance and inductance; M mutual inductance; $\omega_{gl} = \omega_s - \omega_r$ with ω_s et ω_r represent the statoric and rotor pulses; v, i and φ represent voltages, currents and fluxes; p represents Laplace operator.

The electromagnetic couple is expressed in [20]:

$$C_{em} = \frac{3}{2} PM \left(i_{sq}.i_{rd} - i_{sd}.i_{rq} \right) \quad (2)$$

P is the number of pole pairs.

5.2. Twin Supply Asynchronous Generator

The equations system of the generator in Park's point of reference linked to the turning field is given in [6]:

$$\begin{cases} v_{ds} = -r_s i_{ds} - \omega_s \varphi_{qs} + p\varphi_{ds} \\ v_{qs} = -r_s i_{qs} + \omega_s \varphi_{ds} + p\varphi_{qs} \\ v_{dr} = r_r i_{dr} - \omega_{gl} \varphi_{qr} + p\varphi_{dr} \\ v_{qr} = r_r i_{qr} + \omega_{gl} \varphi_{dr} + p\varphi_{qr} \end{cases} avec \begin{cases} \varphi_{ds} = -L_s i_{ds} + M i_{dr} \\ \varphi_{qs} = -L_s i_{qs} + M i_{qr} \\ \varphi_{dr} = L_r i_{dr} - M i_{ds} \\ \varphi_{qr} = L_r i_{qr} - M i_{qs} \end{cases} \quad (3)$$

The electromagnetic couple is expressed in [9], [16]:

$$C_{em} = P \frac{M}{L_s} \left(i_{qr}.\varphi_{ds} - i_{dr}.\varphi_{qs} \right) \quad (4)$$

5.3. Twin Star Asynchronous Generator

The differential equations system of the electrical generator linked to the turning field is given in [12, 18]:

$$\begin{cases} v_{d1} = -r_1 i_{d1} - \omega_s \varphi_{q1} + p\varphi_{d1} \\ v_{q1} = -r_1 i_{q1} + \omega_s \varphi_{d1} + p\varphi_{q1} \\ v_{d2} = -r_2 i_{d2} - \omega_s \varphi_{q2} + p\varphi_{d2} \\ v_{q2} = -r_2 i_{q2} + \omega_s \varphi_{d2} + p\varphi_{q2} \\ v_{dr} = 0 = r_r i_{dr} - \omega_{gl} \varphi_{qr} + p\varphi_{dr} \\ v_{qr} = 0 = r_r i_{qr} + \omega_{gl} \varphi_{dr} + p\varphi_{qr} \end{cases} \quad (5)$$

$$\begin{cases} \varphi_{d1} = -L_{l1} i_{d1} - L_{lm}(i_{d1} + i_{d2}) - L_{dq} i_{q2} + M(-i_{d1} - i_{d2} + i_{dr}) \\ \varphi_{q1} = -L_{l1} i_{q1} - L_{lm}(i_{q1} + i_{q2}) + L_{dq} i_{d2} + M(-i_{q1} - i_{q2} + i_{qr}) \\ \varphi_{d2} = -L_{l2} i_{d2} - L_{lm}(i_{d1} + i_{d2}) + L_{dq} i_{q1} + M(-i_{d1} - i_{d2} + i_{dr}) \\ \varphi_{q2} = -L_{l2} i_{q2} - L_{lm}(i_{q1} + i_{q2}) - L_{dq} i_{d1} + M(-i_{q1} - i_{q2} + i_{qr}) \\ \varphi_{dr} = L_{lr} i_{dr} + M(-i_{d1} - i_{d2} + i_{dr}) \\ \varphi_{qr} = L_{lr} i_{qr} + M(-i_{q1} - i_{q2} + i_{qr}) \end{cases} \quad (6)$$

Indexes 1 and 2 respectively represent star 1 and star 2; L_{dq} represents the inter saturation cyclic inductance; L_{lm} represents the mutual outflow inductance; L_{l1}, L_{l2} et L_{lr} represent the statoric and rotor outflow inductances (Star 1 and star 2).
The electromagnetic couple is expressed in [7]:

$$C_{em} = \frac{3}{2} P \frac{M}{L_r} \left[\left(i_{q1} + i_{q2} \right) \varphi_{dr} - \left(i_{d1} + i_{d2} \right) \varphi_{qr} \right] \quad (7)$$

5.4. Permanent Magnets Synchronous Generator

The equations system in Park's point of reference linked to the turning field is given in [22]:

$$\begin{cases} v_d = -r_s i_d + \omega_s L_q i_q - L_d p i_d \\ v_q = -r_s i_q - \omega_s L_d i_d - L_q p i_q + \omega_s \varphi_f \end{cases} \quad (8)$$

L_d and L_q respectively represent direct and in squaring statoric inductances; φ_f represents the magnets flow.
The electromagnetic couple is expressed in [21]:

$$C_{em} = \frac{3}{2} P \left[\left(L_d - L_q \right) I_d I_q + I_q \varphi_f \right] \quad (9)$$

6. Interpretation

According to the simulation work undertaken during the last years in the LEB research laboratory on the previously mentioned various generators, and after a thorough review of the literature, what has been noted is that the cage winding generators represent 85% of the wind applications in a power range between 100 kW and 1 MW. The twin star generators which have been the subject of very recent research are serious competitors to the cage winding generator. The twin supply generator is very widespread in the range of the big powers. It constitutes along with the permanent magnets generator the two solutions that compete with variable speed windmills.

7. Conclusion

The field of the renewable energies, notably wind energy, constitutes a new opportunity for research in electrical engineering. This research will be both fruitful and multidisciplinary enough to meet the requirements of these complex systems.

Considering the important energy potential available in Algeria, notably solar and wind energies, it would both judicious and opportune to invest in studying, setting up and following up of both small power windmills and hybrid wind and solar systems.

References

[1] A. Mirecki, "Etude Comparative de Chaines de Conversion d'Energie Dédiées à une Eoliennee de Petite Puissssance", Thèse de Docteur de l'Université de Toulouse, France, **(2005)**.

[2] F. Poitiers, "Etude et Commande de Génératrices Asynchrones Pour l'utilisation de l'énergie Eolienne", Thèse de Docteur de l'Université de Nantes, France, **(2003)** Décembre.

[3] O. Gergaud, "Modélisation Energétique et Optimisation Economique d'un Systeme de Production Eolien et Photovoltaique Couplé au Réseau et Associé à un Accumulateur", Thèse de Docteur de l'École Normale Supérieure de Cachan, France, **(2002)** Décembre.

[4] G. Cimuca, "Système inertiel de Stockage d'énergie Associé à des Générateurs Eoliens," Thèse de Docteur de l'Ecole Nationnale Supérieure d'Arts et Métiers de Lille, France, **(2005)**.

[5] H. Camblong, "Minimisation de l'impact des Perturbations d'origine Eolienne Dans la Génération d'Electricité par des Aérogénerateurs à Vitesse Variable," Thèse de Docteur de l'Ecole Nationnale Supérieure d'Arts et Métiers de Bordeaux, France, **(2003)** Décembre.

[6] A. Boyette, "Contrôle-commande d'un Générateur Asynchrone à Double Alimentation Avec Système de Stockage Pour la Production Eolienne," Thèse de Docteur de l'Université de Nancy I, France, **(2006)** Décembre.

[7] G. K. Singh, K. B. Yadav and R. P. Saini, "Modelling and Analysis of Multi-phase (six phase) Self-excited Induction Generator", Proc. IEEE Conf. ICEMS'2005, The Eighth International Conference on Electrical Machines and Systems, **(2005)** ; China

[8] R. Abdessemed et K. Kadjoudj, "Modélisation des Machines Electriques", Presses de l'Université de Batna, Algérie, **(1997)**.

[9] S. Tamazoult, "Etude Comparative de l'alimentation de la Machine Asynchrone à Double Alimentation par un Convertisseur Statique AC/AC à Commutation Forcée et Naturelle", Thèse de Magister de l'Université de Batna, Algérie, **(2005)** Juin.

[10] V. Rogez, "Modélisation Simplifiée de Sources de Production Décentralisée Pour des études de Dynamique des Réseaux", Application à l'Intégration d'Une Production Eolienne Dans un réseau de Distribution Insulaire", Thèse de Docteur de l'Université d'Artois, France, **(2004)** Décembre.

[11] B. Palle, M. G. Simes and F. A. Farret, "Dynamic Simulation and Analysis of Parallel Self-excited Induction Generator for Islanded Wind Fram Systems," IEEE Transactions on Industry Applications, vol. 41, no. 4, **(2005)**, pp. 1099–1106.

[12] O. Ojo and I. E. Davidson, "PWM-VSI Inverter-Assisted Stand-alone Dual Stator Winding Induction Generator", IEEE Tansactions on Industry Applications, vol. 36, no. 6, **(2000)**, pp. 1604–1611.

[13] A. Dendouga, "Commande par Mode Glissant de la Machine à double Alimentation Alimentée par un Onduleur de Tension", Thèse de Magister de l'Université de Batna, Algérie, **(2004)** Octobre.

[14] D. Seyoum, C. Grantham and M. F. Rahman, "The Dynamic Characteristics of an Isolated Self-excited Induction Generator Driven by a Wind Turbine", IEEE Tansactions on Industry Applications, vol. 39, no. 4, **(2003)**, pp. 936–944.

[15] I. Meny, "Modélisation et Réalisation d'une Chaine de Conversion Eolienne Petite Puissance," Laboratoire d'Electrotechnique de Montpellier LEM, France, **(2005)**.

[16] S. Drid, "Contribution à l'étude de la Machine à Rotor Bobiné à double Alimentation," Thèse de Magister de l'Université de Batna, Algérie, **(2000)** Juillet.

[17] K. Idjdarene, D. Rekioua and D. Aouzellag, “Modélisation et Simulation d’une Chaîne de Conversion à Energie Eolienne Basée Sur Une Génératrice Asynchrone en Fonctionnement Autonome”, 3rd Conference on Electrical Engineering, CEE’04, Batna University, **(2004)**.

[18] G. K. Singh, K. B. Yadav and R. P. Saini, “Analysis of a Saturated Multi-phase (six phase) Self-excited Induction Generator”, International Journal of Emerging Electric Power Systems, The Berkeley Electronic Press, vol. 7, no. 2, Article 5, **(2006)**, pp. 1–21.

[19] K. E. Hallenius, P. Vas and J. E. Brown, “The Analysis of a Saturated Self-excited Asynchronous Generator”, IEEE Tansactions on Energy Conversion, vol. 6, no. 2, **(1991),** pp. 336–341.

[20] A. Belamoudi, “Etude et Simulation d’un Système de Conversion d’Energie Electrique à Base d’Une Machine Asynchrone”, Thèse de Magister de l’Université de Batna, Algérie, (1996) Décembre .

[21] A. Goléa, N. Goléa, M. Kadjoudj and N. Benounnes, “Computer-Aided Design of Sliding Mode Control of Permanent Magnet Synchronous Control”, IEEE Proceedings, **(1999)** August ; Hawai USA.

[22] O. Fadli, “Modélisation et Commande Non Linéaire de l’Association : Machine Synchrone à Aimant Permanent-onduleur de Tension à Trois Niveaux,” Thèse de Magister de l’Université de Batna, Algérie, **(2004)** Juin.