**Ibrahim BENGUERGOUR[1], Tayeb ALLAOUI[2], Abdeldjabbar Mohamed KOUADRIA[2], Mouloud DENAI[3]**

Unité de Recherche Matériaux et Energies Renouvelables, Faculté des sciences, Université Abou-bekr Belkaid, Tlemcen, Algerie (1)
Laboratoire de Génie Energétique et de Génie Informatique, Faculté de Téchnologie, Université Ibn Khaldoun, Tiaret, Algérie (2)
École d'Ingénierie et de Technologie, Université du Hertfordshire, Hatfield, Hertfordshire, Ukraine (3)

doi:10.15199/48.2020.02.45

# Optimization and Adaptive Control of Wind water Pumping System based on fuzzy RST and genetic RST

***Abstract**. the use of wind energy in water pumping is an economically viable and sustainable solution to rural communities without access to the electricity grid. The aim of this paper is to present a detailed modeling of the wind-powered pumping system, propose and compare some control schemes to optimize the performance of the system and enhance the quality of the generated power. The wind energy system used in this paper consists of a permanent magnet synchronous generator (PMSG) and static converters directly coupled to an asynchronous motor that drives a centrifugal pump. A typical control is applied to the proposed configuration for the purpose of controlling the generator to extract maximum wind power. Furthermore, four types of controllers (PI and conventional RST polynomials, adaptive RST-fuzzy and genetic algorithm are designed for the wind energy system and tested under various operating conditions.*

***Streszczenie.** wykorzystanie energii wiatru w pompowaniu wody jest opłacalnym i zrównoważonym rozwiązaniem dla społeczności wiejskich bez dostępu do sieci elektrycznej. Celem tego artykułu jest przedstawienie szczegółowego modelowania systemu pompowania napędzanego wiatrem, zaproponowanie i porównanie niektórych schematów sterowania, aby zoptymalizować wydajność systemu i poprawić jakość generowanej mocy. System energii wiatrowej zastosowany w tym artykule składa się z synchronicznego generatora z magnesami trwałymi (PMSG) i przekształtników statycznych bezpośrednio sprzężonych z silnikiem asynchronicznym, który napędza pompę odśrodkową. Typowe sterowanie jest stosowane do proponowanej konfiguracji w celu sterowania generatorem w celu wydobycia maksymalnej energii wiatru. Ponadto cztery typy sterowników (PI i konwencjonalne wielomiany RST, adaptacyjny algorytm rozmytego RST i genetyczny) są zaprojektowane dla systemu energii wiatrowej i testowane w różnych warunkach pracy). **Optymalizacja i adaptacyjne sterowanie system,u pompowania wody wspomaganego elektrownia wiatrową***

**Keywords:** Wind Energy, Water Pumping, PMSG, RST Control, Fuzzy Logic, Genetic Algorithm.
**Słowa kluczowe:** Energia wiatru, pompowanie wody, PMSG, kontrola RST, logika rozmyta, algorytm genetyczny.

## Introduction

In recent years, wind energy has become an increasingly attractive source of renewable energy. While wind energy is a clean and environmentally friendly source of energy, it is an efficient and reliable technology for generating electricity in remote off-grid locations. This would ultimately improve the quality of life of our natural sources [1, 2]. In this context, our application aims to make good use of wind energy for supplying a water pumping system which is particularly useful in rural areas where access to electricity would require a substantial investment.

In fact, the realization of reliable and efficient wind pumping systems offers a practical and economical solution to the problem of lack of water in the desert regions.

These systems are used with alternating current (AC) motors and connected through a charge controller or inverter [3].

The permanent magnet synchronous generator is characterized by high torque density, low inertia and low inductance. All these features provide the high performance synchronous generator with high efficiency and controllability, a wind turbine (WT) converts mechanical energy into electrical energy and produces an AC output voltage that is converted to a DC output using a rectifier. The constant DC link voltage is given to the input of the inverter, into the desired alternating current for the expected output voltage.

The purpose of this article is to present a complete model of the proposed wind energy-based pumping system and propose control strategies to optimize the power produced [1, 4, 5]. The proposed control strategies for the PMSG-based wind energy conversion system include a proportional-integral (PI), polynomial pole-placement RST controller, adaptive fuzzy logic-based RST controllers and genetic algorithm optimized RST controller. A comprehensive comparison of these controllers is also presented to demonstrate the superior performance and robustness of the proposed controllers and the limitations of the fixed parameters conventional PI controller for this application.

*The paper is organized as follows: The description of the wind generator system and centrifugal pump model is presented in Section 2. In Section 3, description of the flux oriented control. In Section 4, the proposed RST-Fuzzy and RST-Genetic control scheme of the* wind system and *simulation results is presented in Section 5 to demonstrate the performance of the proposed system.*

## Description of the wind generator system

The overall system is shown in Fig.1. The wind generator consist of a variable speed turbine coupled directly to a permanent magnet synchronous generator connected to a DC bus through a PWM power converter.

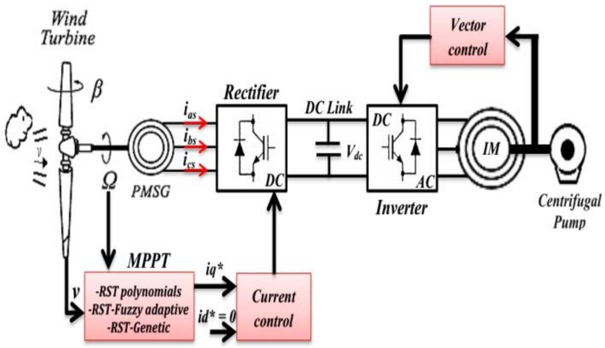



Fig.1. Configuration of PMSG-based wind turbine water pumping system

## Wind turbine model

The turbine power and torque developed are given by the following relation [8, 10]:

(1) $$P_m = \frac{1}{2}\rho\pi R^2 v^3 C_p(\lambda)$$

(2) $$T_m = \frac{P_m}{\Omega} = \frac{1}{2\lambda}\rho\pi R^3 v^2 C_p(\lambda)$$

whereλdenotes the ratio between the turbine angular speed and the wind speed. This ratio is defined as the tip speed ratio and is given as:

(3) $$\lambda = \frac{\Omega R}{v}$$

Where ρ is the air density, R is the blade length, v is the wind speed, Cp is the power coefficient, Ω is the turbine angular speed.

The power coefficient (Cp) represents the aerodynamic efficiency of the turbine and depends on the specific speed λ and the angle of attack of the blades. It differs from one turbine to another, and is usually provided by the manufacturer [11].

**Permanent magnetic synchronous generator**

A detailed model of the PMSG generator drive system is required for a complete and proper simulation of the system [6]. The dynamic model of the PMSG can be represented in the rotating reference frame with the following equations:

(4) $$\begin{cases} Vq = -R_s.I_q - L_q.\dfrac{dI_q}{dt} - w.L_d.I_d + w.\phi_m \\ Vd = -R_s.I_d - L_d.\dfrac{dI_d}{dt} + w.L_q.I_q \end{cases}$$

The electromagnetic torque in the rotor can be written as:

(5) $$Cem = P.\frac{3}{2}.[(L_d - L_q).I_d.I_q + \phi_m.I_q]$$

In a cylindrical rotor is assumed then $L_d \approx L_q$ and hence the above equation reduces to:

(6) $$Cem = P.\frac{3}{2}.\phi_m.I_q$$

Where $P$ is the number of poles, $\Phi_m$ is the magnetic flux, $L_d$ is the direct axis inductance, $L_q$ is the quadrature inductance, $R_s$ is the resistance and $w$ is the rotor speed of the generator [7].

**Centrifugal pump model**

Any pump is characterized by its absorptive power which is obviously a mechanical power on the shaft coupled to the pump, which is given by [12, 13].

(7) $$P = \frac{\rho g H Q}{\eta}$$

(8) $$\eta = \frac{Pu}{P}$$

The final torque equation:

(9) $$T_{pump} = K_1 n^2 + K_2 n Q + K_3 Q^2$$

Where n denotes the rotational speed of the pump shaft (rad/s), ρ is the Water volumic mass ($Kg/m^3$), Q represents water flow ($m^3/s$), $K_1$,$K_2$,$K_3$ are coefficients given by the manufacturer, H is the height of rise (m) and g represents the acceleration of gravity ($m^2/s$).

**Flux oriented control**

The principle of this control is to reduce the electromagnetic torque equation of the machine in order to be comparable to that of a DC machine. The transient torque is expressed in the reference d, q as a cross product of currents:

(10) $$Ce = P.\frac{M}{L_r}.(\phi_{dr} I_{qs} - \phi_{qr} I_{ds})$$

From equation (10), it can be seen that if one eliminates the second product ($\varphi_{qr}$, $I_{ds}$), the torque will be similar will be very much like that of a DC machine. To do so, the dq reference is orientated so as to cancel the component of flux in quadrature. That is to say, a proper rotation angle must be selected so that the rotor flux is entirely aligned with the direct axis (d) and therefore $\varphi_{qr}= 0$. Thus $\varphi_r = \varphi_{qr}$ must hold.

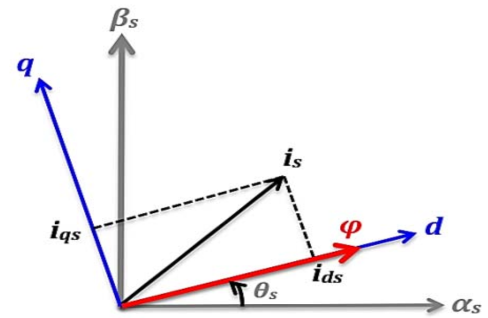



Fig.2. Principle of vector control.

The torque is then given by:

(11) $$Ce = P.\frac{M}{L_r}.\phi_r I_{qs}$$

It should regulate the flow by acting on the component of the stator current ids and it regulates the torque acting on the component $I_{qs}$. Figure 2 summarizes this regulation because it shows a diagram of vector control of induction motor with speed control and regulation of the two currents ids and $I_{qs}$. We then have two action variables as in the case of DC machine. One strategy is to let the constant component ids. That is to say, to fix its reference so as to impose a nominal flux in the machine. The current controller handles $I_{ds^*}$ to maintain the current ids constant and equal to the reference $I_{ds^*}$ ($I_{ds}$ = $I_{ds}$ Reference). If you want to speed up the machine, thus increasing its speed, it requires a reference current $I_{qs^*}$ positive. The current controller $I_{qs}$ will impose the reference current to the machine [16, 17].

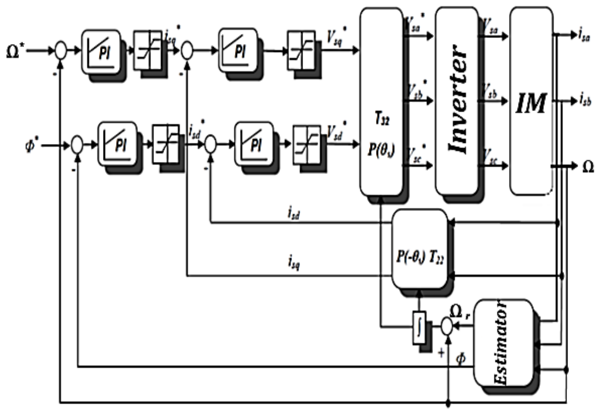



Fig.3. Speed control of induction motor in FOC.

**Controllers design**

**RST-Fuzzy adaptive control**

The order of the polynomials R, S and T which form the controller are determined based on the degree of the transfer function of the open-loop control system, they are calculated using the pole placement strategy [18] [19].

The proposed adaptive fuzzy RST control scheme is illustrated in Fig. 4.

The transfer function of the system is written as follows:

(12) $$Y = \frac{B.T}{A.S + B.R} Y_{ref}$$

Since the design regulator is strictly proper, then if A is a polynomial of degree n, the following must hold:

(13) $$\begin{cases} d^{\circ}(S) = d^{\circ}(A) + 1 = 2 \\ d^{\circ}(D) = 2d^{\circ}(A) + 1 = 3 \\ d^{\circ}(R) = d^{\circ}(A) = 1 \end{cases}$$

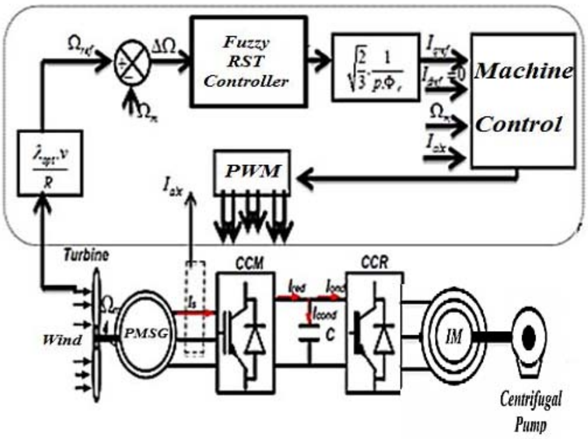



Fig.4. Structure of the adaptive fuzzy RST control scheme.

The transfer function of the mechanical part is given by :

(14) $$G_0(s) = \frac{\frac{1}{J}}{s + \frac{f_v}{J}} = \frac{B}{A}$$

(15) With: $$\begin{cases} b_1 = \frac{1}{J} \\ a_1 = \frac{f_v}{J} \\ a_0 = 1 \end{cases}$$

(16) And $$\tau_A = \frac{J}{f_v}$$

If the polynomial T in this case is fixed at a constant value, then we have [20]:

(17) $$\begin{cases} R(s) = r_0.s + r_1 \\ S(s) = S_0.s^2 + S_1.s \\ D(s) = d_0.s^3 + d_1.s^2 + d_2.s + d_3 \end{cases}$$

The Bezout equation (18) has four unknowns where the coefficients of polynomial D are linked with the coefficients of polynomials R and S by the matrix system:

(18) $$A.S + B.R = D$$

(19) $$(a_0 s + a_1).(S_0 s^2 + S_1 s) + b_1(r_0 s + r_1) = d_0 s^3 + d_1 s^2 + d_2 s + d_3$$

(20) $$\begin{bmatrix} 1 & 0 & 0 & 0 \\ a_1 & 1 & 0 & 0 \\ 0 & a_1 & b_1 & 0 \\ 0 & 0 & 0 & b_1 \end{bmatrix} . \begin{bmatrix} S_0 \\ S_1 \\ r_0 \\ r_1 \end{bmatrix} = \begin{bmatrix} d_0 \\ d_1 \\ d_2 \\ d_3 \end{bmatrix}$$

with:

(21) $$\begin{cases} b_1 = \frac{1}{J} \\ a_1 = \frac{f_v}{J} \\ a_0 = 1 \end{cases}$$

Solving this equation gives:

(22) $$\begin{cases} S_0 = \frac{1}{J} \\ S_1 = d_1 - a_1.d_0 ) \\ r_0 = \frac{d_2 - a_1.S_1}{b_1} \\ r_1 = \frac{d_3}{b_1} \end{cases}$$

According to the robust pole placement strategy, the polynomial D (s) is written as follows:

(23) $$D(s) = C.F = (s + \frac{1}{T_c}).(s + \frac{1}{T_f})^2$$

Where $T_c$ and $T_{fas}$ are selected as follows:

(24) $$\begin{cases} T_c = \frac{\tau_A}{4} \\ T_f = \frac{T_c}{5} \end{cases}$$

(25) $$\Rightarrow \begin{cases} d_0 = 1 \\ d_1 = \frac{2}{T_f} + \frac{1}{T_c} \\ d_2 = \frac{1}{T_f^2} + \frac{2}{T_f.T_c} \\ d_3 = \frac{1}{T_f^2.T_c} \end{cases}$$

To adjust the coefficients of RST, a fuzzy system is added so that RST coefficients are obtained which depend on the output of this system, see Fig.6.

The membership functions in the fuzzy part have a triangular shape as shown in the following Fig.5[9]:

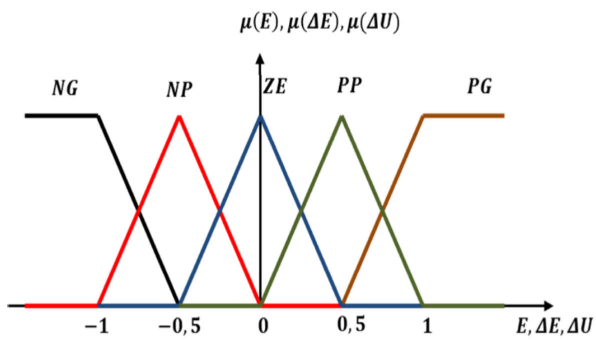



Fig.5. Membership functions of the fuzzy variable.

From a study of the behavior of the system, we can establish the control rules, which connect the output which is the control law with the inputs which are the error of the speed and its variation. Each of the two language inputs of the fuzzy controller has five fuzzy sets, giving a set of twenty-five rules. These can be represented by the following inference matrix:

Table 1. Rule base of the fuzzy controller.

| ΔE \ E | NG | NP | ZE | PP | PG |
|---|---|---|---|---|---|
| NG | NG | NG | NP | NP | ZE |
| NP | NG | NP | NP | ZE | PP |
| ZE | NP | NP | ZE | PP | PP |
| PP | NP | ZE | PP | PP | PG |
| PG | ZE | PP | PP | PG | PG |

A block diagram of the adaptive fuzzy RST control is shown in Fig.6.

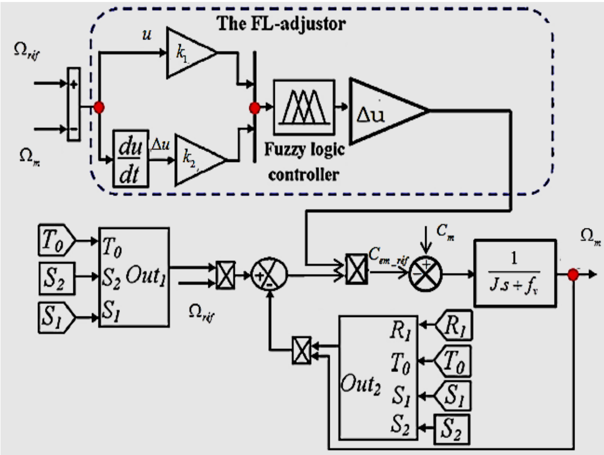



Fig.6. Structure of the adaptive RST-Fuzzy control.

## RST control based on genetic algorithm optimisation

The RST-GA is used to control the direct and quadrature rotor currents as illustrated in Fig.7. [14, 15].

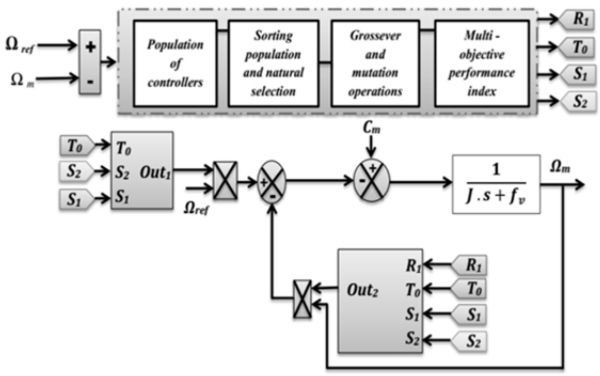



Fig. 7. Structure of the RST controller based on genetic algorithm.

The GA operations of selection, crossover and mutation are described by the flowchart of Fig . 8.

Table 2. GA parameters used in the model

| | |
|---|---|
| Population size | 80 |
| Variable bounds | [0 100;0 100] |
| Max N° of generation | 100 |
| Tolerance | 1e-6 |
| Performance index/ fitness function | Mean square error |
| Probability selection | 0.095 |
| Crossover method | Arithmetic crossver |
| Mutation operator | Multi Non uniformly distributed |
| Probability of mutation | 0.18% |

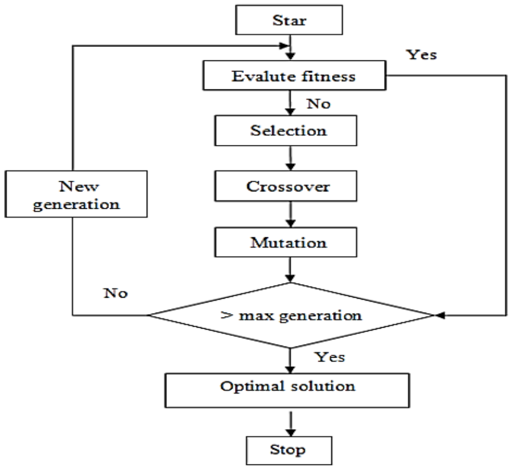



Fig.8. Flowchart of the GA optimization technique.

The GA parameters used in this work are listed in Table 2.

### Simulation results

The variable wind speed profile used in these simulations is shown in Fig. 9. It varies between a minimum value of 7m/s and a maximum value of 13 m/s.

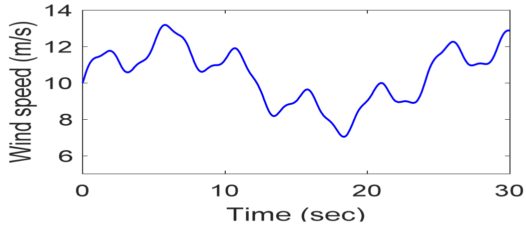
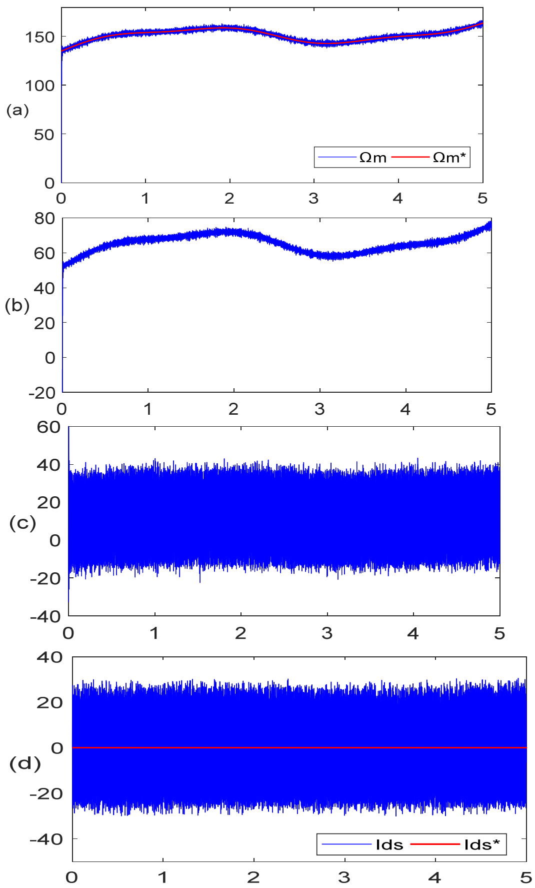



Fig.9. Wind speed profile.

The proposed system is simulated in MATLAB/Simulink environment using SimPowerSystem (SPS) blockset.



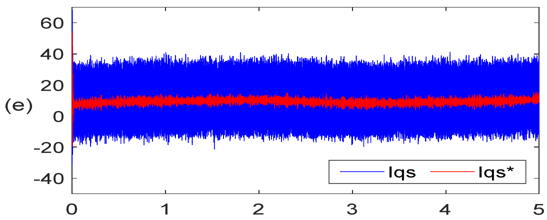



Fig. 10. System performance under random wind speed using an RST controller. (a) rotational speed (rad / s), (b) mechanical torque (Nm), (c) electromagnetic torque (N. m), (d)direct stator current (A), and (e) quadratic stator current (A).

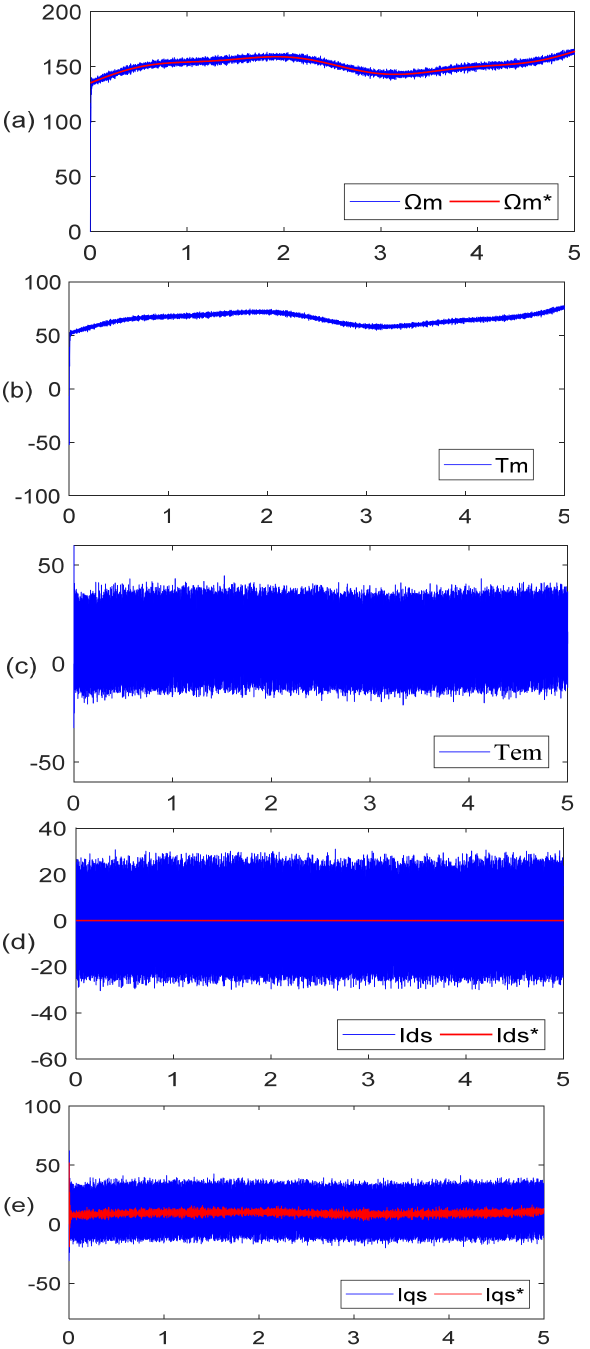



Fig.11. System performance under random wind speed using an genetic RSTcontroller. (a) rotational speed (rad / s),(b) mechanical torque (Nm), (c) electromagnetic torque (N. m), (d)direct stator current (A), and (e) quadratic stator current (A).

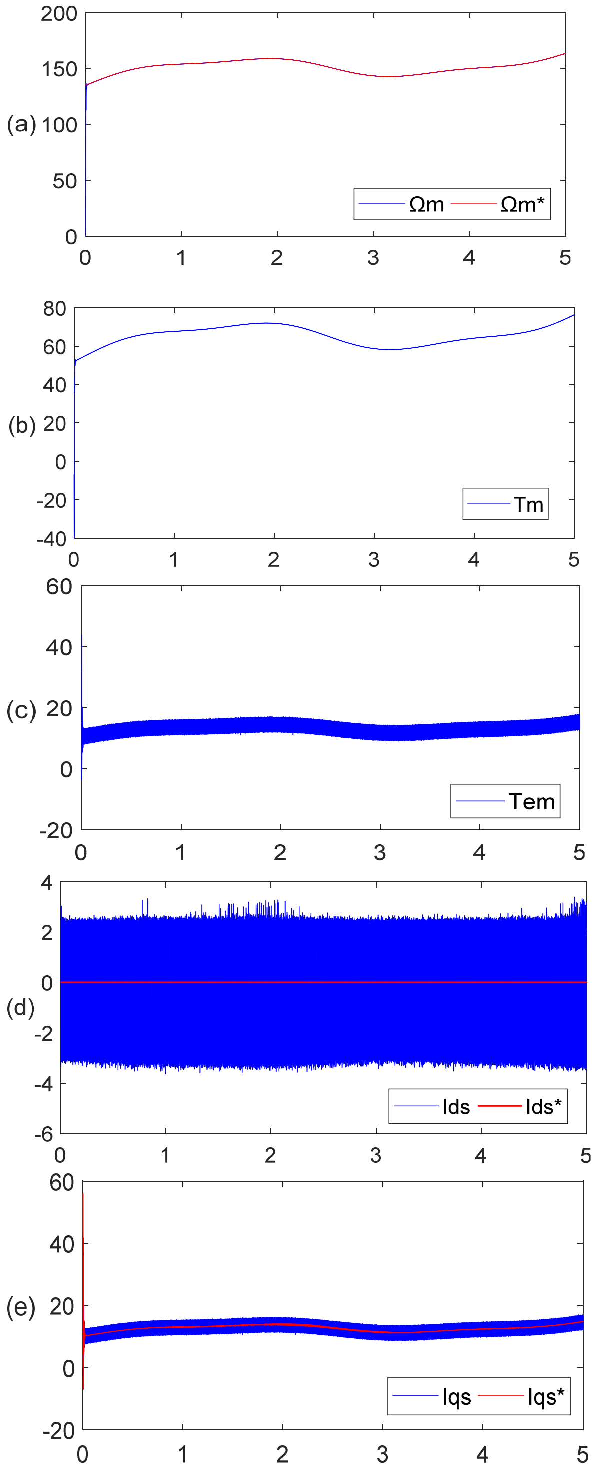
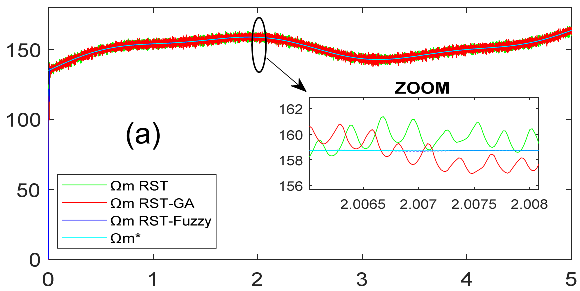



Fig. 12. System performance under random wind speed using a fuzzy RSTcontroller. (a) rotational speed (rad / s), (b) mechanical torque (Nm), (c) electromagnetic torque (N. m), (d)direct stator current (A), and (e) quadratic stator current (A).



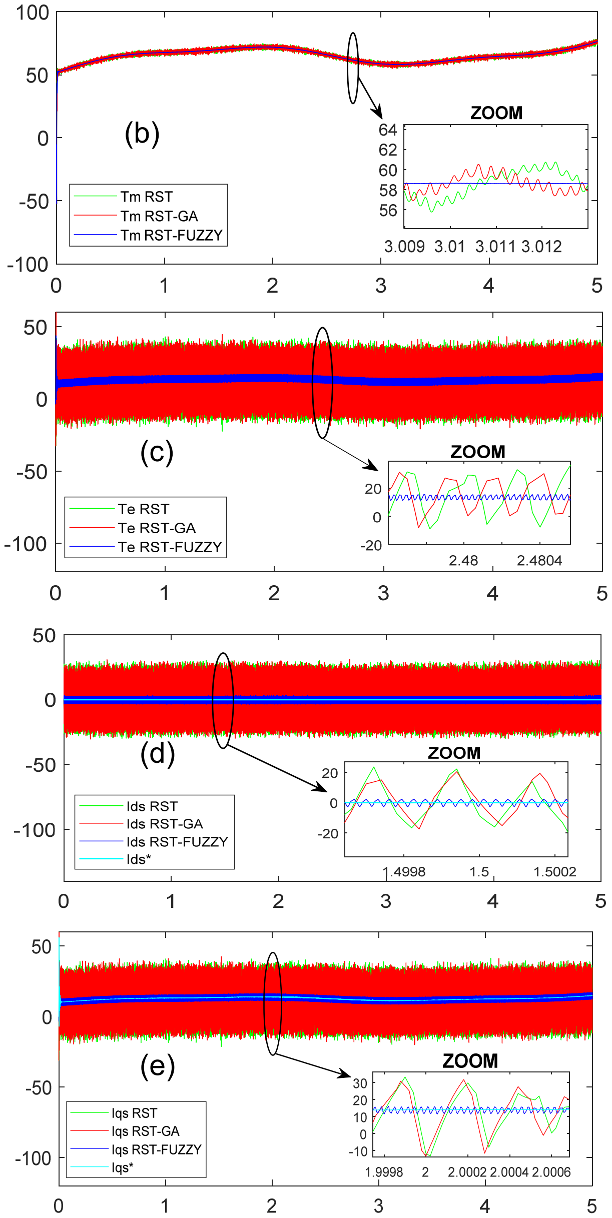



Fig. 13. System performance under random wind speed using a RST, RST-Genetics and RST-Fuzzy controllers (a) rotational speed (rad / s), (b) mechanical torque (Nm), (c) electromagnetic torque (N. m), (d)direct stator current (A), and (e) quadratic stator current (A).

The performance of the control strategies "RST" "RST-GENETIC" and "RST-FUZZY" has been investigated as illustrated in Fig. 13.

This figure comprise five sub figures for each controller as (a) rotationnal speed; (b) mecanical torque, (c) electromagnetic torque ; (d) direct stator current, and (e) stator current. As depicted from these figures, the proposed control strategy "RST-FUZZY" has a better and enhanced response. The oscillations in the system states have been considerably reduced for the proposed control strategy "RST-FUZZY" as compared to both the polynomial RST and the RST-GENETIC control strategies, respectively.

It is observed that the speed of rotation is totally confused with the optimal reference speed after a very short time for the three MPPT algorithm, the variations of the speed of the generator are adapted to the variation of the speed of the wind, thanks to the absence of winding (the inductance increases the time of response) at the rotor level, which makes it perform better compared to several types of generators.

Figures (13.d) and (13.e) show that the torque is the current image iq, tending that the current id carries the value almost Zero, thus the decoupling is assured and therefore a good operation of the vector control.

It can also be seen from these figures that the curves of the various quantities present oscillations for the RST and RST-GA algorithms. On the other hand the algorithm MPPT with the fuzzy logic presents good results and without oscillations

In addition to this, strategy "RST-FUZZY" proves to be most significant in tracking the system states, for both the lower and the higher wind speeds, subjected to the random variation of the wind speed.

## Conclusion

In this article. The aim of this work is to study and realize by the numerical simulation an adaptive RST-fuzzy and genetic algorithm for to the optimization of a wind pumping system. We used fuzzy logic and genetic algorithm for the design of the optimisation mechanism and the internal loop regulator.

The performance of the adaptive RST fuzzy logic and genetic algorithm RST optimization has been tested and compared with the conventional MPPT in order to show the limit of the latter with robustness tests.

The simulation model was developed in the Matlab / Simulink environment and the simulation results prove the controllers' effectiveness in terms of dynamic performance for different operating conditions, disturbance sensitivity, optimization and robustness.

***Authors***

***Benguergour Ibrahim,*** *Faculty of Science, He is Ph.D. in Renewable Energy. His research interests are renewable energy and applications of intelligence technique in power systems; he is a member in Research Unit Materials and Renewable Energy at University of Aboubekr Belkaid, Tlemcen, Algeria. Email: bguergour@yahoo.fr*

***Allaoui Tayeb,*** *Professor of Electrical Engineering, Electrical Engineering Department, He is a Director of Energetic Engineering and Computer Engineering Laboratory at the Ibn Khaldoun University of Tiaret, Algeria. Email: tb_allaoui@yahoo.fr*

***Kouadria Mohamed Abdeldjabbar,*** *is a PhD in the Department of Electrical Engineering, His research activities include the Renewable Energies and the Control of Electrical Systems. He is a member in Energetic Engineering and Computer Engineering Laboratory at the Ibn Khaldoun University of Tiaret, Algeria. Email: abdeldjabbar14@yahoo.fr*

***Denai Mouloud,*** *is a Senior Lecturer in Electric Power and Control. He graduated from the University of Science and Technology of Algiers and Ecole Nationale polythechnique of Algiers, Algeria in Electrical Engineering, and received his PhD in Control Engineering from the University of Sheffield, UK, He is currently with the School of Engineering & Technology, University of Hertfordshire, UK. Email: m.denai@herts.ac.uk*

REFERENCES

[1] S. Chekkal, N. A. Lahaçani, D. Aouzellag, K. Ghedamsi, Fuzzy logic control strategy of wind generator based on the dual-stator induction generator, *International Journal of Electrical Power & Energy Systems,* vol. 59:166-175, July. 2014.

[2] M. N. M. Nasira, M. Y. Ladaa, M. F. Baharoma, H. I. Jaafara, A. N. Ramania, M. F. Sulaimaa, Photovoltaic-Wind Hybrid System for Permanent Magnet DC Motor, *AIP Conf. Proc*, vol. 1660: 070045-1–070045-8, 28–30 May 2014.

[3] Baroudi JA, Dinavahi V, Knight AM. A review of power converter topologies for wind generators. *Renew Energy* 2007;32:2369–85

[4] Abdin ES, Xu W. Control design and dynamic performance analysis of a wind turbine-induction generator unit. *IEEE Trans Energy Convers* 2000;15(1):5–8

[5] J. Ivanqui, H. Voltolini, R. Carlson and E. H. Watanabe, “pq theory” control applied to wind turbine trapezoidal PMSG under symmetrical fault,*IEEE International Electric Machines & Drives Conference (IEMDC):*534-540, 2013.
[6] M. Singh, A. Chandra, Power maximization and voltage sag/swell ride-through capability of PMSG based variable speed wind energy conversion system, *Industrial Electronics, 34th Annual Conference of IEEE:*2206-2211, 2008.
[7] Poitiers F. Study and control of induction generators for wind energy conversion systems. *PhD thesis, University of Nantes;* 2003.
[8] B. K. Bose, expert system, fuzzy logic, and neural network applications in power electronics and motion control, *Proc IEEE,* vol. 82, Issue. 8:1303-1321, August 1994.
[9] Camblong H. Minimizing the impact of wind turbine disturbances in the electricity generation by wind turbines with variable speed. *PhD thesis, ENSAM, Bordeaux;* 2003.
[10] Refoufi L, Al Zahawi BAT, Jack AG. Analysis and modelling of the steady state behavior of the static Kramer induction generator. *IEEE Trans Energy Convers* 1999;14(3):333–9.
[11] A. A. Ghoneim, “Design optimization of photovoltaic powered water pumping systems,” *Energy Conversion and Management*, vol. 47, pp.1449–1463, 2006.
[12] M. Arrouf and S. Ghabrourb, “Modeling and simulation of a pumping system fed by photovoltaic generator in the Matlab/Simulink programming environment,” *Desalination*, vol. 209, pp. 23–30, 2007.
[13] M. Chebre, A. Meroufel and Y. Bendaha, “Speed controlof induction motor using genetic algorithm based PI controller indirect field oriented control of the IM [J]”, *Acta Polytechnica Hungarica*, vol. 8, pp. 141-153, 2011.
[14] L. Fan and E. MengJoo, ”Design for Auto-tuning PID Controller Based on Genetic Algorithms”, *4th IEEE Conference: Industrial Electronics and Applications*, 25-27 May 2009.
[15] D Seyoum, MF Rahman C Grantham. Terminal voltage control of a wind turbine driven isolated induction generator using stator oriented field control. *Proc. IEEE APEC’03, Miami Beach, FL, USA*. 2003; 2: 846–852
[16] Caron, J. P.; Hautier, J. P., Modélisation et commande de la machine asynchrone, *Ed Technip*, 1995, 279p.
[17] B. Hamane, M. L. Doumbia, M. Bouhamida, A. Draou, H. Chaoui and M.Benghanem, “ Comparative Study of PI, RST, Sliding Mode and Fuzzy Supervisory Controllers for DFIG based Wind Energy Conversion System ”, *International Journal of Renewable Energy Research*, Vol.5, No.4, pp. 1174-1185, 2015.
[18] F. Poitiers, T. Bouaouiche, M. Machmoum, “Advanced control of a doubly-fed induction generator for wind energy conversion”, *Electric Power Systems Research*, vol. 79, no. 7, pp. 1085-1096, 2009.
[19] Tahir Khalfallah, C. Belfedal, Allaoui Tayeb, Gerard Champenois, A new control strategy of WFSG-based wind turbine to enhance the LVRT capability, 2016, International Journal of Electrical Power & Energy Systems 79:pp 172-187.
[20] Lara DD, Merino GG, Pavez BJ, Tapia JA. Efficiency assessment of a wind pumping system. *Energy Convers Manag* 2011;52(2):795–803.