Said AZZOUZ[1,2], Sabir MESSALTI[1], Abdelghani HARRAG[3]

Electrical Engineering Department, Faculty of Technology, Msila University, Algeria (1), LGE Laboratory, Msila University, Algeria (2) , CCNS Laboratory, Electronics Department, Faculty of Technology, Ferhat Abbas University, 19000 Setif, Algeria (3)

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Innovative PID-GA MPPT Controller for Extraction of Maximum Power From Variable Wind Turbine

***Abstract**. Although the multitude benefit of wind power, the randomness of wind speed and the fluctuations of wind power are the most disadvantages of wind energy. So, for more efficiency and better performances, wind rotor must be driven at specific optimal rotational speed under each particular wind speed. Therefore, to extract the maximum power from wind turbine, a Maximum Power Point Tracking (MPPT) controller is required. In this paper, modeling of wind energy conversion system WECS using tip speed ratio (TSR) MPPT controller using PID controller tuned by genetic algorithm is investigated. The wind energy conversion is based on a doubly-fed induction generator (DFIG), which it is controlled by robust sliding mode control technique using a generator of 3.6 MW . The obtained results are presented and analyzed, where the performances of both proposed control strategies (MPPT based PID-GA, sliding mode control) have been shown*

Streszczenie.** W pracy przedstawiono system energii wiatrowej wykorzystujący sterownik śledzący szcztową prędkość . W sterowniku zastosowano regulator PID strojony z wykorzystaniem algorytmu generycznego. Jako generator wykorzystano układ DFIG sterowany za pośrednictwem sterownika ślizgowego. **Nowa koncepcja sterownika PID-GA MPPT do zapewnienia maksymalnej mocy farmy wiatrowej o zmiennej szybkości wiatru

Keywords: MPPT based PID-GA, genetic algorithm, DFIG, tip speed ratio (TSR) , active and reactive power control, sliding mode control.
Słowa kluczowe: MPPT – maksimum power tracking, farma wiatrowa, sterownik z algorytmem PID-GA, DFIG.

Introduction

The growing demand of energy and the successive oil shocks since the 70s have demonstrated the economic and geopolitical risks of energy production based on the exploitation of fossil fuels, whose reserves are unevenly distributed and exhaustible. Renewable energy is the energy comes from natural resources such solar energy, wind, rain, tides, geothermal heat and various forms of biomass .These resources are renewable and can be naturally replenished continuously [1-3]. Therefore, development of new forms of energy sources must take a huge consideration as solution in order to cover the future demands and the huge disturbances. Wind energy source is regarded as one of the most important renewable energy source; it can be used today in many applications [4]. Due to previous, many countries have made great progress in wind power technology such as Denmark which produces 40% of its electricity from wind, and at least 83 other countries around the world are using wind power to supply their electricity grids. The global wind power capacity expanded 16% to 369,553 MW. As shown in fig.1.Although several advantages of wind turbine, its random nature of wind and nonlinear characteristic (Power-speed) are the main drawbacks. Therefore, the wind turbine system must be designed to operate at their maximum power for different conditions. So over the last few decades, considerable progress has been made in the MPPT techniques and consequently many Maximum Power Point Tracking (MPPT) methods have been developed [6-10].

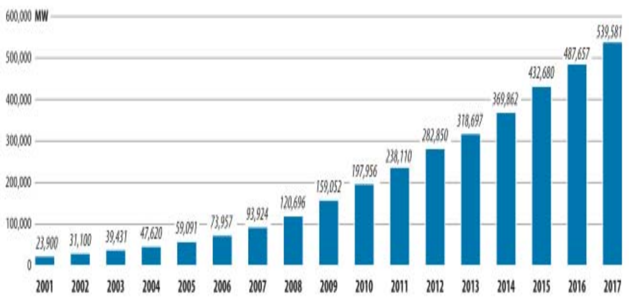


Fig.1. Global wind power cumulative capacity [5]

The doubly feed induction generator is widely used in variable speed wind turbine systems owing to their ability to maximize wind power extraction and to their capability to fulfill the basic technical requirements set by the system operators and contribute to power system security [11-12]. Usually, a DFIG wind turbine is shown in Figure 2.

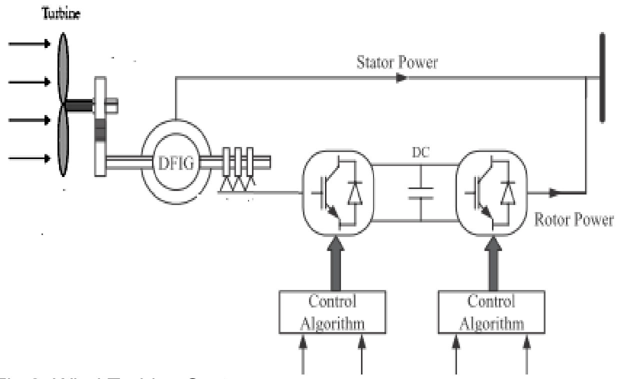


Fig.2. Wind Turbine System

A lot of works have been presented with diverse control diagrams of DFIG (Fig.2), these control diagrams are usually based on vector control (Field oriented control) [12]. Field oriented control using PI controllers makes the DFIG achieve good performance in the wind energy generation. In the vector control scheme, a complex voltage is synthesized from two quadrature components, one of which is responsible for the active power in the generator , and another which controls the reactive power production by the generator [11-15]. But, it may be difficult to adjust PI gains properly due to the nonlinearity and system complexity. In addition, the obtained performances using PI controller depends heavily on accurate of the machine parameters, for this reason many techniques have been developed nonlinear control laws with parameter identification and state estimation to replace PI type controllers [15,16], as artificial neural network control, fuzzy logic control, sliding mode control ...etc. Sliding mode control is one of the best techniques that can offer many advantages[12,16]. Moreover, recently a number of important applications of the theory in the field of power electronics, motion control, robotics, bioprocess, etc. Therefore, the use of the nonlinear sliding mode method provides very satisfactory performance for DFIG control, it is an universal approximators of nonlinear dynamic systems [19]. So the use of robust control methods like sliding mode control is necessary [11].

This paper presents modeling and simulation of wind energy conversion system (WECS), which it driven by tip speed ratio PID (TSR) MPPT controller based on genetic algorithm. This paper is organized in fourth parts: The first part shows modeling of wind turbine, the second part presents the tip speed ratio (TSR) MPPT controller. The third part shows the DFIG model and control based on sliding mode control strategy. The discussion and analysis are presented in the fourth part.

Modeling of Wind Turbine

The mechanical power extraction from the wind can be expressed as follows [11]:

(1) $$P_{aer} = \frac{1}{2} C_p(\lambda,\beta)\rho S v_{wind}^3$$

where: P_{aer} is the extracted power from the wind turbine; ρ : is the air density (Kg/m^3); S : is the turbine swept area (m^2); v_{wind} : is the wind speed (m/s); β : Blade pitch angle (deg); C_p: is the performance coefficient of the turbine, C_p is often given as a function of the tip speed ratio λ; λ : is the ratio of blade tip speed to wind speed defined by

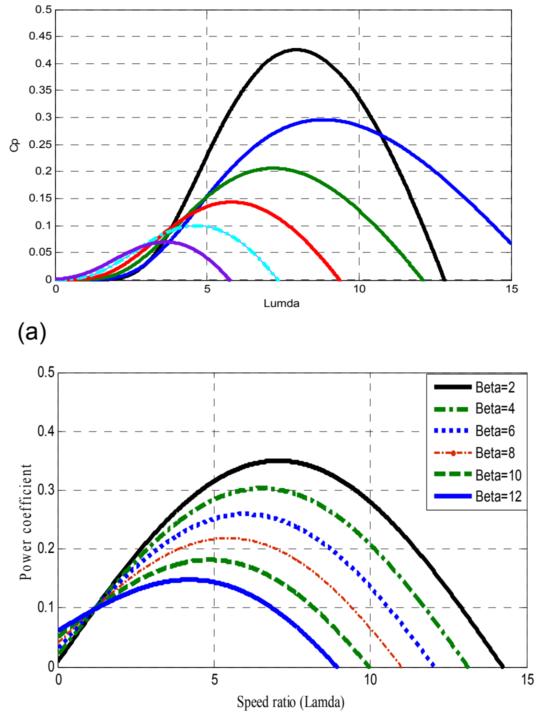
(2) $$\lambda = \frac{R\,\Omega_t}{V_{wind}}$$

where: Ω: the wind turbine rotational speed (rad /sec); R: the wind turbine radius.

The power coefficient C_p of turbine 3 MW is defined by [12] :

(3) $$C_p(\lambda,\beta) = (0.35-0.0167(\beta-2))*\sin\left(\frac{\pi(\lambda+0.1)}{14.34-0.3(\beta-2)}\right)-(0.00184(\lambda-3)(\beta-2))$$

The power coefficient of two wind turbine 1.5 MW and 3 MW for different pitch angles β is presented in Fig.3



(a)

(b)

Fig.3. Power coefficient based on the speed ratio for different pitch angles β (a)1.5MW wind turbine, (b) 3MW wind turbine

Modeling MPPT Controller Using PID Controller Tuned By Genetic Algorithm

The produced power from a given wind turbine depends mainly on wind speed, speed ratio. As these quantities vary with time, maximum power point tracking control algorithm is necessary to control and adjust continuously the rotor speed to the corresponding MPP value at any given time and under rapidly varying environmental conditions. From fig.3, there is a unique operating point called the maximum power point (MPP), where the power generation is maximum. The block diagram of speed ratio PID (TSR) MPPT controller using PID controller tuned by genetic algorithm is shown in Fig.4:

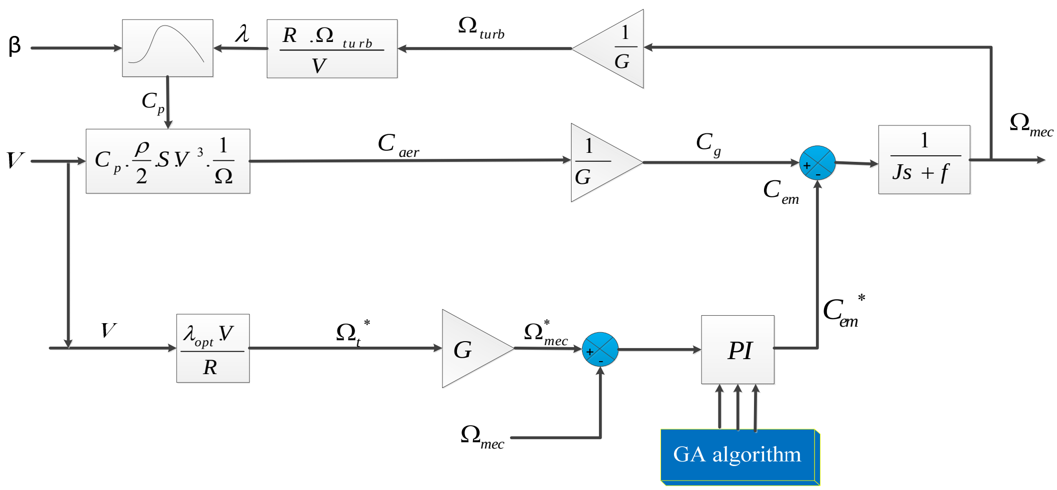


Fig.4. Proposed MPPT controller

The genetic algorithms are a family of computational models inspired by evolution and is a search heuristic that mimics the process of natural selection, which is routinely used to generate useful solutions to optimization and search problems. These algorithms encode a potential solution to a specific problem on a single chromosome and apply recombination operators to them so as to preserve critical information.

The PID controller genetic algorithm tuning procedure is designed, and then is embedded into wind energy conversion system, which the fitness of each chromosome is evaluated by converting its binary string into a real value which represents PID gains [20-22]. Each set of PID parameters is passed to PID controller in order to compute a complete response of the system as described in Fig. 5 .

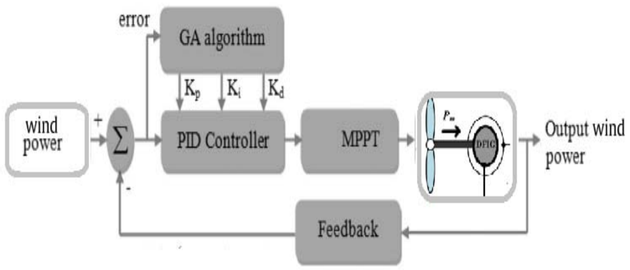


Fig.5. The block diagram of proposed Genetic speed ratio MPPT PID-GA controller

The simulated GA algorithm parameters used to initialize the GA algorithm parameters and generating an initial random population of individuals representing the PI gains (Kp and Ki) are defined in Table I.

Table 1. GA parameters.

Description	Parameters
Population size	20
Maximum iteration	50
Crossover probability	0.5
Mutation probability	0.01
Number of bits per chromosome	16

The PI controller genetic algorithm tuning procedure is evaluated by repeated simulations in an offline mode to find the optimal PI parameters. Once found, the optimal PI controller is used in the online mode to track the MPP point.

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Modeling of Wind Turbine Doubly Fed Induction Modeling

The general model of the DFIG obtained using Park transformation is given by the following equations [12-17].

(4)
$$\begin{cases} V_{sd} = -R_s . I_{sd} + \dfrac{d\,\phi_{sd}}{dt} - \omega_s \phi_{sq} \\ V_{sq} = -R_s . I_{sq} + \dfrac{d\,\phi_{sq}}{dt} + \omega_s \phi_{sd} \\ V_{rd} = R_r . I_{rd} + \dfrac{d\,\phi_{rd}}{dt} - \omega \phi_{rq} \\ V_{rq} = R_r . I_{rq} + \dfrac{d\,\phi_{rq}}{dt} + \omega \phi_{rd} \end{cases}$$

(5)
$$\begin{cases} \phi_{sd} = -L_s I_{sd} + M I_{rd} \\ \phi_{sq} = -L_s I_{sq} + M I_{rq} \\ \phi_{rd} = L_r I_{rd} - M I_{sd} \\ \phi_{rq} = L_r I_{rq} - M I_{sq} \end{cases}$$

The active and reactive stator powers for the DFIG are:

(6)
$$\begin{cases} P_s = -V_{sd} . I_{sd} - V_{sq} . I_{sq} \\ Q_s = -V_{sq} . I_{sd} + V_{sd} . I_{sq} \end{cases}$$

The system of equations can be written as:

(7)
$$\frac{dX}{dt} = \left[L\right]^{-1} . \left[Z\right] . X + \left[L\right]^{-1} . U$$

Where:

(8)
$$\begin{cases} [X] = \left[I_{sd}\ I_{sq}\ I_{rd}\ I_{rq}\right]' \\ [U] = \left[V_{sd}\ V_{sq}\ V_{rd}\ V_{rq}\right]' \end{cases}$$

(9)
$$[L] = \begin{bmatrix} -L_s & 0 & M & 0 \\ 0 & -L_s & 0 & M \\ -M & 0 & L_r & 0 \\ 0 & -M & 0 & L_r \end{bmatrix}$$

(10)
$$[Z] = \begin{bmatrix} R_s & -\omega_s L_s & 0 & \omega_s M \\ \omega_s L_s & R_s & -\omega_s M & 0 \\ 0 & -(\omega_s - \omega) M & -R_r & (\omega_s - \omega) L_r \\ (\omega_s - \omega) M & 0 & -(\omega_s - \omega) L_r & -R_r \end{bmatrix}$$

The DFIG is very common because they are inexpensive and robust and used for electrical energy production [12,15]. In order to easily control the production of electricity by the wind turbine, we will carry out an independent control of active and reactive powers by the technique called vector control.

Based on stator flux oriented, the following equations can be obtained

(11)
$$\phi_{ds} = \phi_s \quad and \quad \phi_{qs} = 0$$

Therefore, the stator active and reactive power, can be written as:

(12)
$$\begin{cases} P_s = -V_s \dfrac{M}{L_s} I_{rq} \\ \varphi_s = \dfrac{V_s^{\ 2}}{\omega_s L_s} - V_s \dfrac{M}{L_s} I_{rd} \end{cases}$$

Equations showing the relationship between the rotor currents and voltages are written as:

(13)
$$\begin{cases} V_{rd} = R_r I_{rd} + (L_r - \dfrac{M^2}{L_s}) \dfrac{dI_{rd}}{dt} - g\,\omega_s (L_r - \dfrac{M^2}{L_s}) I_{rq} \\ V_{rq} = R_r I_{rq} + (L_r - \dfrac{M^2}{L_s}) \dfrac{dI_{rq}}{dt} + g\,\omega_s (L_r - \dfrac{M^2}{L_s}) I_{rd} + g \dfrac{M V_s}{L_s} \end{cases}$$

The block diagram of the DFIG is illustrated in the Fig 6.

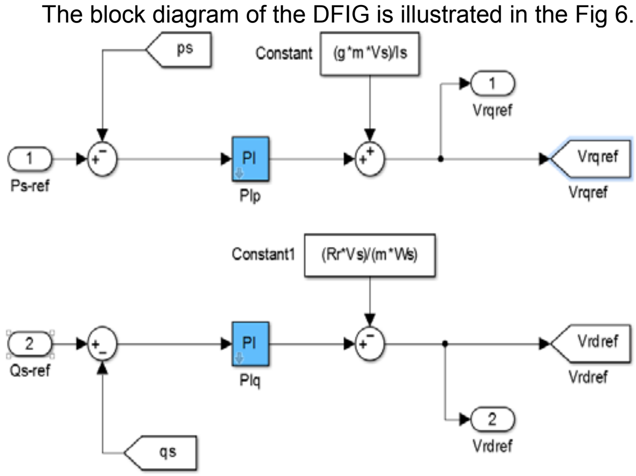

Fig.6. Block diagram of vector control for DFIG.

Sliding mode control of DFIG

Sliding mode control is one of the effective control methodologies for DFIG drive control among nonlinear control strategies, because of its disturbance rejection, strong robustness subject to system parameter variations and uncertainties and particularly its simplicity of practical implementation . SMC algorithm consists to calculate the equivalent and discontinuous components of control variable from an adequate surface of sliding mode chosen. In this case we chose the error as being the sliding surface.

The control algorithm is defined by the relation:

(14) $$u = u^{eq} + u^{n}$$

where: – u is the control vector, u^{eq} – is the equivalent control vector, u^{n} – the switching part of the control (the correction factor), u^{eq} can be obtained by considering the condition for the sliding regime, $s = 0$.

The control law is defined as follows:

(15) $$u^{n} = u^{\max} sat\left(s(X)/\theta\right),$$

(16)

$$sat\left(s(X)/\theta\right)\begin{cases} sign(s) & if \quad |s| > \theta \\ s/\theta & if \quad |s| < \theta \end{cases}$$

General equation given by J.J.Slotine to determine the sliding surface given by:

(17) $$s(X) = \left(\frac{d}{dt} + \lambda\right)^{n-1} e$$

The convergence condition is defined by the equation Lyapunov $s(x).\dot{s}(x) < 0$.

Active power control

For $n = 1$ the sliding surface representing the error between the measured and reference active power is given by this relation:

(18) $$s(P) = \left(P_{s-ref} - P_{s}\right)$$

The derivative of the surface is given by:

(19) $$\dot{s}(P) = \left(\dot{P}_{s-ref} - \dot{P}_{s}\right)$$

By replacing active power equation in the equation of the switching surface, the expression of the surface becomes:

(20) $$\dot{s}(P) = \left(\dot{P}_{s-ref} + \frac{V_s M}{L_s}\dot{I}_{rq}\right)$$

From the equation 12, during the sliding mode and in permanent regime we find:

(21) $$\dot{I}_{rq} = \frac{1}{L_r\sigma}.\left(V_{rq} - R_r I_{rq}\right)$$

We take:.

(22) $$V_{rq} = V_{rq-eq} + V_{rq-att}$$

We have:

(23) $$\dot{s}(P) = \left(\dot{P}_{s-ref} + \frac{V_s M}{L_s L_r \sigma}\left(\left(V_{rq}^{eq} + V_{rq}^{n}\right) - R_r I_{rq}\right)\right)$$

During the sliding mode and in permanent regime, we have:

(24) $$s(P) = 0, \quad \dot{s}(P) = 0, \quad V_{rq}^{n} = 0.$$

Where the equivalent control is:

(25) $$V_{rq}^{eq} = \dot{P}_{s-ref}\frac{L_s L_r \sigma}{V_s M} + R_r I_{rq}$$

Therefore, the correction factor is given by:

(26) $$V_{rq}^{n} = KV_{rq}\, sign\left(s(P)\right)$$

KV_{rq} positive constant.

Reactive power control

For $n = 1$,the sliding surface representing the error between the measured and reference reactive power is given by this relation:

(27) $$s(\varphi) = \left(\varphi_{s-ref} - \varphi_{s}\right)$$

The derivative of the surface is given by:

(28) $$\dot{s}(\varphi) = \left(\dot{\varphi}_{s-ref} - \dot{\varphi}_{s}\right)$$

By following the same steps and from the equation 12:

(29) $$\dot{I}_{rd} = \frac{1}{L_r\sigma}\left(V_{rd} - R_r I_{rd}\right)$$

We take :

(30) $$V_{rd} = V_{rd-eq} + V_{rd-att}$$

(31)

$$\dot{s}(\varphi) = \left(\dot{\varphi}_{s-ref} + \frac{V_s M}{L_s L_r \sigma}\left(\left(V_{rd}^{eq} + V_{rd}^{n}\right) - R_r I_{rd}\right)\right)$$

(32) $$V_{rd}^{eq} = -\dot{\varphi}_{s-ref}\frac{L_s L_r \sigma}{V_s M} + R_r I_{rd}$$

By the convergence condition defined by the equation Lyapunov $s(X)\dot{s}(X) < 0$.

(33) $$V_{rd}^{n} = KV_{rd}\, sign\left(s(\varphi)\right)$$

The Simulink model of DFIG sliding mode control is illustrated in Fig .7

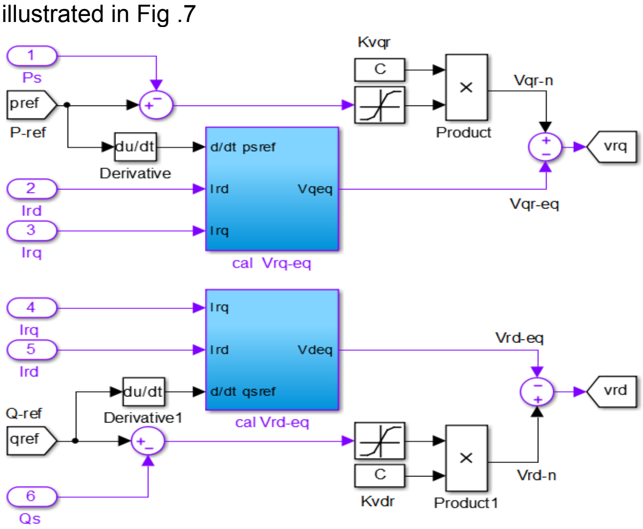

Fig.7. Model of the sliding mode control of DFIG

Simulation Results

To analyze the efficiency of both proposed controllers (sliding mode control for the generator and the proposed PID-GA MPPT for wind turbine system), a set of simulation tests have been performed. Simulations have been investigated with a 3.6 MW generator connected to a

690V/50Hz grid. The machine's parameters are given next in appendix I.

The simulation results active and reactive power control using sliding mode control is presented in the following figures, in which we can observe that both active and reactive power produced by DFIG track perfectly their reference.

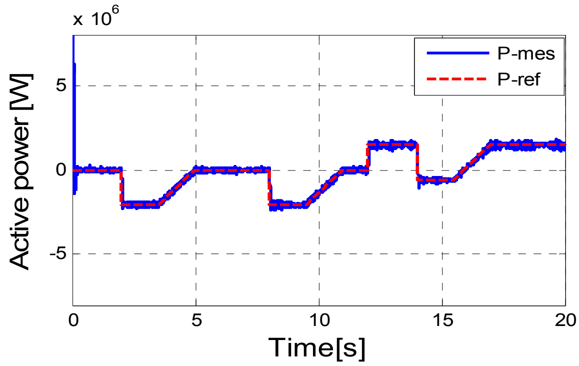

Fig.8. Active power of the DFIG using S.M.C.

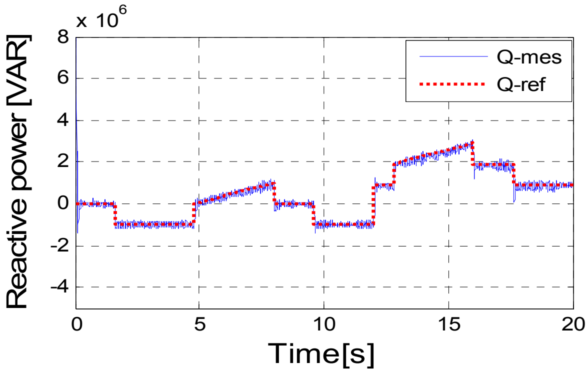

Fig.9. Reactive power of the DFIG using S.M.C.

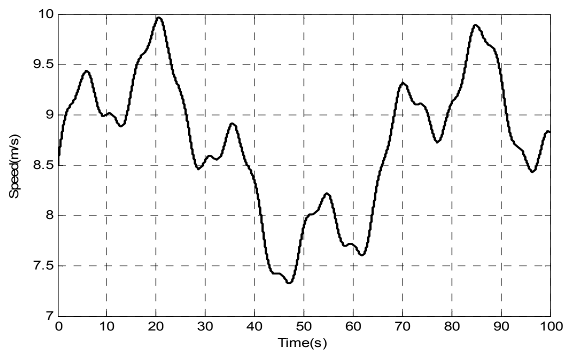

Fig.10. wind profile.

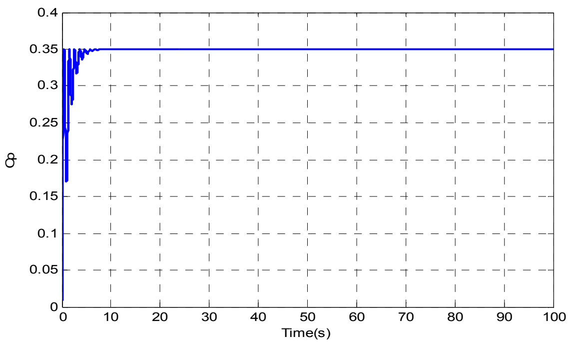

Fig.11. Power coefiicient using proposed GA-PID MPPT controller.

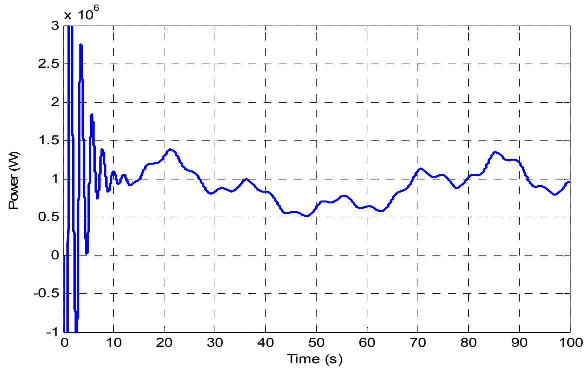

Fig.12. Produced wind turbine using proposed GA-PID MPPT controller.

The planned strategy PID-GA MPPT is tested under different wind conditions. The wind speed profile variation is presented in Fig.10. While both power coefiicient and produced wind turbine using proposed GA-PID MPPT controller are presented in Fig.11 and Fig.12 respectively.

From fig 11, it's clear that we have reached the maximum power coefficient 0.35 (confirmed from turbine DATA) very fast , consequently the wind turbine operates at its optimal power.

Conclusion

In this paper, new method for extraction of maximum power of wind energy conversion system WECS has been proposed and tested, which the new MPPT uses a PID controller tuned by genetic algorithm. The modeling of wind turbine and doubly-fed induction generator have been demonstrated. Simulation results has been carried out using Simulink/matlab , which perfect control of active and reactive power has been proved. In addition , the wind energy conversion system WECS has provided its maximum power and operates at optimal condition under variable wind speed since it driven by PID-GA MPPT controller. So, better operation of the available wind energy is achieved, particularly under variable wind speeds using the proposed PID-GA MPPT controller.

Appendix I.

Parameters	Rated values
Nominal power	3.6 MW
Stator voltage	4.16 kV
Stator frequency	60 Hz
Number of pairs poles	2
Stator resistance	0.0079 Ω
Rotor resistance	0.025 Ω
Stator inductance	0.07937 H
Rotor inductance	0.04 H
Mutual inductance	0.0045 H

Authors

Said Azzouz *was born in Bou Saâda, Algeria, in 1985. He received the Licence degree in Electrical Engineering from M'sila University, Algeria in 2012, his Master degree from M'sila University in 2014. He is currently working towards his PhD degree in Electrical Engineering from M'sila University, Algeria. His current research interest includes power electronics, Electrical Drives and Process Control, modelling and control of wind turbines, artificial intelligence and Renewable energies, control of electrical machines.(**said.azzouz@univ-msila.dz**)*

Sabir Messalti *was born in setif (Algeria), he obtained his Master and PhD in Electrical Engineerig from Setif University. He has worked as an engineer in power system department. Today he is full Professor of Power Systems at Electrical Engineering department of Msila University (Algeria). His research interests includes wind turbines, power systems planning, control of electrical machines, PV systems, FACTS, HVDC, control of voltage* *and frequency, etc. He is author of about 30 papers published on international journals or presented in various national and international conferences. (**sabir.messalti@univ-msila.dz**)*

***Abdelghani Harrag** was born in Setif, Algeria. He received BSc, Magister and PhD Degrees in Electronics from Ferhat Abbas University (UFAS), Setif, Algeria, in 1995, 1998 and 2011, respectively. In 1998, he was awarded the best Magister thesis prize in Electronics by UFAS. He worked as Project Manager during more than 10 years in France with French and American Societies. He is the creator of the standard Arabic langage on all mobile and intelligent systems sold by Alcatel Lucent all over the world including Arab countries from Atlantic ocean to Arabic gulf. He taught at University Pierre Mendes France and Joseph Fourier 1999–2000, Grenoble, France, at Ferhat Abbas University 1996–1999, Setif, Algeria. In 2009, he joined Mohamed Boudiaf University, Msila, Algeria, where he works currently as Associate Professor. He supervised many BSc, Master and PhD students. His research interests mainly concerned intelligent control, renewable energy, heuristic and evolutionary optimization, embedded systems and signal processing. He is currently interested in bioinformatics and control applied to renewable energy systems. He is member of several research projects at University of Msila and CCNS Laboratory at UFAS University.(**abdelghani.harrag@gmail.com**)*

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