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Modeling and control energy management of an hybrid system associated a continuous load and coupled with the electrical network

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Abstract: This paper presents the modeling and control of a multi-sources hybrid system using the renewable energy combining wind and photovoltaic electric energy production. The considered wind system is constituted of a multipolar permanent magnetic synchronous generator (MPMSG). The wind turbine works at variable-speed is piloted according to the wind speed. The stator of the generator is connected directly to a control rectifier system wich his command is based on pulse width modulation (PWM) concept, and the field oriented control method (FOC). To guarantee a maximum power point tracking regime (MPPT) for different insulations, the photovoltaic system is connected to the continuous bus through a boost DC/DC converter. *The two considered sources have non-linear electric characteristics. The hybrid system is integrated via static converters to the continuous bus voltage. Two interesting control structures are developed: the first deals with the continuous bus coupled to a DC load and the second concerns the interconnection of the hybrid system to the network. The used control strategy is to control the voltage of the continuous bus and the management of active and reactive powers using proportional integral regulators (PI). The simulation results show the control performances of the hybrid system in terms of a good regulation of the continuous bus voltage and an efficient management of the produced electric energy.*

Keywords: *Wind turbine, Generator photovoltaic, Network, Hybrid System, Modeling, Control, MPPT.*

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1. Introduction

The global warming leads to limit the emission of gas to greenhouse effect coming largely from the fossil-base electric energy production. In this setting, the new world energizing conjuncture imposes the use of renewable energies. These energies are undoubtably of big interest in terms of environnemental value. However, the production of the photovoltaic or wind energy is too expensive for medium and strong powers compared to the other sources of energies. So, specialists have been brought to combine several energizing systems (wind, solar…), in order to make less uncertain the variables of inputs and possibly optimize the system of storage if available [1].

As these production systems are of a weak energizing capacity, and considering their decentralization, it is interesting to worry their availability, conditioning, safety of working and mode of management in order to optimize their working. These production systems require units of conditioning, control and management. In this setting, the renewable energies are some potential candidates for the massive production of electric energy. Certainly, the future one can see the development of intensive programs on the decentralized production based on renewable sources [2].

In order to decrease the portion of traditional energy used in global consumption, we should overcome some problems in the use of the renewable energies. One of these difficulties is the optimization strategy in combining several different nature energy sources [3]. Certainly, it is necessary to take into account the climatic conditions. Furthermore, it's important to note here that the integration of an hybrid system to the network implies some specific difficulties Such as disturbance on current and voltage. So, the stability of the power injected to the network will be affected. To guarantee the decoupling between the electric variable frequency injected to the network and the climatic conditions, the strategy currently used in the literature uses a conversion system of the renewable energy via a continuous bus [4]. So, to maintain the continuous bus voltage to a constant reference value permits to ensure the management of the energy transferred toward the network correctly. One aims is to optimize the exploitation of the hybrid system according to the availability of energy sources as well as the consummated energy.

This paper is organized in seven sections. Section two gives the structure of the hybrid system. In the section three, one presents the model and control principle of the wind system. Section four deals with the model and control of the photovoltaic system. The principle and control lows of management energy transferred in the network are developed in section five. Analysis of simulation results is presented in section six.

2. Structure of the studied hybrid system

The configuration of the studied hybrid system is represented by the figure 1. The wind system is constituted of a wind turbine coupled to a multipolar MPMSG and of a controlled converter AC/DC. The control of the converter permits to control the voltage of the MPMSG and indirectly the of power working point of the wind turbine. The photovoltaic system constituted of several panels is connected to the continuous bus via a DC/DC converter. This converter controls the panel working and thereafter the generated power [5]. The current produced by the wind conversion system (I_w) are injected in the continuous bus. A voltage V_{dc} to the interconnection point of the two conversion system is applied simultaneously to a continuous load and to the input of a PWM inverter connected to the network. An electronic system assuring the swithing of the energy toward the DC load or toward the network.

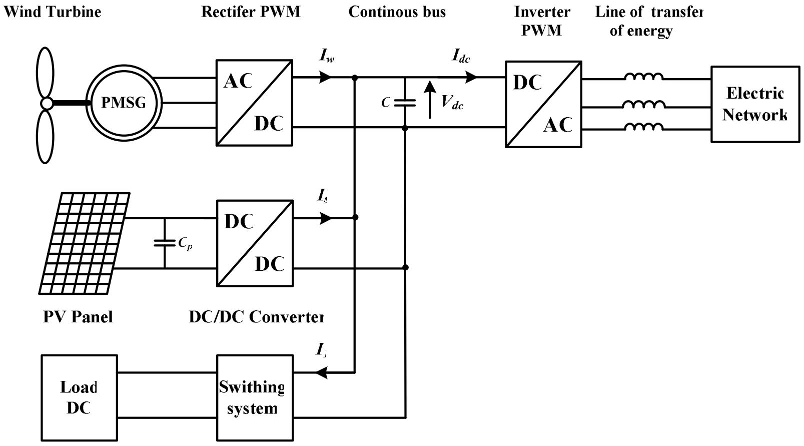


Fig.1. Configuration of the hybrid generation system

3. Modeling and control of the wind system

3.1. Modeling of the wind system

The available aerodynamic power on the turbine rotor is given by the following expression:

$$P_e = \frac{1}{2} \rho \, \pi \, R_e^{\,2} \, v^{3} \, c_p \qquad (1)$$

With ρ is an air volumic mass, v is the wind speed, c_p is the power coefficient that presents the aerodynamic output of the wind turbine witch depends on the specific speed λ.

The evolution of the mechanical speed of the synchronous generator can be easily determined using the dynamic equation. The simplified model of this equation is given by:

$$J\frac{d\Omega}{dt} = C_m - C_{em} - f\Omega \qquad \textbf{(2)}$$

With j is the total inertia that appears on the rotor of the wind turbine, C_m is the mechanical torque, C_{em} is the electromagnetic torque, Ω is the mechanical speed of the rotor and f is a viscous friction coefficient.

With regard to the MPMSG modeling, the used model is based on the Park transformation [6]. While considering the first fundamental harmonic of the distribution of the flux in the air-gap of the machine, equations of the voltages stator dynamics are given by:

$$\begin{cases} V_{sd} = R_s I_{sd} + L_d \dfrac{dI_{sd}}{dt} - \omega_e L_q I_{sq} \\ V_{sq} = R_s I_{sq} + L_q \dfrac{dI_{sq}}{dt} + \omega_e L_d I_{sd} + \omega_e \phi_a \end{cases} \qquad (3)$$

With R_s is the resistance of a stator phase, L_d and L_q are respectively the cyclic inductances of the direct axis d and quadratique axis q, ϕa is the rotor flux created by the permanent magnets circuit V_{sd} and V_{sq} are respectively the components d and q of stator voltage vector I_{sd} and I_{sq} are respectively the components d and q of stator current vector and ω_e is the rotor electric speed. The electromagnetic torque produced by the MPMSG is expressed by:

$$C_{em} = \frac{3}{2} p\left(\varphi_{sd} I_{sq} - \varphi_{sq} I_{sd}\right) \qquad \textbf{(4)}$$

With p is the number of poles pairs.

3.2. Control of the wind production system

The control structure of the wind conversion system is given in figure2. This system includes the wind turbine, the MPMSG and the control PWM rectifier. These latter permits to control the voltage of the continuous bus and therefore the speed of the generator. The regulation block of the continuous bus voltage provides the value $I_{sq\text{-}ref}$ corresponding to the value $C_{em\text{-}ref}$ of the electromagnetic torque. In this survey, one chose among strategies of vectorial control applied to a synchronous machine, the one that consists in imposing a reference of the direct current reference to zero $I_{sd\text{-}ref}$ [7]. The control rectifier voltage is assured by the vectorial PMW strategy mostly adopted in real time implementation [8].

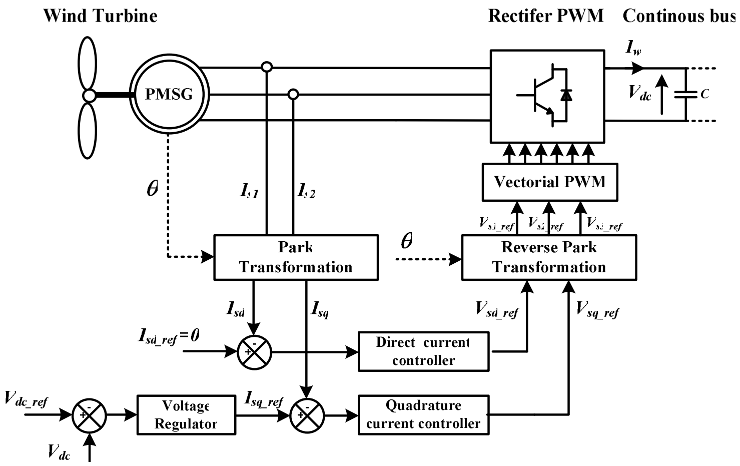


Fig.2. Structure of control of the wind conversion system

4. Modelling and control of the photovoltaic production system

4.1 Modelling of the photovoltaic production system

The eclectic power generated by a photovoltaic panel is fluctuating according to the insulation and the temperature. The characteristic of the photovoltaic generator describing the relation between the current I_p and voltage V_p is relative to a mixed grouping formed in series by the stake of modules N_{ms} and N_p branches in parallel and that is based on the carelessness of the resistances set and shunt, is given by the relation (5).

$$I_p = N_p \left[I_{ph} - I_0 \left(\exp\left(\frac{V_p}{N_{ms} \cdot V_T} \right) - 1 \right) \right] \qquad \textbf{(5)}$$

With I_{ph} is phto-current, of proportional cell to the insulation, I_0 is the current of inverse saturation of the bridge and V_T is the potential thermodynamic.

4.2. Control the photovoltaic production system

The control structure of the photovoltaic system is given by the figure 3. The photovoltaic system contains besides the generating PV, a L_pC_p filter and a DC/DC converter. The boost converter, of which the value of reference V_{p_ref} is calculated by the

MPPT block, permits to adapt the voltage of the photovoltaic generator to the one of the continuous bus.

As regards to control, this structure of conversion possesses a double requirement that consists in controlling the current in the inductance and to ensure the voltage of input V_p so that it corresponds to reference. We opted for a cascade regulation (current / voltage), one will define a fast mode relative to the inductance current and a slow mode corresponding to capacitor voltage.

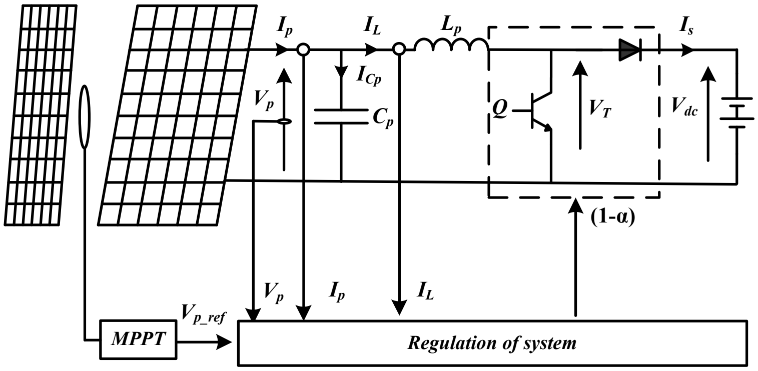


Fig.3. Control structure of the photovoltaic system

4.3. Modelling of the continuous bus

The continuous bus voltage is given by [9]:

$$\frac{dV_{dc}}{dt} = \frac{1}{C}(I_w + I_s - I_{dc}) \tag{6}$$

With I_{dc} , the continuous current provided to the DC load or injected to the input of the voltage inverter interconnected to the network.

The choice of the continuous bus voltage is largely imposed by wind system. The photovoltaic system doesn't take place in the choice of this voltage because the photovoltaic module system permits a set–parallel association implying an increase of the available system in exit of the module association.

The regulation of the continuous voltage bus is mainly achieved by the wind system. The output of the photovoltaic system inverter assures a constant voltage for this continuous bus.

5. Control of the energy movement injected to the network

The energy provided by the renewable energy sources is transmitted according to the continuous mode, and applied to an inverter. The role of this inverter is to ensure the control of the active and reactive power level injected to the network which is characterized by a constant voltage V_R =*cte* and frequency 50 Hz (ω_R = *cte*). Figure 4 shows the control strategy adopted in this work.

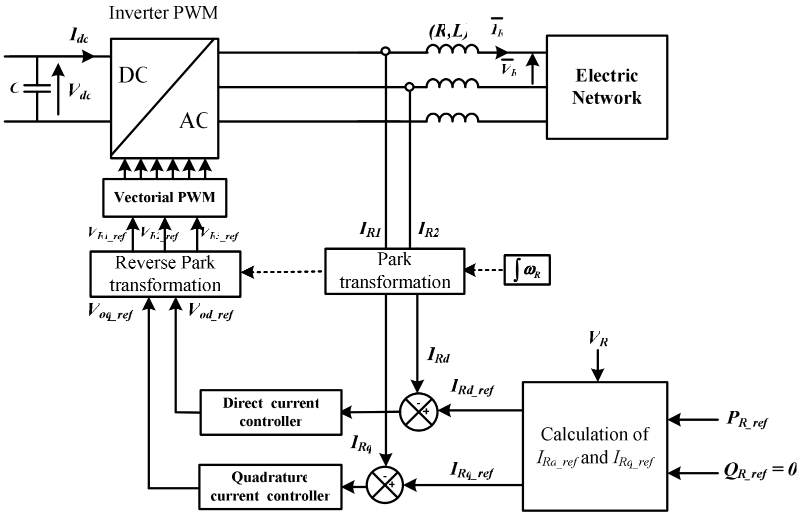


Fig.4. Bloc diagram of control of the inverter interconnected to the network

5.1. Principle of the inverter control

The control of the voltage inverter is determined from the model established in a referential frame rotating to the constant speed of the network vector voltage.

$$\overline{V}_s = R_R \bar{i}_R + jL\omega_R \bar{i}_R + \overline{V}_R \tag{7}$$

The decomposition of the relation (7) in real and imaginary parts gives:

$$\begin{cases} V_{od} = RI_{Rd} + L\dfrac{dI_{Rd}}{dt} - L\omega_R I_{Rq} + V_{Rd} \\ V_{oq} = RI_{Rq} + L\dfrac{dI_{Rq}}{dt} + L\omega_R I_{Rd} + V_{Rq} \end{cases} \tag{8}$$

The active and reactive powers exchanged with the network are expressed according to component direct I_{Rd} and the quadrature I_{Rq} of the vector current network $\overline{i_R}$ and the vector voltage $\overline{V}_R$ network as follows:

$$\begin{cases} P_R = \frac{3}{2}(V_{Rd}I_{Rd} + V_{Rq}I_{Rq}) \\ Q_R = \frac{3}{2}(V_{Rq}I_{Rd} - V_{Rd}I_{Rq}) \end{cases} \tag{9}$$

The considered problem is to be able to control the active and the reactive power independently. For that we should orient the reference frame *(d,q)* in order to set to zero the quadrature voltage component.

$$\begin{cases} \overline{V_R} = V_{Rd} \\ \overline{V}_{Rq} = 0 \end{cases} \tag{10}$$

While taking into account the condition of the network vector voltage orientation to, the relation (8) becomes:

$$\begin{cases} V_{od} = RI_{Rd} + L\frac{dI_{Rd}}{dt} - L\omega_R I_{Rq} + V_R \\ V_{oq} = RI_{Rq} + L\frac{dI_{Rq}}{dt} + L\omega_R I_{Rd} \end{cases} \tag{11}$$

According to the direct link between the control voltages (V_{od}, V_{oq}) and output currents inverter (I_{Rd}, I_{Rq}), it is essential to achieve a decoupling by compensation of coupling terms while considering them as perturbation.
Each component of the control voltages (V_{oq}, V_{od}) can be decomposed as follows:

$$\begin{cases} V_{od} = V_{od1} + V_{od2} \\ V_{oq} = V_{oq1} + V_{oq2} \end{cases} \tag{12}$$

The voltages V_{od1} and V_{oq1} given by the equation (13) constitute the new variables of control:

$$\begin{cases} V_{od1} = RI_{Rd} + L\frac{dI_{Rd}}{dt} \\ V_{oq1} = RI_{Rq} + L\frac{dI_{Rq}}{dt} \end{cases} \tag{13}$$

However, the voltages V_{od2} and V_{oq2} given by the equation (14) constitute those of compensation, as shown in figure 5:

$$\begin{cases} V_{od2} = V_R - L\omega_R I_{Rq} \\ V_{oq2} = L\omega_R I_{Rd} \end{cases} \tag{14}$$

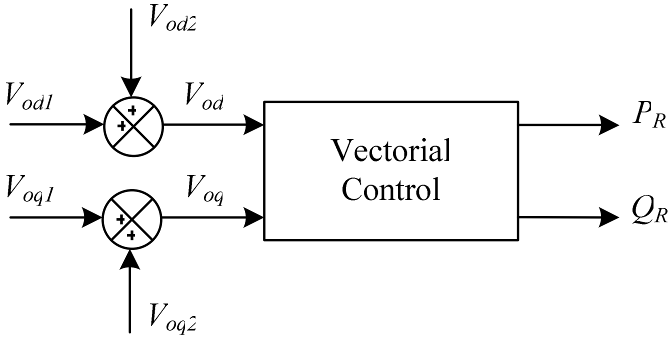


Fig.5. Reconstitution of the control voltage V_{od} and V_{oq}

The orientation condition of the vector voltages network permits to express the active power and the reactive power as follows:

$$\begin{cases} P_R = \dfrac{3}{2} V_R I_{Rd} \\ Q_R = -\dfrac{3}{2} V_R I_{Rq} \end{cases} \tag{15}$$

The level of the active power depends only on the direct component of the current network, also, the level of the reactive power depends only on the quadrature component. On records a natural decoupling between the control of active power and that of the reactive power.

5.2. Study of the regulation loop

For a network characterized by a constants voltage and frequency, the control system acts on the amplitude and the phase of the current in exit of the inverter to the network. The control of the system is made via first order PI controllers.

In order to have the maximum of active power given toward the network, one will suppose that the reference reactive power is set to zero *(Q_{R}_ref)* [10]. So, one will determine, in the reference frame of Park, the reference currents of the network from equation (16):

$$\begin{cases} I_{Rd\_ref} = \dfrac{P_{R\_ref}V_{Rd} + Q_{R\_ref}V_{Rq}}{(3/2)(V_{Rd}^{2} + V_{Rq}^{2})} = \dfrac{P_{R\_ref}}{(3/2)V_{Rd}} \\ I_{Rq\_ref} = \dfrac{P_{R\_ref}V_{Rq} - Q_{R\_ref}V_{Rd}}{(3/2)(V_{Rd}^{2} + V_{Rq}^{2})} = 0 \end{cases} \tag{16}$$

The structure of control of the active and reactive power is illustrated by the figure 6.

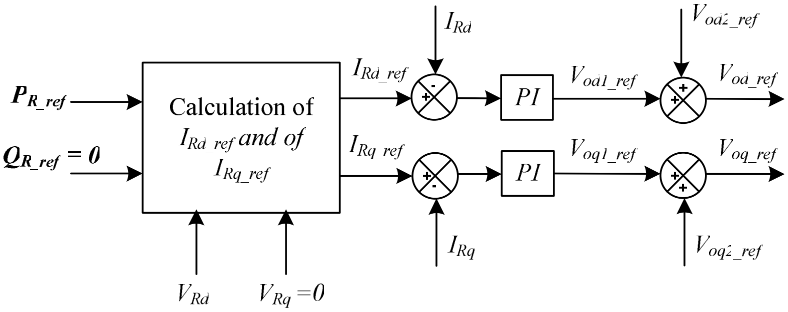


Fig.6. The block diagram of the network current regulation

5.2.1. Regulation of the direct component of the current network

From (8), the direct output voltage of the inverter is written as :

$$V_{od} = V_{od1} + V_{od2} \tag{17}$$

with:

$$\begin{cases} V_{od1} = RI_{Rd} + L\dfrac{dI_{Rd}}{dt} \\ V_{od2} = V_R - L\omega_R I_{Rq} \end{cases} \tag{18}$$

The block diagram of the current I_{Rd} loop of control is given by figure 7.

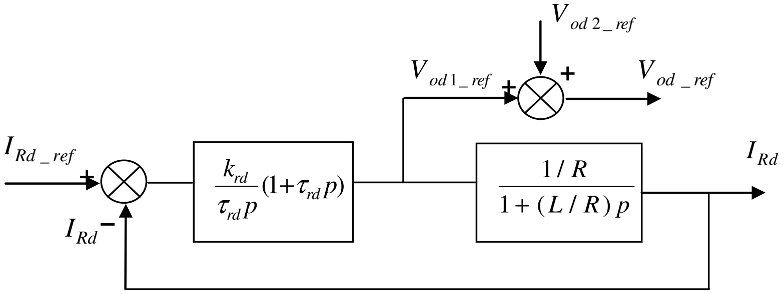


Fig.7. Bloc diagram of the loop control for the component I_{Rd}

The parameters k_{rd} and τ_{rd} are determined using the pole compensation method by the zero. By applying this technique, the parameters τ_{rd} and k_{rd} are expressed in terms of parameters of energy transfer lines by :

$$\tau_{rd} = \frac{L}{\mathrm{R}} \quad \text{and} \quad k_{rd} = \frac{R\tau_{rd}}{T_{BF}} \tag{19}$$

5.2.2. Regulation of the quadrature component of the current network

From (8), the quadrature output voltage of the inverter is written as :

$$V_{oq} = V_{oq1} + V_{oq2} \tag{20}$$

with.

$$\begin{cases} V_{oq1} = RI_{Rq} + L\dfrac{dI_{Rq}}{dt} \\ V_{oq2} = L\omega_R I_{Rd} \end{cases} \tag{21}$$

The block diagram of the current I_{Rq} loop of control is given by figure 8.

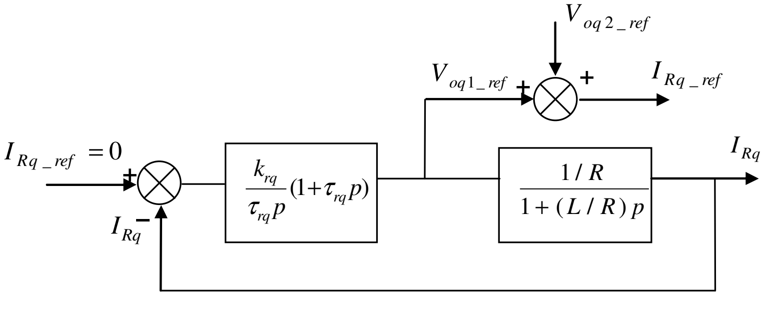


Fig.8: Bloc diagram of the loop control for the component I_{Rq}

The values adopted for parameters k_{rq} , τ_{rq} of the current regular are the following:

$$\tau_{rq} = \frac{L}{\mathrm{R}} \qquad \text{et} \qquad k_{rq} = \frac{R\tau_{rq}}{T_{BF}} \tag{22}$$

6. Structure of global control of the hybrid system interconnected to the network

Starting from structures of control of the wind system and the photovoltaic system developed in the previous parts, while taking account of the inverter connected to the network, a diagram of implementation of the control of the wind system-photovoltaic interconnected to the network has been elaborated. This structure is given by the figure 9. The technique of the Vectorial PWM permits to generate the six command voltages of the six switch power converter.

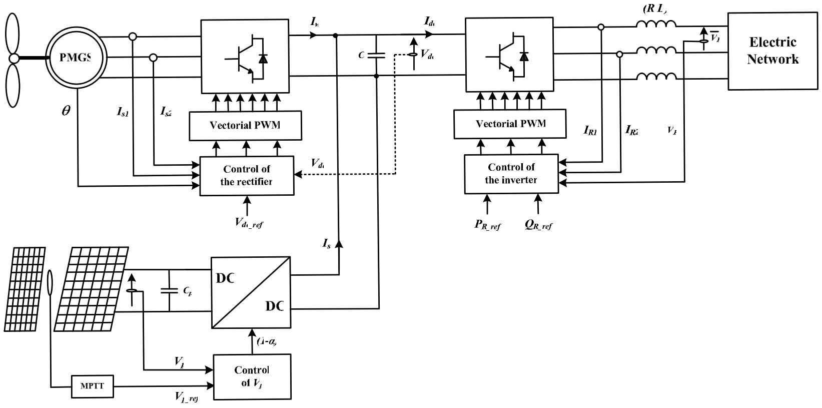


Fig.9. Global structure of the hybrid system interconnected to the network

7. Simulation results

The simulations covered two scenarios of regimes, one is dedicated for the analysis of performances in stand alone site and the other is reserved for the management and the control of the renewable energy sources interconnected to the network of infinite power.

7.1. Case of stand alone regime

In this case, the simulation has been achieved in the climatic conditions of a wind speed represented on the figure 10 and 1000 W/m2 constant insulation. The hybrid system produces on an isolated load Rc=50Ω. Figure 11 to 14 show, respectively, the rotation speed of the MPMSG, the electromagnetic torque, the voltage of the continuous bus, the wind power (Pw), the photovoltaic power (Ps) and the power injected to the DC load (Pdc). From figure 11, we can conclude that the speed of the MPMSG is greatly concluded with the wind speed. It is clear from figure.12 that the electromagnetic torque shows a good correspondence to the reference. According to the figure 13, one notes that the voltage of the continuous bus appears appropriately regulated to 600V and proves the efficiency of the implemented regulators. The figure 14 shows very clear the energizing balance of the DC load: one finds that the power produced by the photovoltaic system with the standard solar (E=1000W/m^2 and T=25◦C) is constant. The wind system generates a variable power under a variable wind. The total power received by the continuous bus and transmitted toward the DC load, receives nearly all variation of the wind power and it is equal to the sum of the two powers wind and the photovoltaic powers.

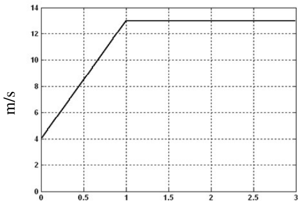
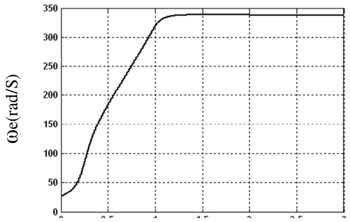
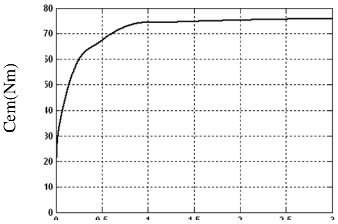
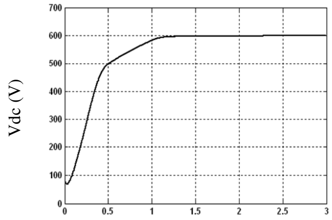


Fig.10. Profile wind speed







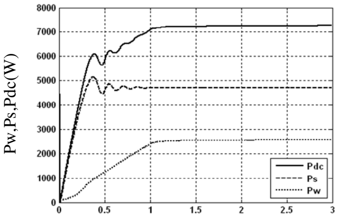


Fig.13. Voltage of the continuous bus

Fig.14. Wind power (Pw), photovoltaïc power (Ps) and the injected power to the DC load(Pdc)

7.2. Case of the interconnection to the network

To achieve the connection of the hybrid system to the network, one replaces the load R_C by a voltage inverter placed in series with a line impedance *(R,L)* representing to the losses of the transportation lines average voltage. In this case, the simulation has been achieved in the climatic conditions of a wind speed represented on the figure 10 and a constant insulation equal to 1000W/m^2. We recorded the temporal evolution of the electromagnetic torque, the speed of the MPMGS, the voltage of the continuous bus, the currents network, active powers (P_R) and reactive powers (Q_R) transferred to ward the network. Figures 16 and 17 represent respectively the electromagnetic torque and the speed of the MPMGS. The figure 18 shows that the voltages of the continuous bus is perfectly constant and converge to its reference value. The currents injected to the network and are given on figures 19 and 20. From this figure, we can conclude that the current become start after a short dynamic regime. Figures 21 and 22 show that the loop of regulation of the active and reactive power provided to the network permitted to maintain them to their reference values. The reference active power represents the sum of the maximal wind power plus the photovoltaic power minus the stator losses and the transfer line losses respectively. Note that, the reactive power is regulated to a zero average.

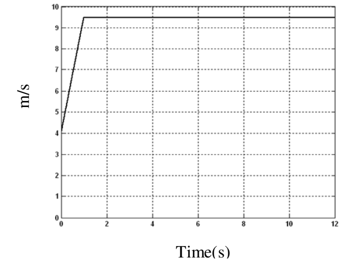


Fig.**15**.profile wind speed

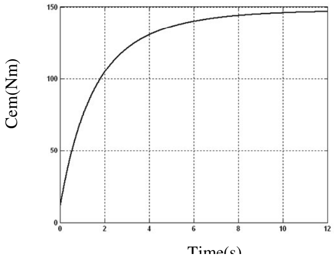


Fig.16. Electromagnetic torque C_{em}

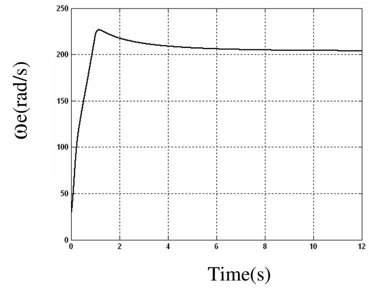


Fig.17. Speed of the MPMGS

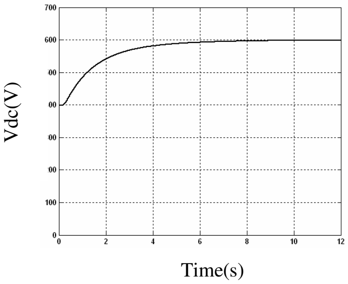


Fig.18. Continuous bus voltage

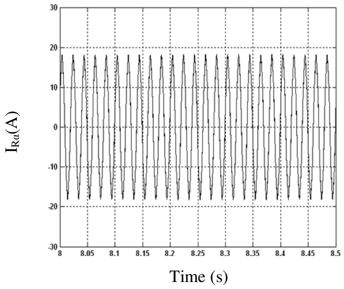


Fig.19. Network current $I_{R\alpha}$

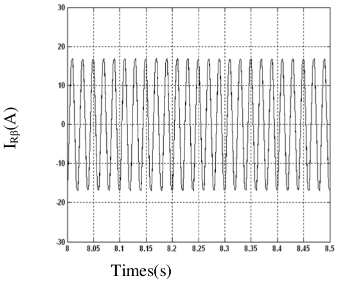


Fig.20. Network current $I_{R\beta}$

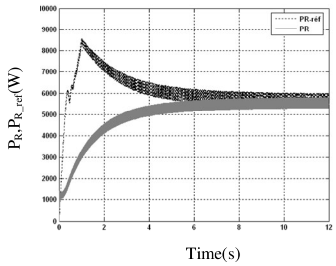


Fig.21. Active power injected to the network

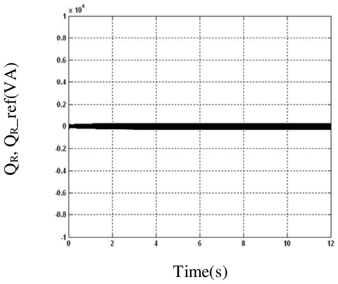


Fig.22. Reactive power injected to the network

Conclusion

In this paper, the modelling and the control of an hybrid production system has been carried out. At first, we have developed the mathematical model of the system of wind energy generation, based on MPMGS associated to a controlled rectifier and the model of the photovoltaic system to a DC/DC converter. After that, we have developed the model of the continuous bus. In a second stage, we have elaborated an algorithm of control permitting to ensure a constant voltage of the continuous bus for the hybrid system, the working in MPPT regime for the photovoltaic system and the decoupling between the control of active and reactive power for the electric network. For that, a control strategy based on conventional PI regulators shows good performances of the hybrid system has been adopted.

Simulation results presented demonstrated good performances of the developed control strategy in terms of a good tracking performances illustrated in the control of the continuous bus voltage and a correctly management of electric power to the grid. Moreover these simulations show the efficiency and the flexibility of the developed methodology to control an hybrid system.

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