DESIGN OF A ROBUST CONTROLLERS FOR POWER ELECTRONICS CONVERTERS POWERED BY A HYBRID (PVG)/(WTG) POWER SYSTEM

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Abstract: *Wind and photovoltaic are the most major type of energy used to create hybrid power energy source. In a renewable energy conversion system, power electronics converters are used to charge storage batteries and to transform the dc current to alternative current and vice versa. In order to fully exploit the energy provided by both sources and ensure a very high efficiency, it is necessary to oblige the hybrid photovoltaic/wind system to produce the maximum possible power. For this, the use of MPPT methods is required. This paper presents a theoretical study and design of two MPPT controllers using to control a photovoltaic (PVG)/wind turbine generator (WTG) hybrid system. For the photovoltaic generator, a MPPT based on sliding mode technique (MPPTSMC), is adopted. In another hand, a MPPT based on a torque control (TC) is used to extract maximum power from the wind turbine generator. The proposed approach is designed using the PSIM software tools. The results of simulation show the effectiveness of this solution.*

Key words: *(PVG)/(WTG) hybrid system, Buck converter, Three phase active rectifier, MPPT Sliding mode control (MPPTSMC), Torque Control (TC).*

1. INTRODUCTION

The wind and photovoltaic is the most environment friendly type of energy to use. The importance of utilizing the photovoltaic and wind turbine generator systems, has become apparent because electricity demand is rapidly growing all over the world, these two sources are among the greatest sources of renewable energy that have been increasing the four corners of the earth year after year. Photovoltaic and wind power sources allow an achievable form of power generation and are able to cover the load request. A system of energy production based on a photovoltaic/wind hybrid system can be used in two famous applications namely: standalone application [1], [2], [3] and grid-connected applications [4], [5]. In addition, a hybrid photovoltaic/wind system may also include power converters, a storage system and a control unit for load management. Nevertheless, to satisfy load demand, the system should present a good exploitation and a high general efficiency . For that, it is necessary to extract the maximum of power from the two energy sources. MPPT is an indispensable component of a hybrid photovoltaic/wind system. Various techniques of maximum power tracking have been considered in photovoltaic/wind power applications. For the photovoltaic generator (PVG), the perturbation and observation (P&O) method allows MPP tracking even in changing environmental conditions [6], [7]. For the wind turbine generator applications, various methods have been developed in [8], [9]-[20], [21], [22]. Sliding mode control is used, in many research studies, to track the MPP in photovoltaic applications [10], [11], [12], [13].The main advantage of the sliding mode technique is the simplicity of implementation, robustness, and the great performance. In this paper, a theoretical study of two MPPT strategy of power control using in a photovoltaic/wind hybrid system is detailed . Also, the mathematical modeling is developed for the entire hybrid system. The paper is subdivided as as follow: a description of the photovoltaic/wind hybrid power system is presented in section 2. The model of the buck converter is described in Section 3. The proposed strategies of control are detailed in section 4. Results of simulation and conclusion are presented in Section 5 and 6 respectively.

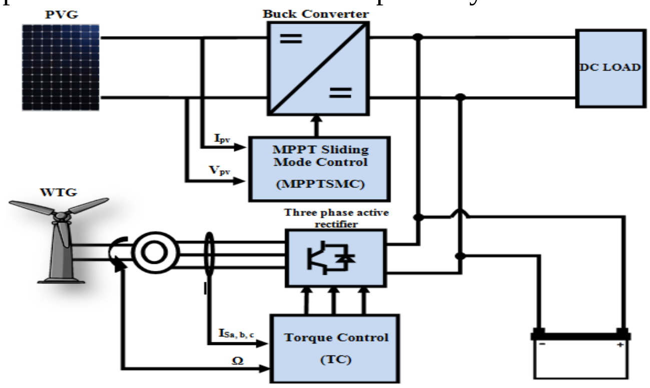


Figure 1. Proposed photovoltaic/wind hbrid power system

2. G LOBAL PROPOSED HYBRID SYSTEM

Fig.1 depicts the topology of a hybrid photovoltaic/wind system consisting of a wind turbine generator (WTG), a Permanent Magnet Synchronous Generators (PMSG), a three phase active rectifier, a photovoltaic generator (PVG), a (DC/DC) buck converter and a DC load connected. The two energy sources are connected in parallel to a common DC. The hybrid power generation system consists of a 400(W) small wind turbine, 240(W) photovoltaic generator.

2.1. Modeling of the photovoltaic generator

Solar cell (SC) generate electric power when illuminated by sun light or artificial light. Fig.2 represents the simplified equivalent electric circuit of a photovoltaic cell defined by the following equations [6], [7]:

$$I_{pv} = I_{ph} - I_d \quad (1)$$

$$I_d = \left[\exp\left(\frac{V_{pv}}{V_t}\right)\text{-}1\right] \quad (2)$$

$$V_t = \frac{n_i K T_p}{q} \quad (3)$$

$$I_p = I_{cc} * \frac{E}{E_r} + K_{isc}\left(T + T_r\right) * \frac{E}{E_r} \text{-} Is * \left[\exp\left(\frac{V_{pv}}{V_t}\right)\text{-}1\right] \quad (4)$$

- n_i : Ideality factor of the (SC);
- K: Boltzmann constant;
- q: electric charge;
- I_{ph}: photo_current (A);
- I_d: the current passing through the diode (A);
- I_{cc}: short_circuit current of the (SC) under standard meteorological conditions (E_c and T);
- I_{pv} :current delivered by the (SC) (A);
- V_{pv}:voltage generated by the (SC) (V);
- R_{sh}:parallel resistance (Ohm) ;
- R_s: series resistance (Ohm);
- V_T: the thermodynamic potential.

Fig.3 illustrates the calculated $P_{pv}(V_{pv})$ and $I_{pv}(V_{pv})$ characteristics. At fixed sunshine and temperature (1000W/m^2 and 25°C).

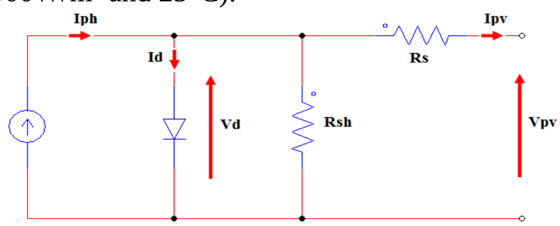
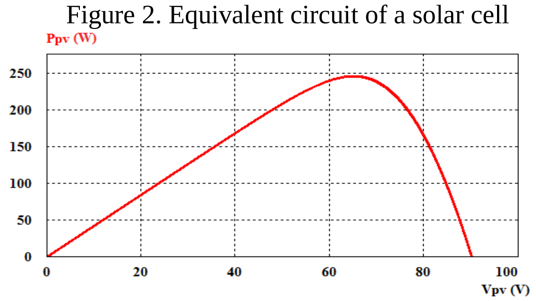
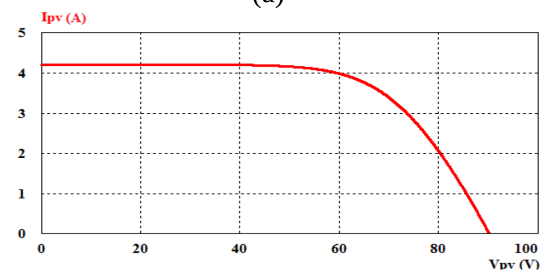


Figure 2. Equivalent circuit of a solar cell



(a)



(b)

Figure 3. Photovoltaic generator curve characteristics under (1000w/m^2 et 25°C): (a): $P_{pv}(V_{pv})$ characteristics (b): $I_{pv}(V_{pv})$ characteristics.

2.2. Modeling of the wind turbine generator

Power produced by a wind turbine generator is given by [14]:

$$P_{turbine} = \frac{1}{2} C_p(\lambda) \rho \pi R^2 v_{turbine}{}^3 \quad (5)$$

Where $V_{turbine}$ is the wind speed, ρ is the air density, C_p is the power coefficient, which generally given as a function of λ which is the speed ratio of the turbine, and R the rotor radius in meters.

The tip speed ratio is calculated by:

$$\lambda = \frac{R\omega}{v_{turbine}} \quad (6)$$

Where, Ω is the angular velocity of the rotor. Fig.4 shows the output power of the wind turbine generator versus to the wind speed $V_{turbine}$.

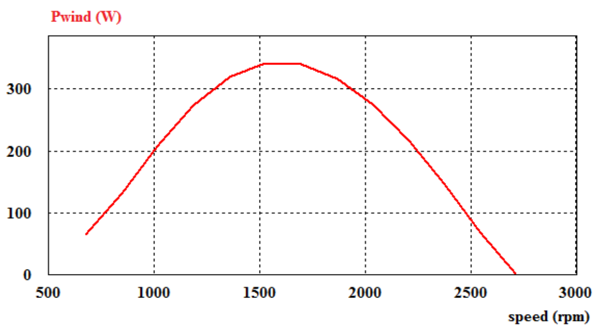


Figure 4. Wind turbine generator output power versus to the wind speed

2.3. Modeling of the Permanent-Magnetic Synchronous Generator (PMSG)

The PMSG differs from the induction generator in that the magnetization is provided by a permanent magnet pole system on the rotor. The expression for the electromagnetic torque can be described as [15]:

$$T_{em} = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left[\left(L_d - L_q\right) i_q i_d - \lambda_m i_q\right] \quad (7)$$

where L_d and L_q are stator inductances in direct and quadrature axis, respectively; i_d and i_q are the currents in direct and quadrature axis, respectively; ω_e is the electrical angular speed of the generator; P is the number of poles ; λ_m is the amplitude of the flux linkages established by the permanent magnet viewed by the stator windings.

The relation between electrical angular speed ω_e and mechanical angular speed Ω_{mec} is expressed by:

$$\omega_e = \frac{P}{2} \Omega_{mec} \quad (8)$$

3. (DC/DC) BUCK CONVERTER

DC/DC Converters are most widely applied in photovoltaic systems as an intermediate between the solar cells and the load to pursue the maximum power point (MPPT). In this study, the buck converter is used. We can deduce easily the voltage and current in the load by the following equations [16], [17], [18], [19]:

$$\begin{cases} V_{out} = DV_{in} \\ I_0 = (1/D) I_{in} \end{cases} \quad (9)$$

Where D is the duty cycle, I_0 is output current; I_{in} is input current, V_{in} is input voltage and V_{out} is the output voltage of the buck converter. Figure 5 shows the structure of this converter.

The following equations can be used as a good estimation to choose the output value of inductor and capacitor for the currently power converter [16]:

$$L_{min} = \frac{V_{out} * (V_{in} - V_{out})}{\Delta I_L * f_s * V_{in}} \quad (10)$$

$$C_{out(min)} = \frac{\Delta I_L}{8 * f_s * \Delta V_{out}} \quad (11)$$

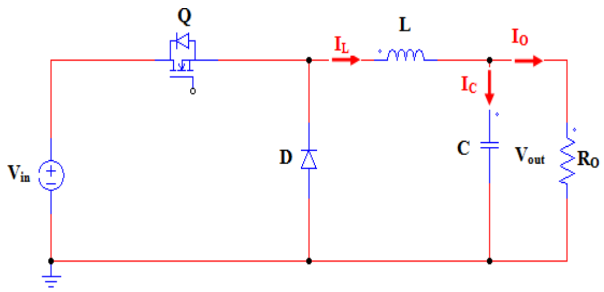


Figure 5. (DC/DC) Buck converter

4. Control strategies

4.1. Torque control (TC) strategy

The aim of the MPPT technique is to set the power coefficient C_p to its maximal value. $C_p = C_{p\max}$, corresponding to the λ_{opt} [22]:

$$\Omega_{opt} = \frac{\lambda_{opt}}{R} V_{wind} \quad (12)$$

We deduce the maximal value of the wind power as:

$$P_{\max} = K_{opt} \Omega_{mec}{}^{3} \quad (13)$$

For any wind speed, the MPPT controller imposes a torque reference able to extract the maximum power of the wind turbine. In order to read out the maximum power from the permanent magnet synchronous generator (PMSG) of the wind turbine for a given wind speed. We have to put $I_{sd} = 0$ and we have to use the (F.O.C) technique to control the three phase active rectifier. We can calculate the torque from the mechanical angular speed measurement. The optimal torque allowing the (MPPT) is given by [20], [21]:

$$C_{em\_ref} = K_{opt} \Omega_{mec}{}^{2} \quad (14)$$

Where

$$K_{opt} = 0.5 \rho \pi R^{2} \left(\frac{R}{\lambda_{opt}}\right)^{3} C_{p\max} \quad (15)$$

The torque control simulation bloc of the (PMSG) is shown on Fig.6.

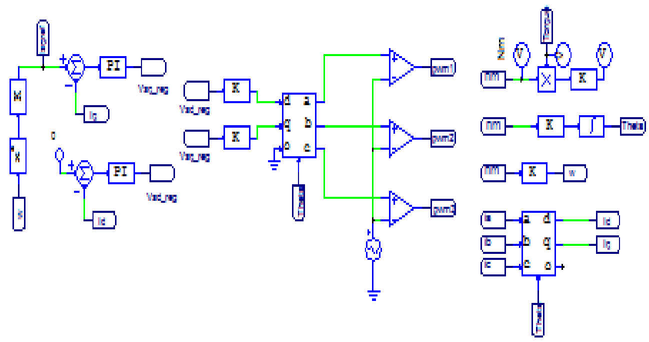


Figure 6. Torque control (TC) simulation bloc

4.2. The Proposed MPPT Sliding Mode Control approach

The aim of this section is to develop a novel approach to draw the maximum power from the photovoltaic generator (PVG) using a sliding mode control approach.

4.2.1. Sliding mode control theory

Sliding mode (SMC) is a nonlinear control solution and a variable structure control (VSC) [23]. It is a technique that maintains the system trajectory along a particular surface, which is commonly called a sliding surface. The design of the control can be realized in three main steps very dependent on each other:

- The choice of the surface.
- The establishment of the existence of convergence conditions.
- Determining the control law.

Let us consider the nonlinear system represented by the following state equation:

$$\dot{x} = F(x,t) + G(x,t)U(t) \quad (16)$$

For the considered system the control input is composed by two components a discontinuous component U_n and a continuous one U_{eq}.

$$U = U_n + U_{eq} \quad (17)$$

The equivalent control that maintains the sliding surface satisfies the condition:

$$\dot{S} = 0 \quad (18)$$

In this case, the switch control signal can be selected as:

$$U(x) = \begin{cases} U^{+}(x) & S(x) > 0 \\ U^{-}(x) & S(x) < 0 \end{cases} \quad (19)$$

4.2.2. MPPT (P&O) technique

Perturb and Observe (P&O) is one of MPPT techniques. This method uses the photovoltaic voltage/current to compute maximum power. The (P&O) method is generally the most used due to its simplicity and ease of implementation. This method allows MPP tracking even in changing climatic conditions [24], [25], [26]. Fig.7 shows (P&O) algorithm flowchart.

4.2.3. MPPT sliding mode control using (P&O) algorithm

In this section, we are interested in the synthesis of a sliding mode control using a reference voltage provided by an MPPT algorithm to extract the maximum power from the photovoltaic generator. After determined the V_{ref}, the (SMC) algorithm calculate the difference between the obtained photovoltaic voltage V_{PV} and the V_{ref} and then, via the buck converter force the photovoltaic generator to operate at the reference voltage value V_{ref} and therefore at the maximum power zone. The sliding mode surface is given by [27], [28]:

$$S(x) = \varepsilon = V_{PV} - V_{ref} \quad (20)$$

The control law for this case is described by:

$$U = \begin{cases} 1 & S \geq 0 \\ 0 & S < 0 \end{cases} \quad (21)$$

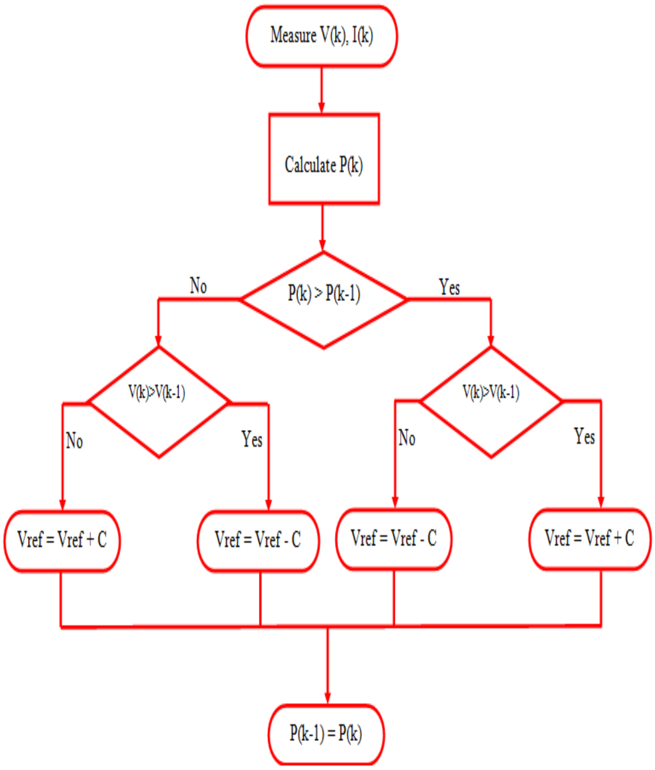


Figure 7. The (P&O) algorithm flowchart

In order, to study the condition of existence of the sliding mode, we have to use the Lyapunov stability method.
A positive definite function is defined as:

$$V(x) = \frac{1}{2} S(x)^2 > 0 \tag{22}$$

The attractiveness condition is given by:

$$\dot{V}(x) = S(x)\dot{S}(x) < 0 \qquad \forall \quad S(x) \neq 0 \tag{23}$$

Whose time derivative is:

$$\dot{S}(x) = \dot{V}_{PV} = \frac{dV_{PV}}{dt} \tag{24}$$

When $S(x) > 0$

In this case, the operating point is in the right of the reference voltage V_{ref} and $U = 1$. This leads to the left the operating point involving the decay of voltage V_{pv} :

$$\frac{dV_{pv}}{dt} < 0 \quad \Rightarrow \quad S(x) < 0 \tag{25}$$

From where:

$$S(x)\dot{S}(x) < 0 \tag{26}$$

For $S(x) < 0$

In this case, operating system is in left of the reference voltage V_{ref} and the control $U = 0$. This leads to the right the operating point involving the growth of the voltage V_{pv} :

$$\frac{dV_{pv}}{dt} > 0 \quad \Rightarrow \quad S(x) > 0 \tag{27}$$

From where:

$$S(x)\dot{S}(x) < 0 \tag{28}$$

It concludes that the system is asymptotically stable. The MPPT sliding mode (MPPTSMC) simulation bloc is shown on Fig.8.

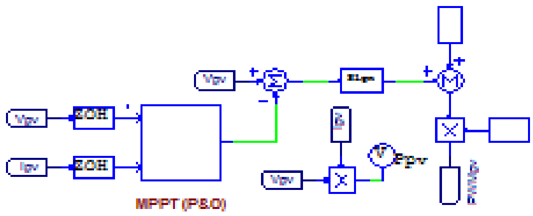


Figure 8. MPPT sliding mode (MPPTSMC) simulation bloc.

5. Results and analysis

MPPT control of photovoltaic generator with buck converter is modeled using PSIM software [29]. Four Solar modules of Kaneka k60 of 60(W) are connected in parallel, and a combined block is formed. Parameters of photovoltaic array are shown in Table 1. In the other hand, MPPT control of wind turbine with three phase active rectifier converter is modeled using PSIM software. Parameters of wind turbine are shown in Table 2.
Fig.9 showed the photovoltaic/wind hybrid system simulation bloc.
In order to verify the correct operation of the proposed integrated renewable energy system, photovoltaic and Wind sources, were simulated using PSIM to behave as if the wind source and the photovoltaic generator worked simultaneously for different periods of time. Fig.10 and Fig.11 represent values of photovoltaic irradiance and wind speed respectively.
The simulation results described the dynamic performance of the MPPT strategies control of the photovoltaic/wind hybrid system when the climatic conditions changes rapidly and cont

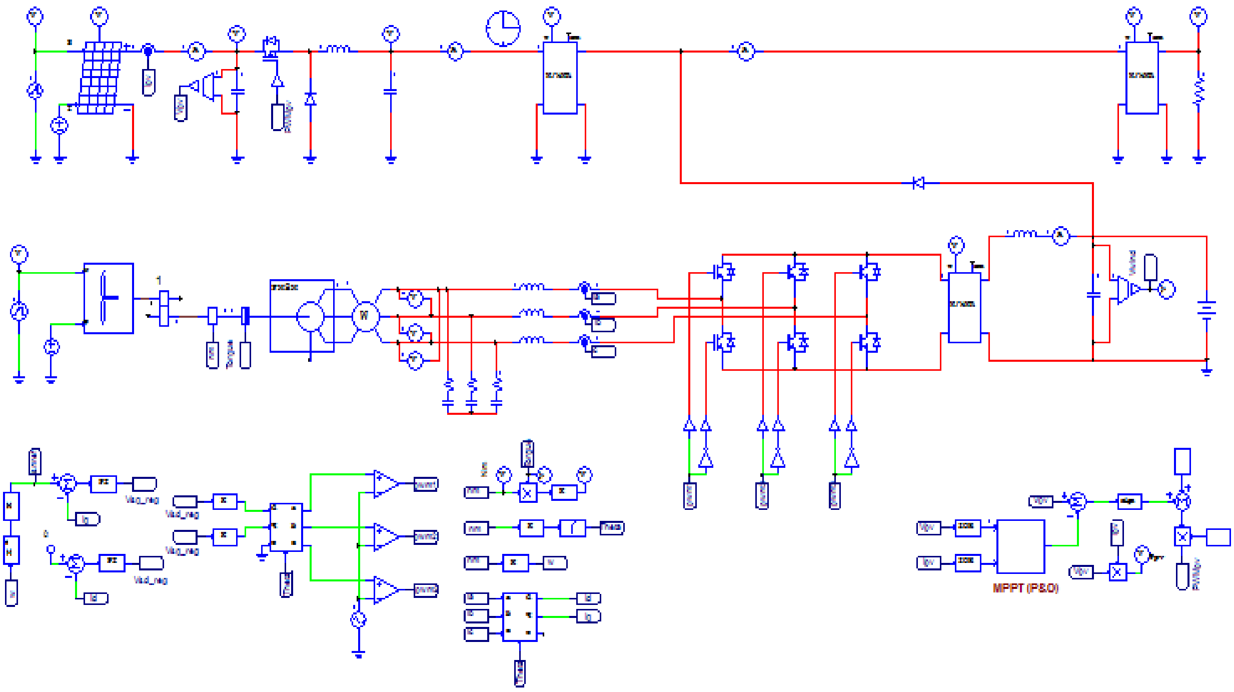


Figure 9. The photovoltaic/wind simulation bloc

Fig.12 shows the wave form for output currents which are obtained from the (PMSG). And with this the line power is depends. And Fig.13 shows the simulation result for (PMSG) output voltages.

Fig.14 shows the waveform of the output powers of the permanent magnet synchronous generator (PMSG) and the three phase active rectifier for different changes of wind speed. At 0.78s, the wind speed value is at 13 (m/s). The output power of the PMSG is equal to 408.14 (W) and the output power of the three phase active rectifier is equal to 406.09(W). So we can deduce that the values of the two powers are nearly equal.

Fig.15 illustrates the output power of the photovoltaic generator without and with the use of the MPPT sliding mode controller (MPPTSMC). According to the simulation results, it can be observed that without using the (MPPTSMC) controller, the exploited output power is 53.26 (W) during the simulation period of 0.4s to 0.6s. But, when we integrate our controller in our design, the exploited power is 240.84 (W) for the same period of simulation. So, it is clear that without using a MPPT controller there is a huge lack of power to win. The output power of the (PVG) reaches the maximum value at a value of time less than 0.1s.

Table 1. Kaneka K60 values extracted from datasheet

Parameters	Values
Maximum Power	60W (+10/-5%)
Voltage at Maximum Power	67 V
Current at Maximum Power	0.9 A
Open Circuit Voltage	92 V
Short-Circuit Current	1.19 A

Table 2. Technical specifications of the Air X wind turbine

Parameters	Values
Rotor Diameter	1.17 meters
Start up wind speed	3.0 m/s
Rated Power	400W at 12.5 m/s
Weight	6kg

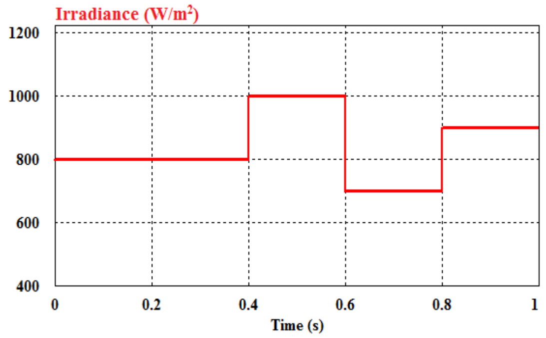


Figure 10. Photovoltaic irradiance profile

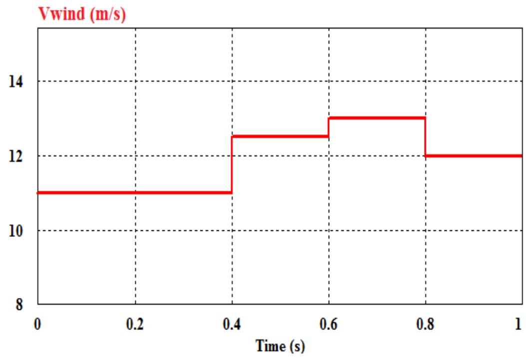


Figure 11. Wind speed profile

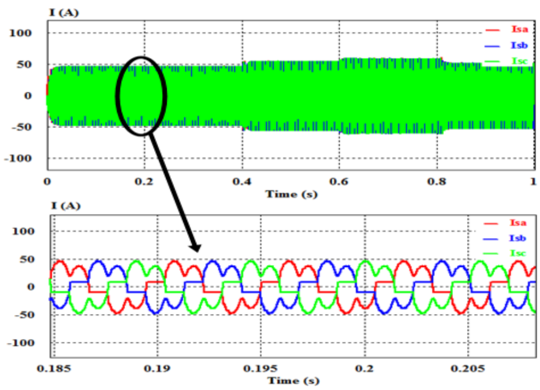


Figure 12. Output currents of the (PMSG)

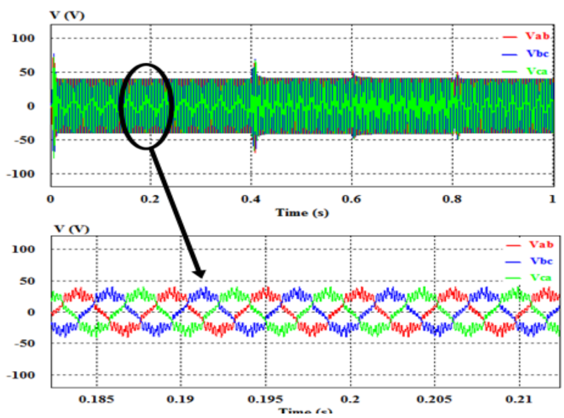


Figure 13. Output voltages of the (PMSG)

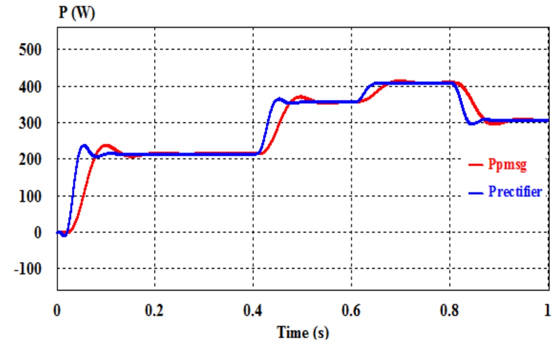


Figure 14. Output power of the (PMSG) and three phase active rectifier

Fig.16 point out the simulation results of output currents. We can deduce that when the climate factors changes, the output currents changes. The output current I_{hybrid} of the combined sources is nearly stable at 9.04 (A) at (1000W/m^2) and 12.5(m/s).

The output voltages which are obtained from the photovoltaic/wind hybrid system, is illustrated in Fig.17. We can notice that the output voltage V_{hydrid} of the combined sources is equal to the output voltage of the buck converter. The output voltage V_{hydrid} of the combined sources is nearly stable at 25(V) at (1000W/m^2) and 12.5(m/s).

Fig.18 shows the simulation results of the output powers which are obtained from the hybrid photovoltaic/wind system for varying sunshine values (800W/m^2, 1000W/m^2 700W/m^2 and 900W/m^2) and varying wind speed (11 m/s, 12.5 m/s, 13 m/s and 12 m/s). From 0.4s to 0.6s, the output power of the (PVG) is about 245.46(W) at 1000(W/m^2). At 12.5 (m/s), the power produced by the wind turbine generator (WTG) is 384.30(W). From this result we can observed that the value of the output power P_{hybrid} , of the combination of the two sources is almost close to a value of 244.85(W).

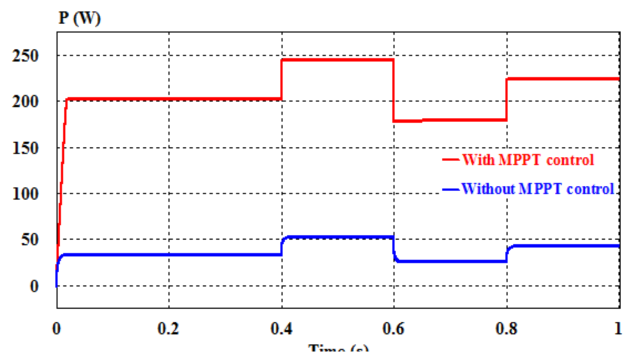


Figure 15. Output power of the photovoltaic generator

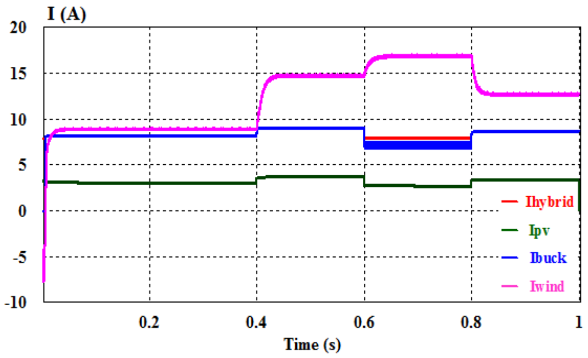


Figure 16. Different output currents of the Photovoltaic/wind hybrid system

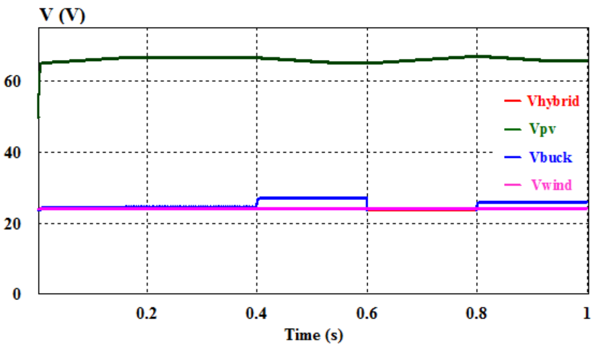


Figure 17. Different output voltages of the Photovoltaic/wind hybrid system

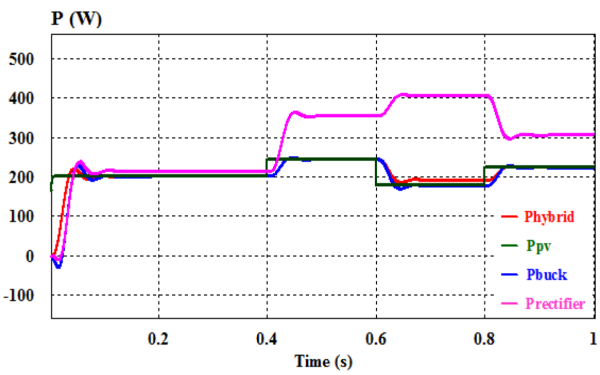


Figure 18. Different output powers of the Photovoltaic/wind hybrid system.

6. Conclusion

In this paper, a design of a photovoltaic/wind hybrid power system with battery storage is presented. The proposed power control strategies are based on the MPPT sliding mode control (MPPTSMC) technique for photovoltaic generator (PVG) and MPPT based on a Torque control (TC) for wind turbine generator. The aim of this two strategy of control is to extract the maximum power from this two renewable source energy under different climatic conditions. The control of the overall proposed photovoltaic /wind hybrid power system is modeled and simulated with PSIM software system. The results obtain improves the efficiency of the hybrid system topology.

The hybrid photovoltaic/wind system is a good proposal to be used for producing energy to supply small-scale standalone applications. The simulation results demonstrate that the controller operates very well and shows very good dynamic and steady-state performance.

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