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Modeling and simulation of wind energy chain conversion

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ABSTRACT

Alongside the substantial market for wind generation of high power systems grows smaller power (about 100 W to several kW) which is especially dedicated to remote sites. The chain of energy conversion is very different from those of great power, they are often based on the use of a three-phase alternator with permanent magnets debiting directly through a rectifier diodes in a generally electrochemical battery low voltage (12–48 V). In this article, we propose a model of the conversion chain, few conventional, for the estimation of energy production.

Keywords: Wind turbine generator; Synchronous generator; Permanent magnetic; Continuous source; Fuzzy logic; Simulation

1. Introduction

Today, the sustainable development and energy renewable arouse the interest of several research teams. Therefore, the development of wind turbines is a major investment in research technology. The systems that produce electrical energy from the wind can be an alternative to technological and economic exhaustible energy sources. In fact, the growth of the global wind industry is about 30% per year since the early 2000s [1]. In 2011, wind projects made up more than 28% of the $260 billion investment in clean energy projects. A significant portion of this investment was from public sector institutions. The use of wind turbines has important advantages [2]. Indeed, they are currently one of the greenest ways to get electricity. Also, this source is inexhaustible. However, in Algeria, the cost of wind energy is still too high for this energy source has an alternative to traditional sources.

2. Chain modeling of low wind power

Generally, any wind power conversion system that will be dedicated to remote site can be represented as it is shown in the Fig. 1.

The wind speed can be modeled by a sum of some harmonious [6]:

$$V_V(t) = A + \sum_{n=1}^{i} (a_n.\sin(b_n.\omega_V.t)) \quad (1)$$

where A is the constant and $b_n.\omega_V$ represent, respectively, the amplitude and the pulse of sample wind.

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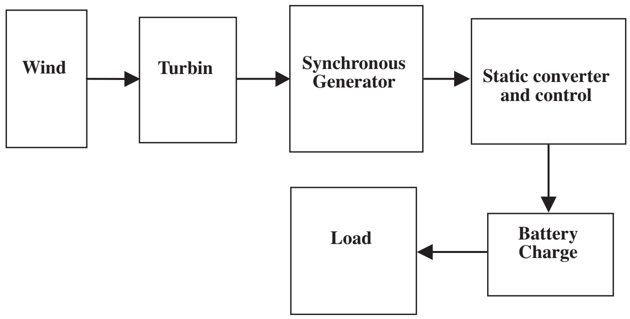

Fig. 1. Low wind power chain conversion [5].

Total wind power through a disk of radius R is given by the following relation [3,4]:

$$P_V = \frac{1}{2}.\rho.S.V_V^2 \tag{2}$$

Power of the air mass, which crosses the surface equivalent to the active surface S of the wind turbine, is given by following relation:

$$P_{\text{eol}} = \frac{1}{2}.C_P(\lambda, \beta).\rho.S.V_V^3 \tag{3}$$

$C_P(\lambda, \beta)$ is the power coefficient of wind turbine, and its value cannot exceed (16/27), Betz limit [4];
β is the pitch angle and
λ is the linear speed rations at the end of pales the turbine and wind speed.

$$\lambda = \frac{R \cdot \Omega}{V_V} \tag{4}$$

The mechanical expression optimal power $P_{\text{mec.opt}}$ is obtained as follows:

$$P_{\text{mec}\cdot\text{opt}} = -\frac{1}{2}\frac{C_{P\max} \cdot \rho \cdot \pi \cdot R^5}{G^3 \lambda_{C_{p\max}}^3}\Omega_{\text{mec}}^3 \tag{5}$$

where G is the multiplier ration and Ω_{mec} is the angular speed of generator rotor (see Fig. 2).

In our study, the vertical axis wind turbine called Savonius is used. The used dimensions, the input and output parameters and the power efficiency of the Savonius turbine are defined, respectively, in Figs. 3 and 4. The height H and the diameter $2R$ of the rotor are equal to 2 and 1 m, respectively.

This last factor is defined by the following equation:

$$C_p(\lambda) = -0.2121\lambda^3 + 0.0856\lambda^2 + 0.2529\lambda \tag{6}$$

With: $C_P^{\text{opt}}(\lambda_{\text{opt}}) = 0.15$

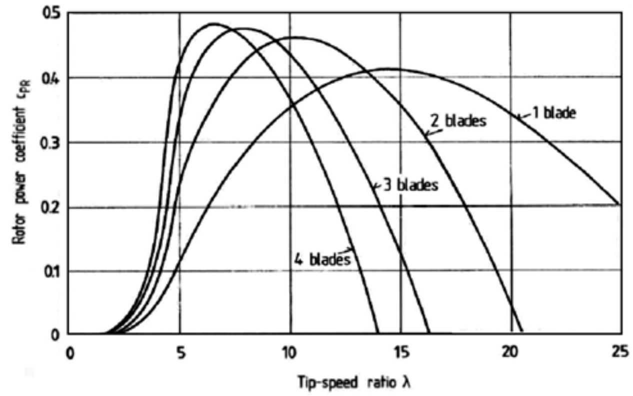

Fig. 2. Aerodynamic power coefficient depending on the tip wind speed and the number of the blade [5].

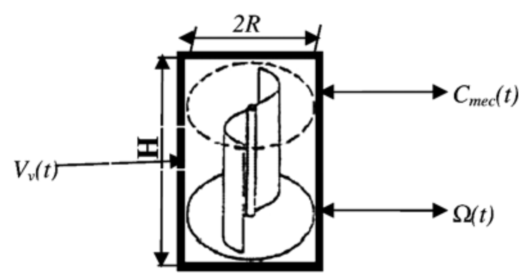

Fig. 3. Input–output Savonius model [7].

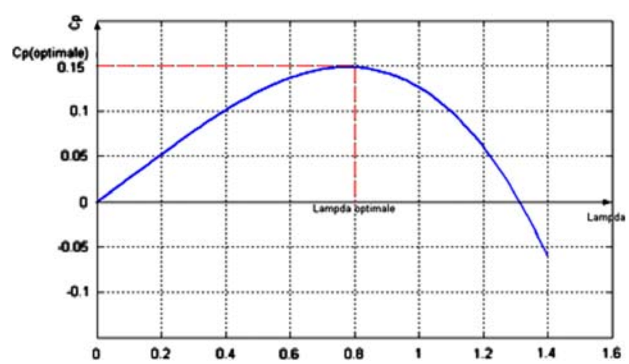

Fig. 4. C_p characteristics in the function of λ [8].

$\lambda_0 = 1.31$

$\lambda_{\text{opt}} = 0.78$

For optimum low speed, the power coefficient is the maximum and the wind turbine delivers the maximum mechanical power. It is therefore highly desirable to exploit the wind energy system on this point (see Fig. 5).

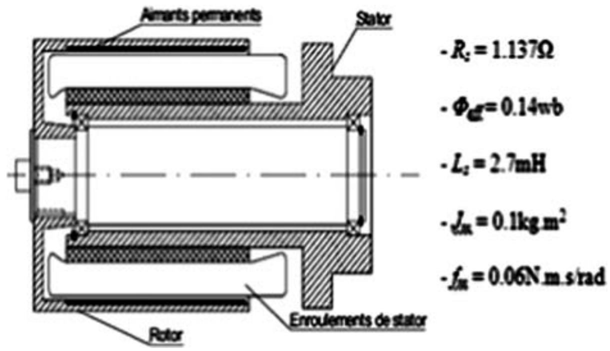

Fig. 5. Generator mechanical construction [8].

The generator model takes into account frames with smooth poles (not pole piece), so that there is no saturation and the winding up is perfectly symmetrical.

2.1. Static converters

Static converters are essential part of wind energy conversion system. They achieve the desired shape of the electric energy and also maximize the power drawn. Assuming negligible losses in all the assemblies studied are shown in [9] (see Figs. 6–10).

3. Research methods of maximum power point

See Fig. 11.

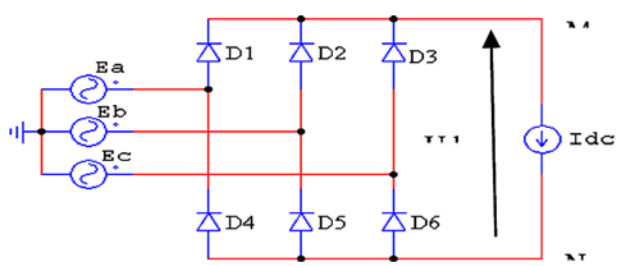

Fig. 6. Diode bridge structure.

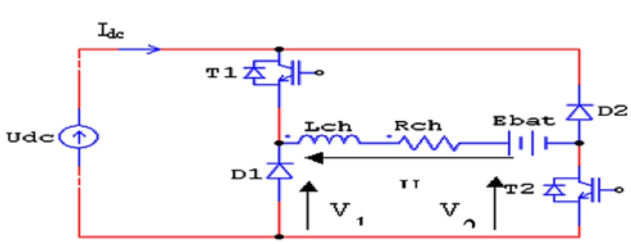

Fig. 7. Buck chopper structure.

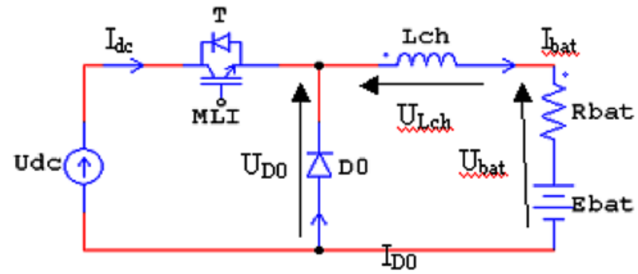

Fig. 8. Bridge converter structure controlled differential.

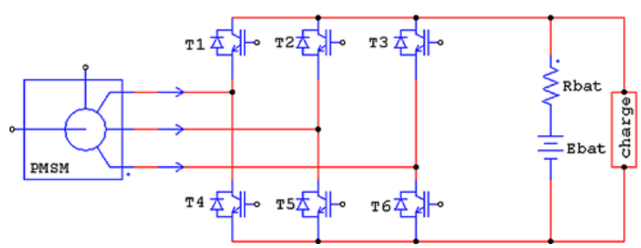

Fig. 9. Pulse-width modulated rectifier.

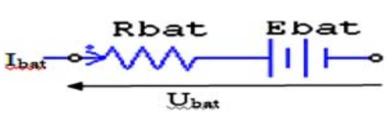

Fig. 10. Battery's model.

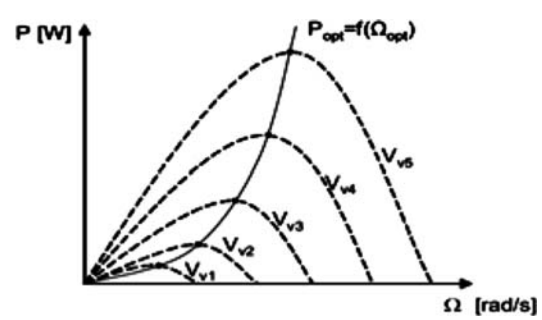

Fig. 11. Wind turbine characteristic power – speed [8].

3.1. Maximizing power without knowledge $C_P(\lambda)$

See Figs. 12 and 13.

3.1.1. MPPT by fuzzy logic

Fuzzy logic application in the system (stator flux oriented) assure the continuation, the instruction of

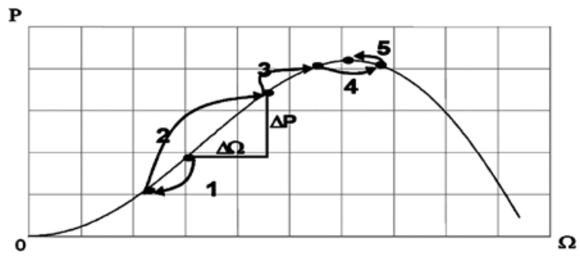

Fig. 12. MPPT's in case constant wind speed.

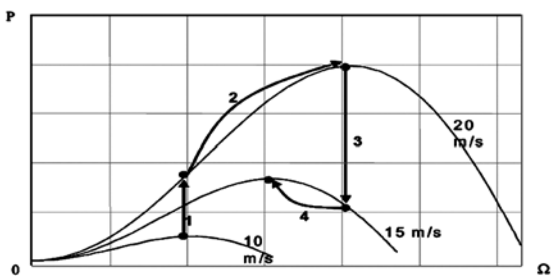

Fig. 13. MPPT's in case not constant wind speed.

speed rotation, and the turbine training which corresponds to the optimal point bound to optimal specific speed λ_{opt} and power ration maximum $C_{P\max}$ [8,9] (see Figs. 14–18).

Calculation of the difference between the optimal energy resulting from optimal power P_{opt} and that obtained using maximum power point tracking (MPPT) device provides an overview of the numerical specimen quality energy on a given time.

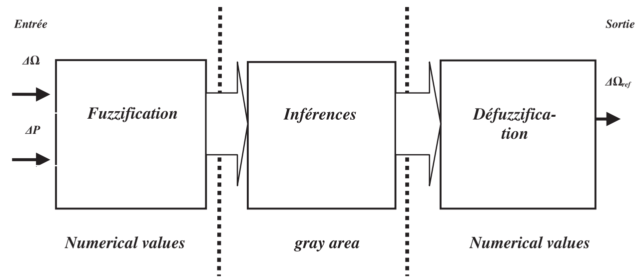

Fig. 14. Basic structure of fuzzy MPPT [8].

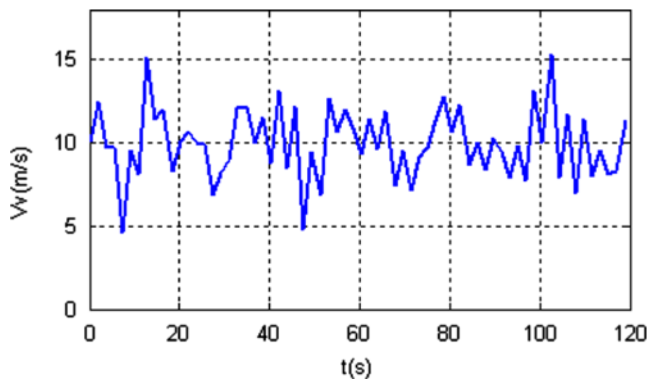

Fig. 15. Wind speed temporal form.

3.2. *Maximizing power with knowledge $C_p(\lambda)$*

See Fig. 19.

3.2.1. *Simple buck chopper simulation results*

See Figs. 20 and 21.

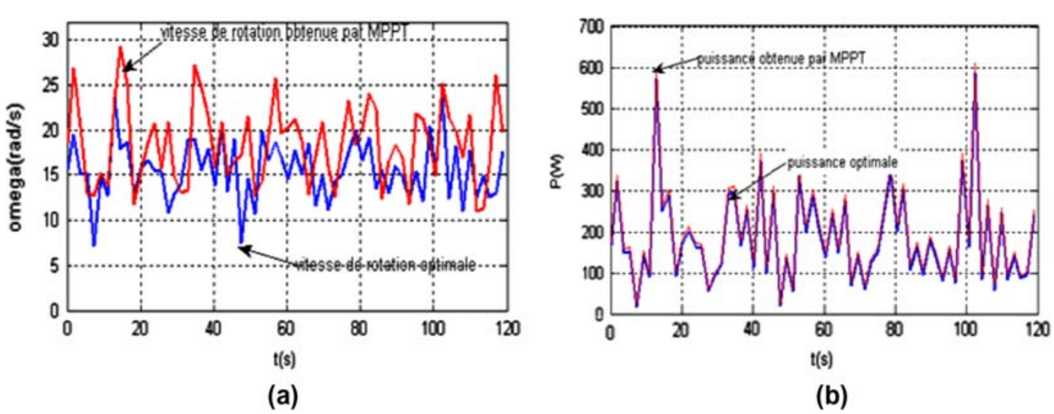

Fig. 16. MPPT optimal: (a) speed rotation and (b) wind power.

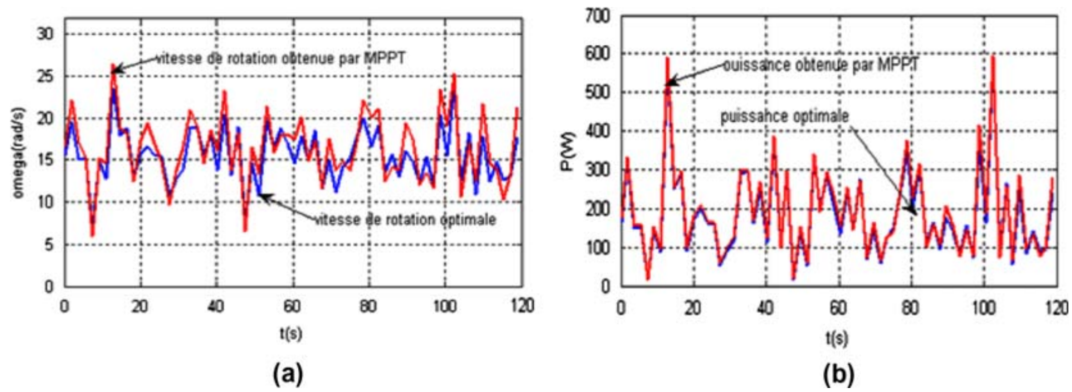

Fig. 17. Curves comparison between functioning with and without MPPT: (a) speed rotation and (b) wind power.

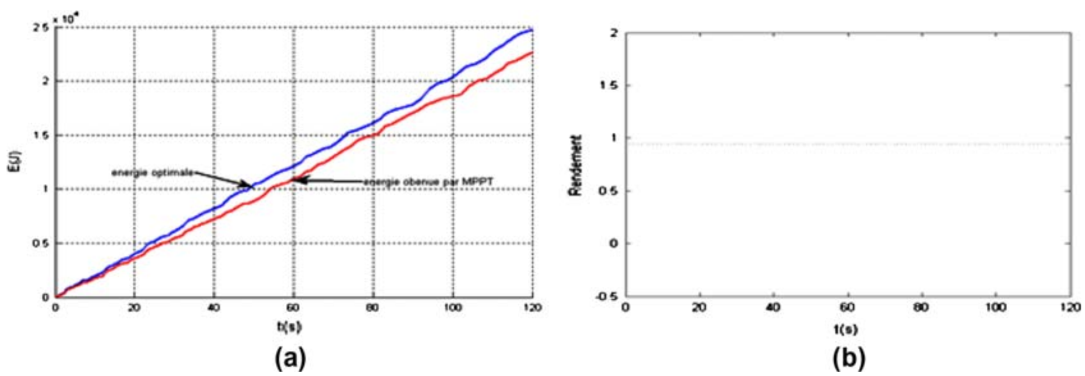

Fig. 18. Energy comparison: (a) wind energy and (b) efficiency obtained by MPPT fuzzy.

3.2.2. Asymmetric chopper simulation results

See Fig. 22.

4. Simulation results in linear wind speed

See Fig. 23.

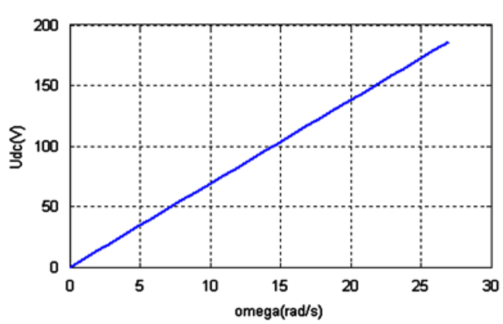

Fig. 19. Rectified voltage depending on the rotating speed in an optimal regime.

4.1. Results simulation without knowledge $C_p(\lambda)$

See Figs. 24 and 25.

4.2. Results simulation with knowledge $C_p(\lambda)$

4.2.1. Simple buck chopper simulation

See Figs. 26 and 27.

4.2.2. Asymmetric chopper simulation

See Figs. 28 and 29.

5. Conclusion

In this study, we showed the interaction between several parameters such as wind profile. Finally, in this power range and with an appropriate system design, the application of different wind fields allowed us to conclude on the high competitiveness of the simplest circuit against the cost/performance compromise: diode bridge association with buck chopper.

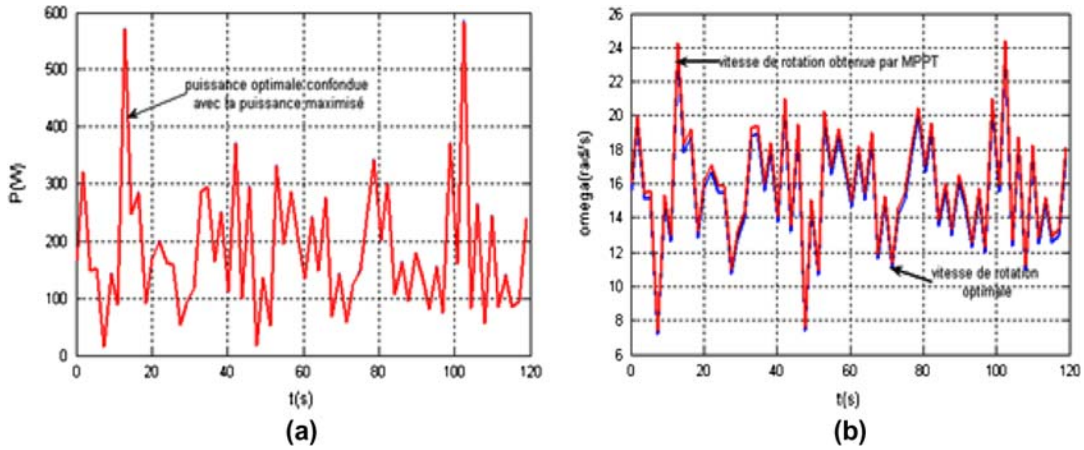

Fig. 20. (a) Wind turbine power and (b) rotating speed.

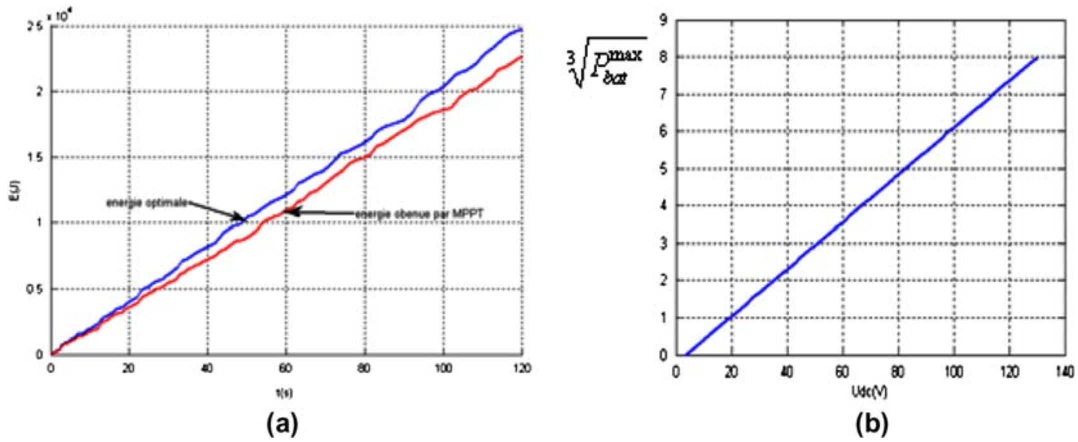

Fig. 21. (a) Energy efficiency and (b) maximum power (48 V battery according to the rectified voltage).

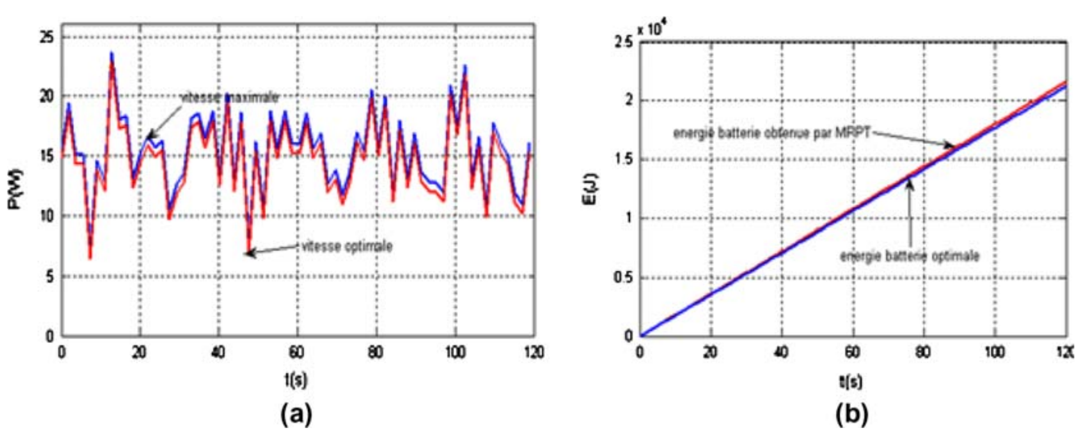

Fig. 22. (a) Rotating speed and (b) energy efficiency.

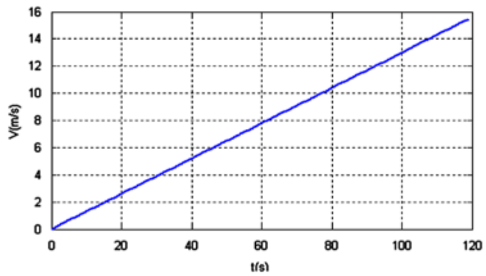

Fig. 23. Wind speed temporal form.

Although the MPPT is reliable in all cases studied, we see large differences in the amount of energy according to the configuration and the wind resource profile. To ensure greater availability of energy, more renewable resources can be interconnected together (wind–photovoltaic–fuel cells).

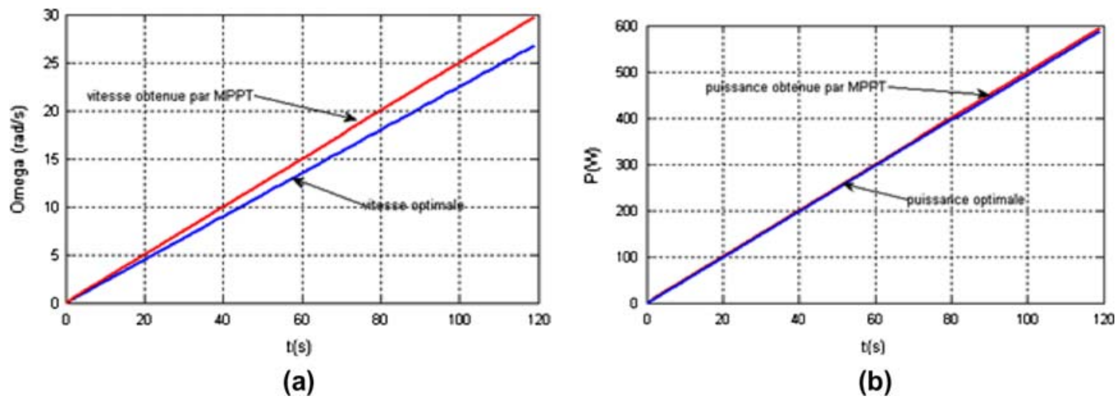

Fig. 24. Comparison between functioning with and without MPPT: (a) speed rotation and (b) wind power.

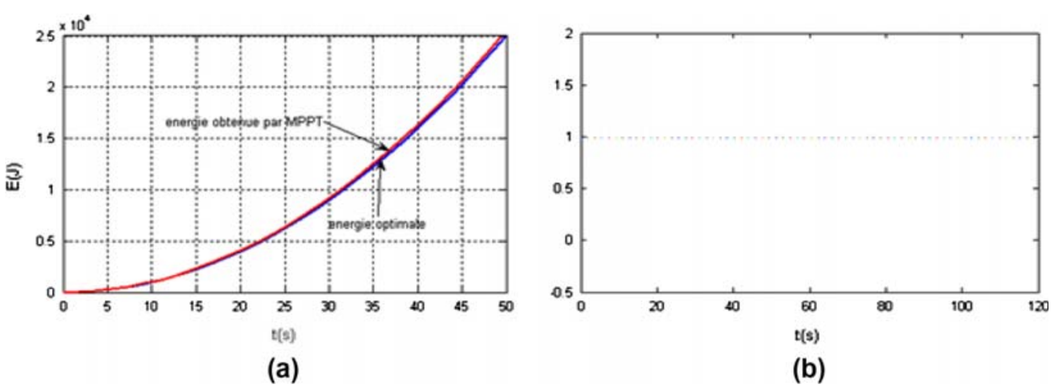

Fig. 25. Energy comparison: (a) wind energ and (b) efficiency obtained by MPPT fuzzy.

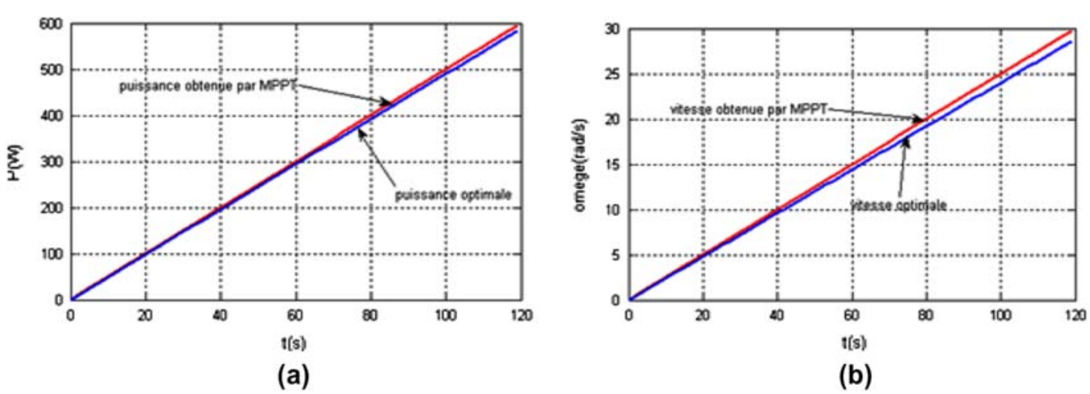

Fig. 26. (a) Wind power and (b) speed rotation.

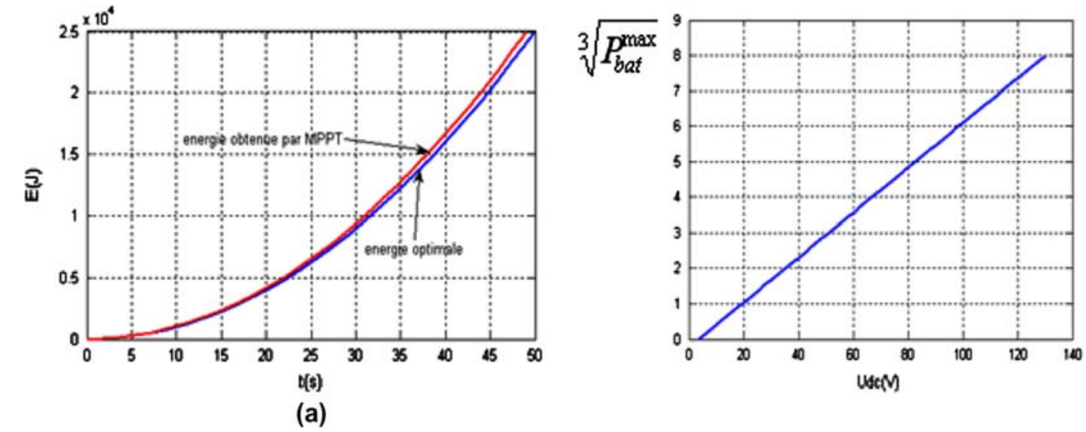

Fig. 27. (a) Energy efficiency and (b) maximum power of 48 V battery according to the rectified voltage.

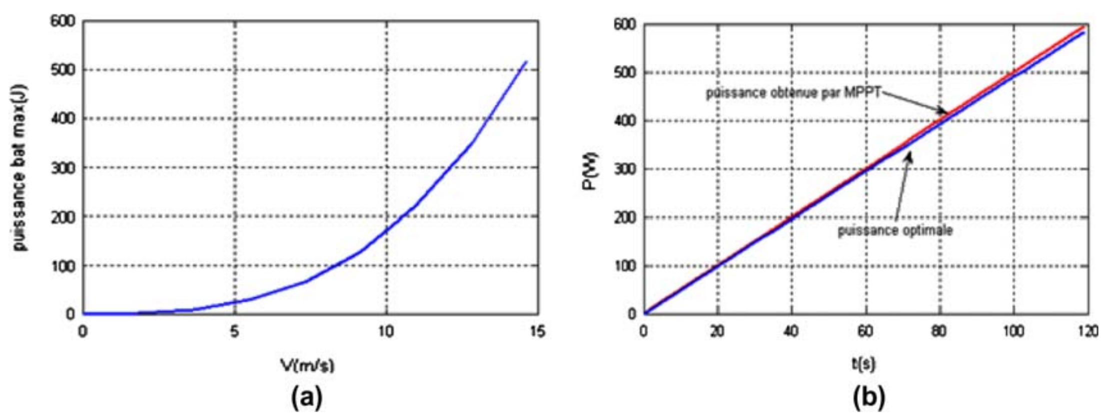

Fig. 28. (a) Battery power maximum (48 V) depending on wind and (b) power 48 V battery and maximized by optimal MPPT.

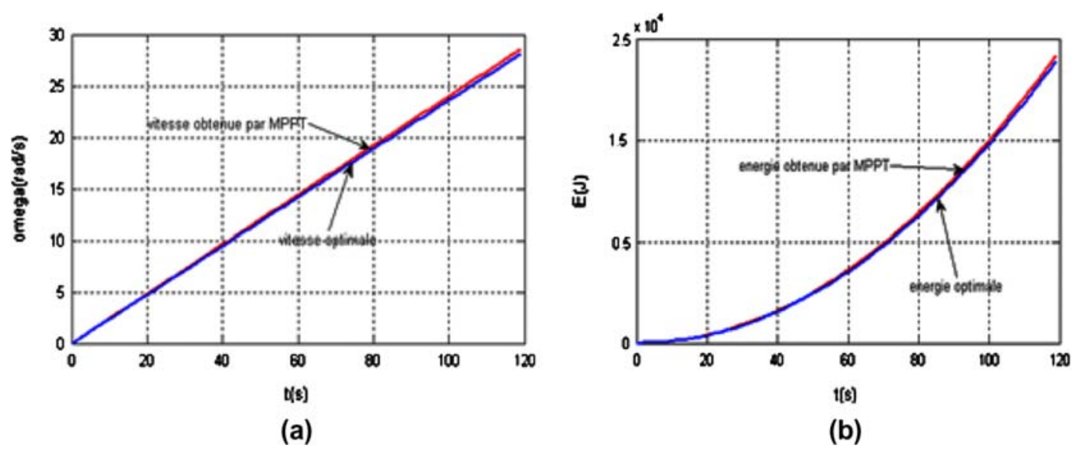

Fig. 29. (a) Rotating speed and (b) energy efficiency.

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