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Conference paper

Wind pumping with possibility to eliminate the power electronics bay

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ABSTRACT

In this article, we propose an application which resides in wind pumping, in particular the possibility to eliminate the power electronics interface. This fact is based on the exploitation of the torque-speed characteristic of the centrifugal type pump. The pumping system proposed in this article is made up of a three-blade turbine, two permanent magnets synchronous machines, one of which plays the role of the generator and the other motor driving the centrifugal pump. The good choice of machines and the centrifugal pump made possible the operation of the system of pumping with elimination of the static converter.The mathematical model to eliminate the static converter is developed and presented, implemented and simulated in the Matlab/Simulink environment.The simulation results obtained are validated by comparison with other simulation results of a wind pumping system with the presence of the power electronics interface.

1. INTRODUCTION

Population growth leads to a considerable demand for water quantity. The scarcity of surface water makes the depletion of available underground water indispensable.In order to contribute to the purification of the atmosphere, the use of energy from renewable sources is essential. The latter is exploited in several applications namely; feeding isolated sites, pumping, etc. Much works have been

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developed on techniques and strategies for the production of electrical energy from wind power. The latter is applied to the supply autonomous loads as well as the loads connected to the electrical grid.

Wind pumping is now becoming more attractive than traditional mechanical pumping (Al Suleimani et al., 2020) that is, for several advantages against mechanical pumping (Badran et al. 2003). A non-linear control is applied in (Evangelista et al, 2013) in order to optimize wind power production. In (Ghennam et al., 2015; Belaid et al., 2022), an optimization algorithm has been used in wind energy system for reactive power management at the input and the output of the converter. In (Idjdarene et al., 2011; Ghoudelbourk et al., 2016) a new technique is presented to set the active power injected into the electrical grid and to correct the power factor by the reactive power produced by the generator. The control of wind power generation, in order to adapt it to that required by the autonomous system is presented in (Abdoune et al. 2016). In reference (Pereira et al.; 2014), a regulation of energy production is ensured using the active stall technique, by actuating on half of the blade; however this technique requires the integration of actuators which makes the control complex. Another interesting wind pumping proposal in (Pali et al., 2018) resides in the elimination of static converters; on the other hand, the drawn water is exploited only to produce electrical power. The Optimal selection of pumped hydro storage based renewable energy generator(s) for isolated community using binary sort and search algorithm is shown in(Clark 1992).In these works, the observation is that the power flow from the wind source to the load passes through a power electronics interface. However, this solution is expensive and usually requires adequatecontrol. Moreover, this converter is often the source of harmonics which impairs the right functioning of the system and requires well-adapted filters.In this context a new topology of the wind pumping system is proposed in this article. This is lessbulky with a more attractive operating efficiency. It is based on the elimination of the powerelectronics interface with its control. Consequently, all the above-mentioned handicaps are eliminated, the elimination of harmonics generated by the static converter. Harmoniccurrents have variousharmfuleffects, namely increasedlosses, increased noise, interferences and vibration torque and causes heating of cables, motors and generators.The realization of this idea is based on the following points:

- ✓ The motor pump is powered directly by a permanent magnet synchronous generator driven by a variable speed wind turbine;
- ✓ The operation of a centrifugal type pump whose mechanical torque-speed characteristic is the image of the adjustment characteristic resulting from the MPPT algorithm of the wind turbine. Therefore, the speed-power curve of the centrifugal pump can be adapted during its construction to match that of the wind turbine;
- ✓ Lightening the pumping system, i.e. Motor Pump/Generator group, by eliminating the power electronics interface with its control, contributes to the reduction of stress and requires less maintenance on the proposed system and an extension of its lifespan;

The work presented in this article renter in the optic of water pumping with less bulky wind systemand more interesting efficiency. This lies in the elimination of the power electronics interface and its control, on the one hand, eliminating the harmonics generated by the static converter and requiringless maintenance on the other hand.This article is mainly composed of two parts: The first is devoted to the description of the system studied with the presence of the power electronics bay, to the presentation of the mathematical models governing the operation of the pumping system and to the presentation of the flow-oriented control. While, the second part presents the model and the study of the elimination possibility of the power electronics bay in a wind pumping system, by exploiting the torque-speed characteristic of the centrifugal-type pump.Simulation results with and without the power electronics bay are finally presented and discussed.

2. DESCRIPTION OF THE STUDIED SYSTEM

The system studied is composed of a Pith angle control wind turbine, rotationally driving a permanent magnets synchronous generator (PMSG). The latter powers, a permanent magnets motor (PMSM) which drives a centrifugal pump. From the motor pump supply, we can obtain two different configurations:Firstly, it is the classic configuration, where the moto-pump is supplied via a power electronicsinterface. Secondly, this is our new topology, where the static converter is eliminated. Hence, the Moto pump is connected directly to the wind generator. Both machines operate in master-slave mode, where, the motor operates as master, while the synchronous generator operates as slave.The overall diagram of the studied model is shown in Fig1.

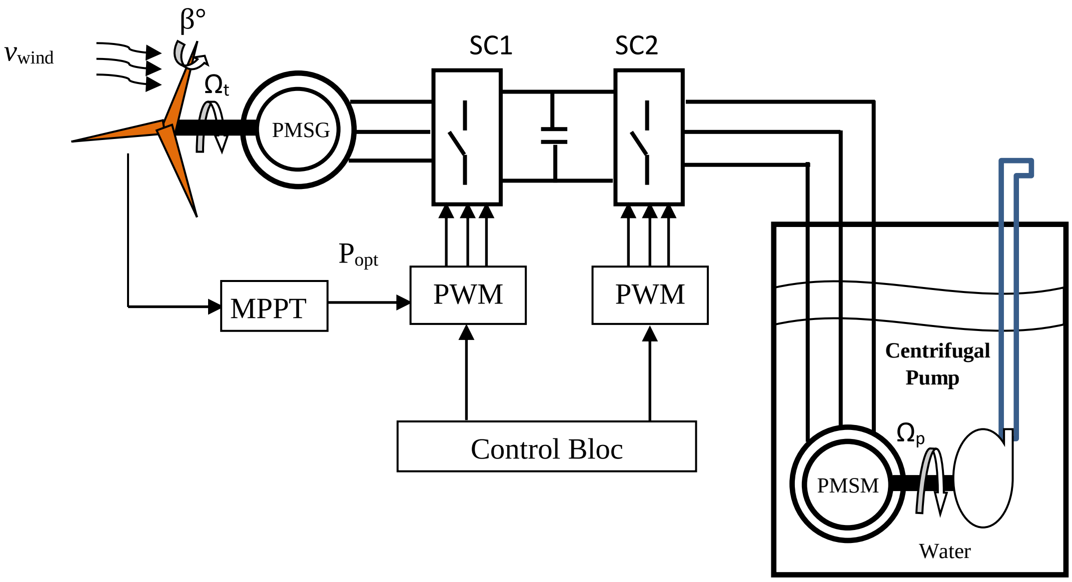


Fig.1. Global synoptic diagram of the studied system

3. MODEL OF THE TWO PMSMS WITH SALIENT POLES WITHOUT DAMPERS

The synchronous machine is chosen according to its advantages in terms of simplicity, absence ofbrushes, increase in speed, reduction of losses compared to the asynchronous machine, has aninteresting specific volume and easy control (the flow not estimated).The models of the two salient pole PMSMs without dampers are given by the following two systems of equations (Al Suleimani et al., 2000; Rekioua et al, 2009)

$$\begin{cases} v_{d1} = r_1 i_{d1} + L_{d1}\dfrac{di_{d1}}{dt} - \omega_p L_{q1} i_{q1} \\ v_{q1} = r_1 i_{q1} + L_{q1}\dfrac{di_{q1}}{dt} + \omega_t\left(L_{d1} i_{d1} + \Psi_{f1}\right) \end{cases} \tag{1}$$

$$\begin{cases} v_{d2} = r_2 i_{d2} + L_{d2}\dfrac{di_{d2}}{dt} - \omega_p L_{q2} i_{q2} \\ v_{q2} = r_2 i_{q2} + L_{q2}\dfrac{di_{q2}}{dt} + \omega_p\left(L_{d2} i_{d2} + \Psi_{f2}\right) \end{cases} \tag{2}$$

Where: v_d, v_q are the direct stator and quadrature stator voltage, i_d , i_q are the direct stator and quadrature stator current respectively, r_1, r_2 are the stator resistance for PMSG and PMSM respectively, Ψ_{f1} is the permanent magnetic flux and ω_t , ω_p are the electrical rotating speed of the generator and the motor-pump.

The electromagnetic torque is given by the expression (3)

$$T_{em} = p_1\left[\left(L_{d1} - L_{q1}\right)i_{d1}i_{q1} + i_{q1}\Psi_{f1}\right] \tag{3}$$

To achieve a control similar to that of separately excited DC machine, it is necessary to keep the current id at a zero value, and to regulate the speed by current through voltage.The system of equations (1), (2) becomes (Rekioua et al., 2009, Aissou et al., 2016)):

$$\begin{cases} v_{d1} = -\omega_p L_{q1} i_{q1} \\ v_{q1} = (r_1 + S.L_{q1})i_{q1} + \omega_t \Psi_{f1} \end{cases} \tag{4}$$

$$\begin{cases} v_{d2} = -\omega_p L_{q2} i_{q2} \\ v_{q2} = (r_2 + S.L_{q2})i_{q2} + \omega_t \Psi_{f2} \end{cases} \tag{5}$$

4. MPPT CONTROL ALGORITHM

The maximum power point tracking PMPPT curve is defined as function of the speed referred to the generator side (Rekioua et al., 2005):

$$P_{MPPT} = k.\,\omega_{t-opt}^3 \tag{6}$$

When the wind speed reached the nominal value, the pitch angle controller enters in operation in order to decrease the power coefficient, so the rated rotor speed and the power are maintained for above rated wind speed. The wind energy Pith angle controller diagram is shown Fig 2.

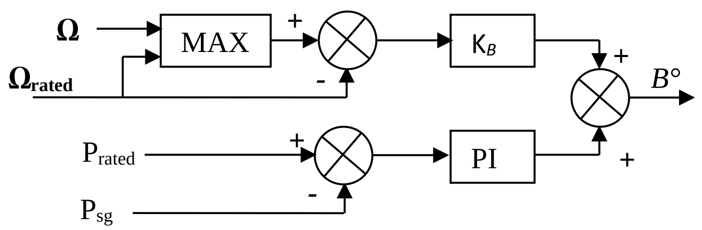


Fig.2 Pitch angle Controller

5. STUDY OF THE ELIMINATION POSSIBILITY OF THE STATIC CONVERTER

In order to eliminate the static converter and make an electrical coupling between the two PMSGs the mathematical path is done this way:

$$\begin{cases} v_{d2} = v_{d1} \\ v_{q2} = v_{q1} \\ i_{d2} = -i_{d1} \\ i_{q2} = -i_{q1} \\ \omega_t = \omega_p = p_1\Omega_t = p_2\Omega_p = \omega \end{cases} \tag{7}$$

By replacing (3) in (2), it is obtained the overall system (two MSAP) without mechanical equations:

$$\begin{cases} v_{d1} = r_1 i_{d1} + L_{d1}\dfrac{di_{d1}}{dt} - p\Omega_t L_{q1} i_{q1} \\ v_{q1} = r_1 i_{q1} + L_{q1}\dfrac{di_{q1}}{dt} + p\Omega_t (L_{d1} i_{d1} + \Psi_{f1}) \\ v_{d1} = -r_2 i_{d1} - L_{d2}\dfrac{di_{d1}}{dt} + pp\Omega_p L_{q2} i_{q1} \\ v_{q1} = -r_2 i_{q1} - L_{q2}\dfrac{di_{q1}}{dt} + pp\Omega_p (-L_{d2} i_{d1} + \Psi_{f2}) \end{cases} \tag{8}$$

After simplification, we obtain:

$$\begin{cases} 0 = (r_1 + r_2) i_{d1} + (L_{d1} + L_{d2})\dfrac{di_{d1}}{dt} - \omega(L_{q1} + L_{q2}) i_{q1} \\ 0 = (r_1 + r_2) i_{q1} + (L_{q1} + L_{q2})\dfrac{di_{q1}}{dt} + \omega[(L_{d1} + L_{d2}) i_{d1} + \Psi_{f1} - \Psi_{f2}] \end{cases} \tag{9}$$

By adding the two mechanical equations of the turbine and the pump, we will obtain:

$$\begin{cases} 0 = (r_1 + r_2) i_{d1} + (L_{d1} + L_{d2})\dfrac{di_{d1}}{dt} - \omega(L_{q1} + L_{q2}) i_{q1} \\ 0 = (r_1 + r_2) i_{q1} + (L_{q1} + L_{q2})\dfrac{di_{q1}}{dt} + \omega[(L_{d1} + L_{d2}) i_{d1} + \Psi_{f1} - \Psi_{f2}] \\ J_t\dfrac{d\Omega_t}{dt} + f_t\Omega_t = T_t - T_{e1} \\ J_p\dfrac{d\Omega_p}{dt} = T_{e2} - T_p - f_p.\Omega_p \end{cases} \tag{10}$$

With: T_{e1} and T_{e2} are the electromagnetic torques of the two PMSG;

$$T_{e1} = p1.[(L_{d1} - L_{q1}) i_{d1} i_{q1} + i_{q1}\Psi_{f1}] \tag{11}$$

$$T_{e2} = p2.[(L_{d2} - L_{q2}) i_{d2} i_{q2} + i_{q2}\Psi_{f2}] = p1[(L_{d2} - L_{q2}) i_{d1} i_{q1} - i_{q1}\Psi_{f2}] \tag{12}$$

$J_t$andJ_p : Total inertia of the turbine and the pump;f_t and f_p : Viscous friction coefficients of the turbine and pump;$T_t$and T_p: Turbine and pump torque respectively.

We rewrite in Cauchy form:

$$\begin{cases} \dfrac{di_{d1}}{dt} = \dfrac{1}{(L_{d1}+L_{d2})}\left(-(r_1+r_2)i_{d1} + \omega\left(L_{q1}+L_{q2}\right)i_{q1}\right) \\ \dfrac{di_{q1}}{dt} = \dfrac{1}{\left(L_{q1}+L_{q2}\right)}\left(-(r_1+r_2)i_{q1} - \omega[(L_{d1}+L_{d2})i_{d1} + \Psi_{f1} - \Psi_{f2}]\right) \\ \dfrac{d\Omega_t}{dt} = \dfrac{1}{J_t}\left(T_t - f_t\Omega_t - p[\left(L_{d1}-L_{q1}\right)i_{d1}i_{q1} + i_{q1}\Psi_{f1}]\right) \\ \dfrac{d\Omega_p}{dt} = \dfrac{1}{J_p}\left(pp[\left(L_{d2}-L_{q2}\right)i_{d1}i_{q1} - i_{q1}\Psi_{f2}] - T_p - f_p.\Omega_p\right) \end{cases} \tag{13}$$

And we can eliminate the third equation since $\omega_t = \omega_p = p_1.\Omega_t = p_2.\Omega_p = \omega \Rightarrow \Omega_t = \frac{p_2}{p_1}\Omega_p$

For the sizing of the two machines: the power of the second machine must be the efficiency of the first machine multiplied by the power of the first machine (the second < a little of the first).Either the two PMSMs have the power factor = 1, or one has cos(θ) in rear and the second in advance.

The transformations used are (Concordia + Park), shown in Fig.3.

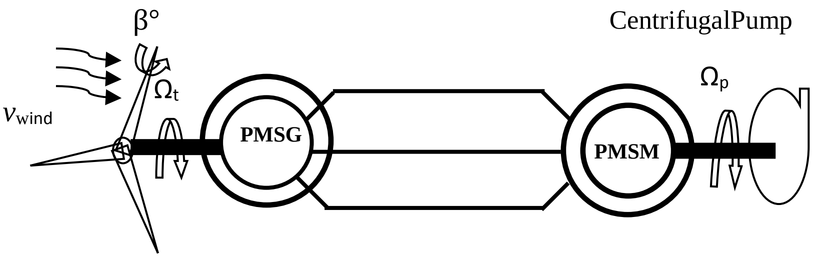


Fig.3. Global synoptic diagram of the studied system without electronics bay

6. CENTRIFUGAL PUMP MODELING

The operation of a centrifugal pump involves 3 parameters, height, flow andspeed.It opposes a resistant torque such as (Badran 2003; Evangelista et al., 2013):

$$T_r = K_r\Omega_p^2 + T_s \tag{14}$$

With: K_r: Proportionality coefficient; T_s: Static torque which is very small.

By neglecting the static torque (T_s) in equation (8), the resisting torque becomes:

$$T_r = K_r\Omega_p^2 \tag{15}$$

The mechanical and hydraulic powers of the pump are given by the following relationships (Ghennam et al., 2015):

$$P_{mec}=Kr\Omega p^3 \tag{16}$$

$$P_h = \rho . g . Q . H \qquad (17)$$

The pump efficiency is given by the following expression:

$$\eta_h = \frac{P_h}{P_{mec}} \qquad (18)$$

7. SIMULATION RESULTS

Simulation results are obtained with a wind profile shown in Fig.4 and with two synchronous machines with permanent magnets of powers 2.3 kW and 2 kW, generator and motor respectively.The wind profile used for the two systems, is shown in Fig. 4.

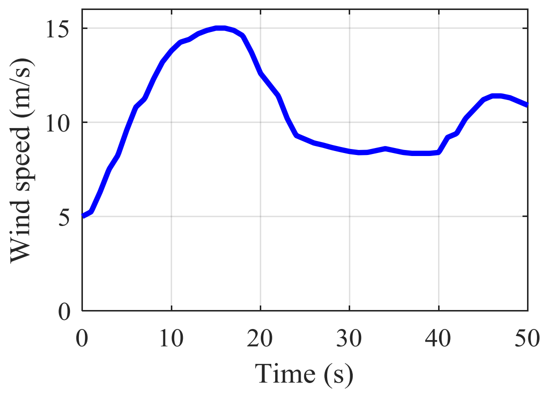
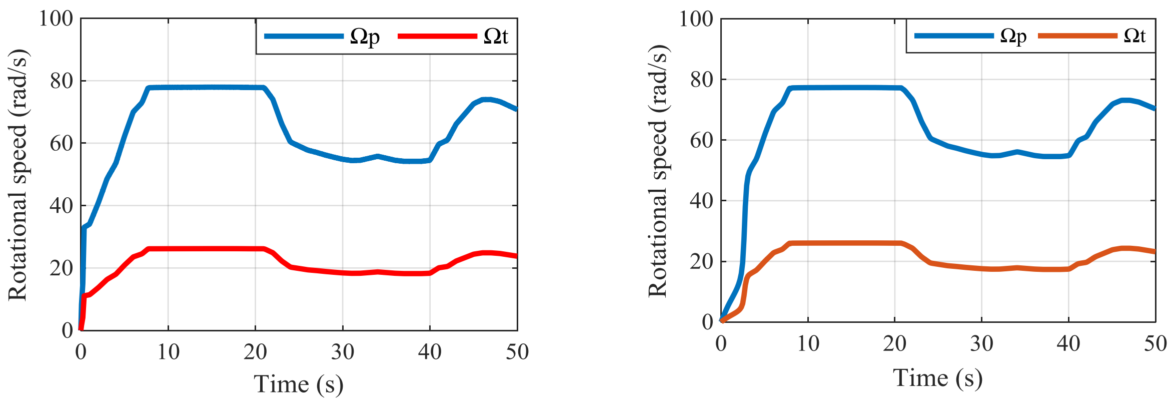


Fig.4. wind profile

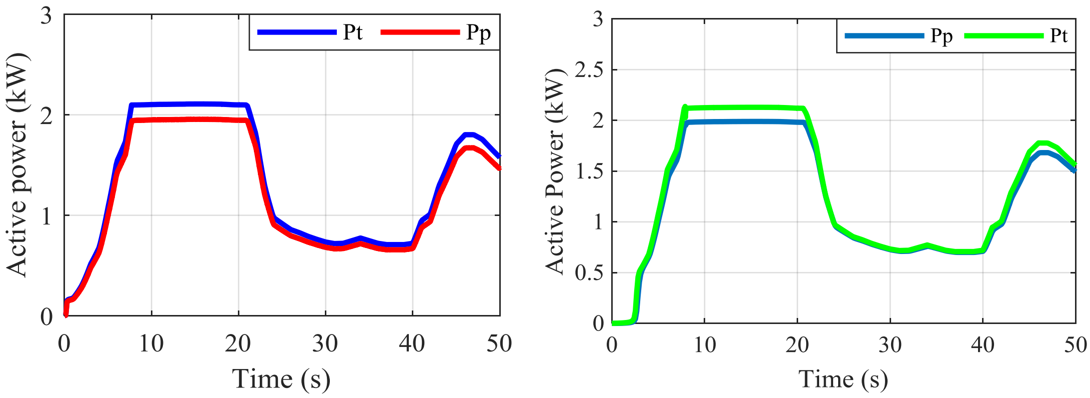
The dynamic behavior of the wind pumping system with the recommended static converter it'sconversely, the simulation results of the same pumping system without the static converter, all are depicted in Figs. 5 to 14.In Figs. 5-a, 5-b, the turbine and pump speeds are represented for the two cases. Also, the active power is shown in 6-a, and 6-b for each case.
It was noticed that these results, with and without a static converter, are practically similar. Fortunately, the speeds and powers are limited to their nominal values thanks to the pitch control of the blades, as illustrated in Figs. 7-a and 7-b.



(a) With using static converter

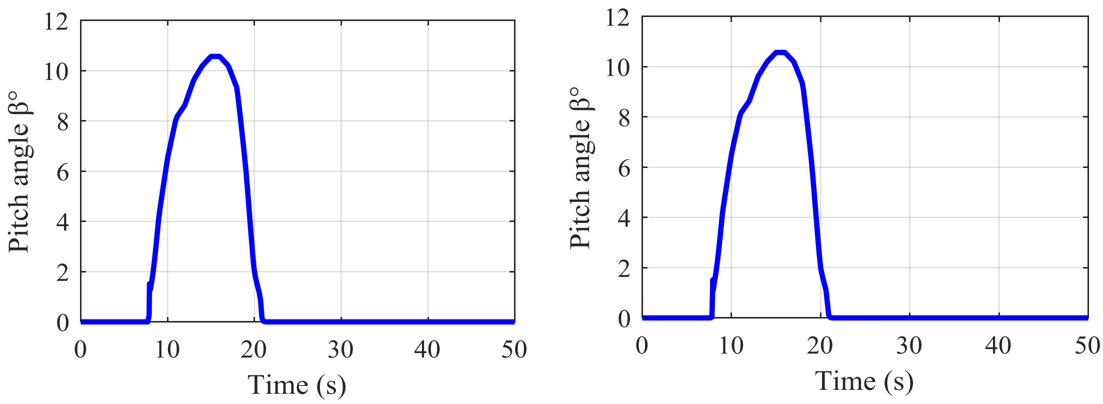
(b) Without static converter

Fig.5. Rotational speed (Rad/s)



(a) With using static converter (b) Without static converter

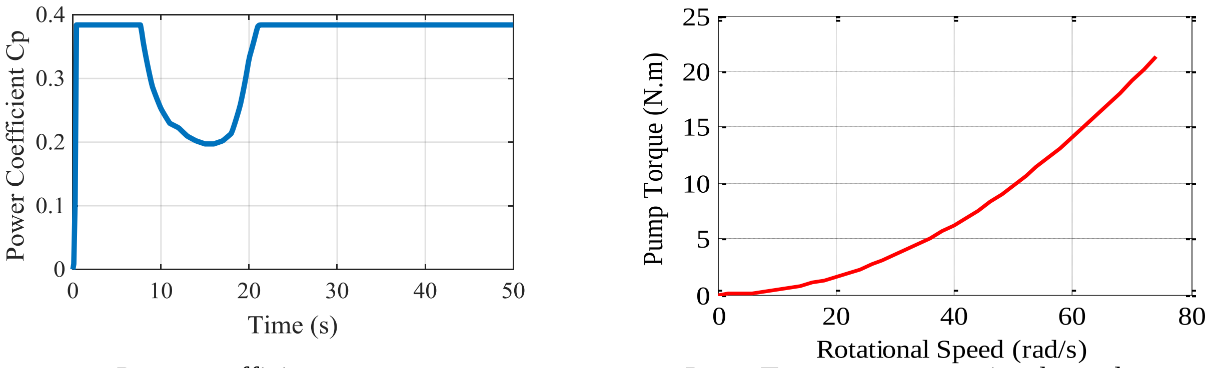
Fig.6 Active power



(a) Without using static converter (b) With static converter

Fig.7 Pitch angle

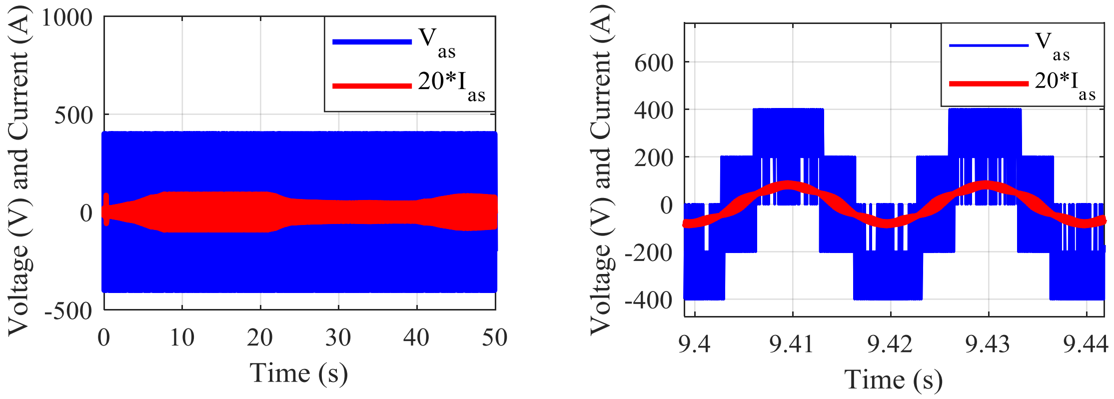
However, this leads to the degradation of the power coefficient over the speed and power limitation interval, as seen in Fig. 8-a and in Fig. 6-a respectively.The torque-speed characteristic of the operated centrifugal pump is shown in Fig. 8-b.



(a)Power coefficient (b)Pump Torque versus rotational speed

Fig.8 Power coefficient and Pump Torque versus rotational speed

The voltage and current levels supplying the pump motor with used a static converter are shown in figure 9.

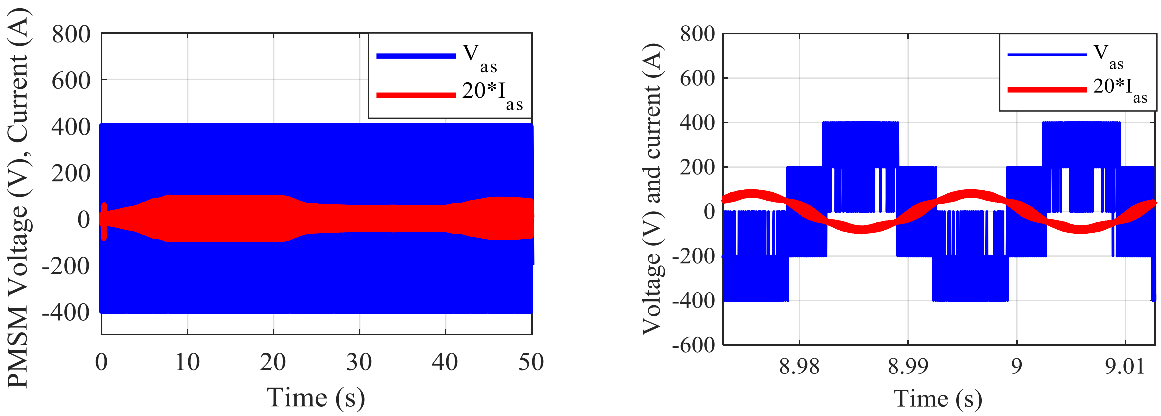


(a) Voltage and current waveforms; (b) zoom

Fig.9 Voltage and current levels supplying the pump motor with static converter

Zoom on a period represented in Fig. 9-b. It is noted that the current-voltage phase shift is less than 90°, confirming operation in motor mode.

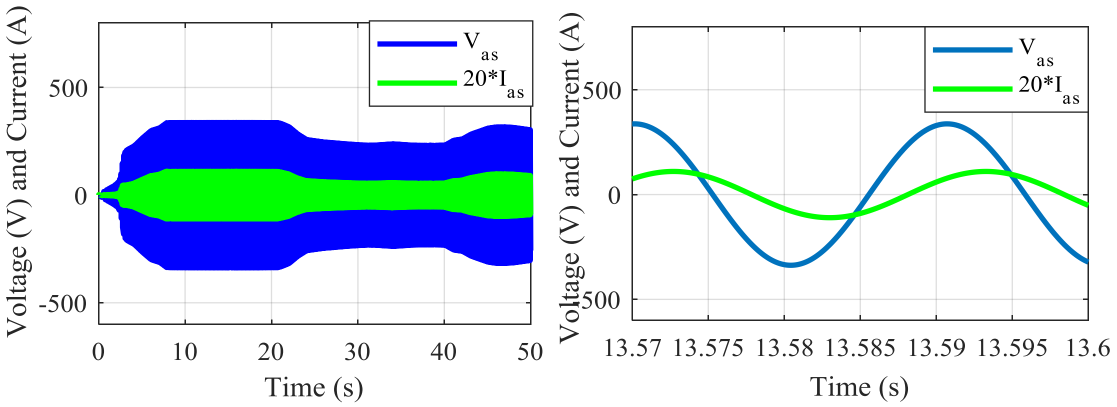
Conversely, in Fig. 10-a, the voltage and current levels generated by the permanent magnet generator are shown, with a zoom on a period in Fig. 10-b. Here, it is noted that the current-voltage phase shift is greater than 90°, confirming operation in generator mode.



(a) Voltage and current waveforms; (b) zoom

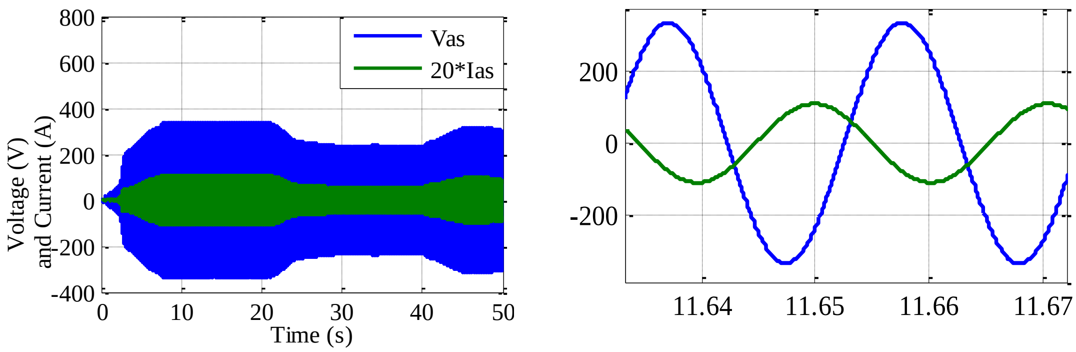
Fig.10 Voltage and current levels generated by PMSG with static converter

Similar observations without static converter,are made in Figs. 11-a and 11-b, voltage and current PMSM. Again, similar observations are made in Figs. 12-a and 12-b.voltage and current PMSG.



(a) Voltage and current waveforms (b) zoom

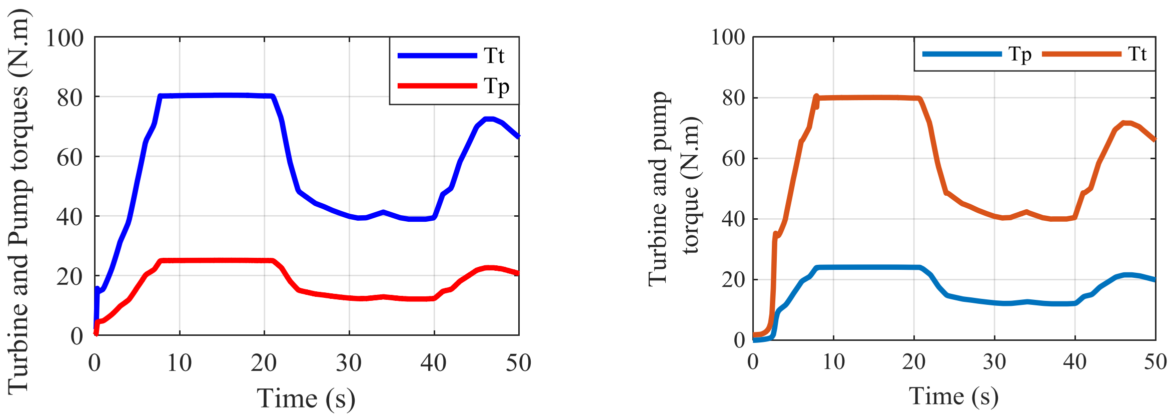
Fig.11.Voltage and current waveforms applied to the PMSM and its zoom without using static converter



(a) Voltage and current waveforms (b) zoom

Fig.12 Voltage and current waveforms generated by the PMSG and its zoom without using static converter

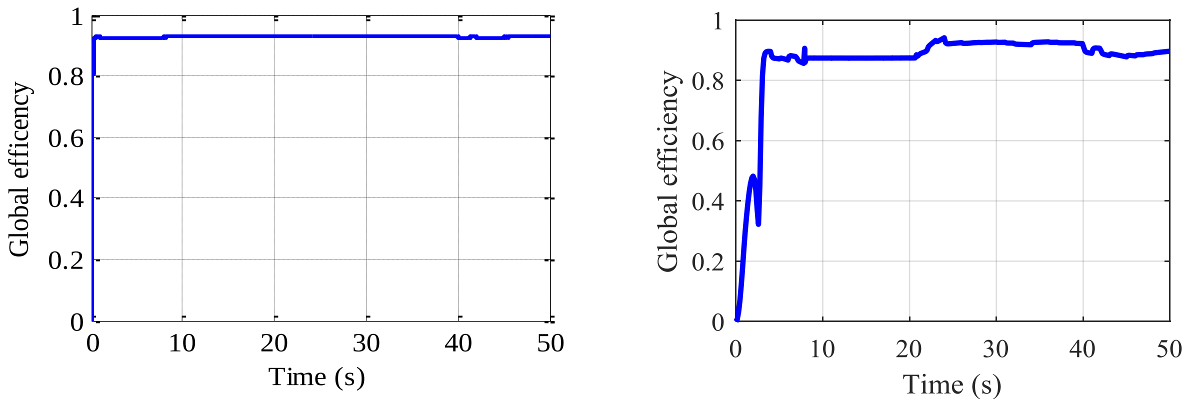
In Figs. 13-a and 13-b, the evolution of the torques developed by the turbine and the centrifugal pump are shown, with and without using a static converter respectively. And it is noted that the results are very close, demonstrating the effectiveness of pitch control in limiting the torques, thus protecting the studied pumping system.



(a) With static converter (b) Without static converter

Fig.13.Evolution of the torques developed by the turbine and the centrifugal pump

Finally, Figures 14-a and 14-b show the overall efficiency of the two wind pumping systems with (Fig. 14-a) and without (Fig. 14-b) the static converter. It was found that the performance results are practically close, with a very slight variation for the proposed case.



(a) With using static converter

(b) Without static converter

Fig.14.the overall efficiency of the two wind pumping systems

8. CONCLUSION

The objective of this research was to investigate the feasibility of eliminating the power electronics interface in a wind pumping system comprising two permanent magnet machines, while leveraging the torque-speed characteristic of the centrifugal pump. To achieve this, we simulated a wind pumping system based on pre-existing models and then developed a model without a power electronics bay. By applying the torque-speed characteristic of the centrifugal pump—appropriately selected to closely match the MPPT algorithm with a static converter—the system could maintain efficient operation.In this approach, the torque-speed characteristic serves as the adjustment characteristic, with the synchronous generator adhering to it, resulting in a master-slave operation mode. The simulation results for systems with and without a static converter were remarkably similar, showing a mere one percent difference. This confirms that the elimination of the static converter in the studied system is indeed feasible.

NOMENCLATURE

MPPT	Maximum power point tracking;	T_t[Nm]	Turbine torque
FOC	Flux oriented control;	T_p[Nm]	Pump torque
SC1	Static converter in side generator;	P_t[W]	Turbine Power
SC2	Static converter in side Motor;	P_p[W]	Pump power
PMSM	permanent magnets synchronous motor	p_1	Number of pole pairs PMSG
PMSG	permanent magnets synchronous generator	p_2	Number of pole pairs PMSM

Table 1. Internal parameters of the PMSM

Parameters	Values
Stator resistance r	$173.77.10^{-3}$ Ω
Direct inductance L_d	$0.8524.10^{-3}$ H
Quadrature inductance L_q	$0.9515.10^{-3}$ H
Rotor flux Ψ_{f1}	0.12 Wb

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