Control the Flywheel Storage System by Fuzzy Logic Associated with the Wind Generator

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Abstract- Conversion system of wind energy has become a focal point in the search for renewable energy sources. This article then exhibits a study of the overall operation of a wind generator to provide a constant power or variable the consumer demand while providing services system. In order to provide system services, we consider a variable speed wind turbine coupled to a double-fed induction generator (DFIG) combined with energy storage system. We consider the Flywheel Energy Storage System (FESS) based on fuzzy logic controlled by IM. Due to the use of power converters, The double fed induction Generator and the storage system are electrically coupled by a DC bus. Simulation results showing the benefits of using energy storage.

Keywords- Wind energy, Doubly Fed Induction Generator (DFIG), Induction Machine (IM), Flywheel Energy Storage System (FESS), Fuzzy logic Controller (FLC).

1. Introduction

Renewable energy is clean and inexhaustible, and since other energy sources are high-cost, several countries have encouraged researchers to study and develop systems of renewable energy conversion (solar, wind, etc ....). In, fact, renewable energy is developing rapidly worldwide; especially wind power is developed by many countries and is growing very important + 30% per year for 10 years [1, 2].

The wind generators are generators whose primary source of energy is the wind. It is well known that the wind has characteristics very volatile and unpredictable. Even if there are static assessments to predict the mean wind for a few days or for the whole year, wind speed changes very frequently and it is impossible to predict its value for a given time [3]. There is a strong contradiction between the operation of wind generators and operation of electrical networks:

- Wind generators are controlled in such a fate they extract maximum power from the wind in order to return without really considering the problems of adjustment and stability of the network,
- Network managers expect from a production Network managers expect from a production facility that does not disrupt the network and it participates in the management of it is to say, it provides system services.

The generation of wind power connected to the grid was generally regarded as "passive generator" because it was not directly involved in the system services (adjustment of voltage and frequency, islanding...).The penetration of distributed generation must be limited (20% or 30% of the power consumption according to some experience) in order to guarantee the stability of the network in acceptable conditions. Increase the penetration of wind power will be possible if this type of source: participates in the management of the network (system services), can operate stand-alone, this increased availability despite the unpredictability of the primary energy source [1, 4].

Due to the highly fluctuating and unpredictable wind, a wind alone can not participate in ancillary services. It is necessary to add energy storage systems can have an extra reserve of energy. To ensure balanced production/consumption, a storage system is proposed inertial type. There are several reasons for this choice: good dynamics, good performance, service life similar to the wind, etc. [2, 5] .The first wind generator was coupled directly to the network which requires a constant speed. The development of power electronics has made possible the coupling of wind generators to the grid through power electronic converters. This allows the turbine to operate at variable speed to extract maximum power in the wind [6].

In this paper a description of the study will be introduced in the first part. Then in a second part, we will explore in particular the modeling and control of the construction. Follows the model and the control of the FESS presented to the third party. The simulation results presented in the last Part.

Figure 1 shows the configuration of the generating system studied. The wind turbine is directly coupled to a DFIG with a rated power of 1.5MW. The rotor is connected to the DFIG through a power converter that provides variable speed operation. The grid side converter 2 is used to control the DC bus voltage and keep it constant regardless of the magnitude and direction of the power of the rotor. The rotor side converter 1 DFIG is used to generate optimal active power depending on wind speed and characteristics of the turbine. The presence of a DC bus allows easy connection of a storage unit consists of an asynchronous machine rated power 450kW.

2. Modelling of Wind Turbine

The aerodynamic power appearing at the turbine rotor, power coefficient and the ratio of speed are given by:

$$P_t = C_p(\lambda,\beta)P_v = C_p(\lambda,\beta)\frac{1}{2}\rho S v^3 \tag{1}$$

$$C_p(\lambda,\beta) = (0.5-0.00167(\beta-2))\sin[\frac{\pi(\lambda+0.1)}{18.5-0.3(\beta-2)}] -0.00184(\lambda-3)(\beta-2) \tag{2}$$

$$\lambda = \frac{\Omega_t R}{v} \tag{3}$$

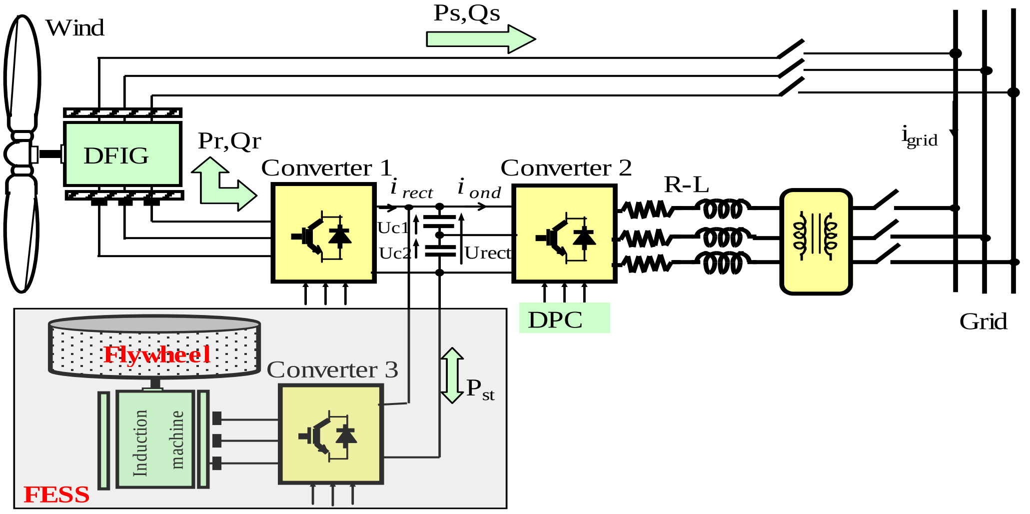


Fig. 1. System under study

The figure 2 shows the power coefficient as a function of λ for different values of pitch of the blades β. several curves are distinguished, but we are interested in one with the highest peak. This curve is characterized by the optimal point (λ_{opt}=9, C_{pmax}=0.5, β=2°) which is the point corresponding to the maximum power coefficient Cp and therefore the maximum mechanical power recovered is the mode MPPT [7]. The increase in β can degrade the coefficient Cp and thus cause the decrease in mechanical power recovered from the axis of the wind turbine. The relation (2) allows to deduce the characteristic related to a given wind speed, the power of the turbine according to its speed to β=2° as shown in figure 3.

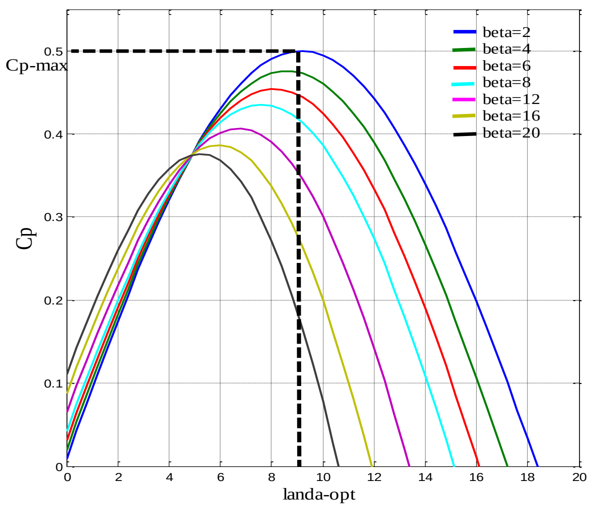


Fig. 2. Cp as a function of λ for different β

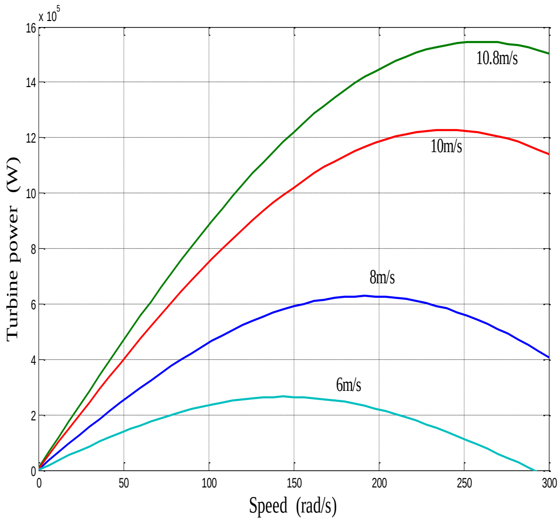


Fig. 3. Power-Speed characteristics of the wind turbine

3. Energy Storage Systems

With the aim to involve a variable speed wind turbine service systems, energy storageinertial type is considered, a flywheel mechanically coupled to an asynchronous machine and driven by a power converter as shown in figure 1. The energy Ev stored in the flywheel J_v to the expression:

$$E_V = \frac{1}{2} J_V \Omega_V{}^2 \tag{4}$$

To calculate the inertia of flywheel, Based on a power to be provided for a time Δt: we want the inertial storage furnish the rated power P_{masN} for a time Δt the energy required is then:

$\Delta E_V = P_{masN} \Delta t$. knowing that: $\Delta E_V = 1/2 J_V \Delta \Omega_V$ and that $\Delta \Omega_V^2 = \Delta \Omega_{VMAX}^2 - \Omega_{VMIN}^2$ it comes:

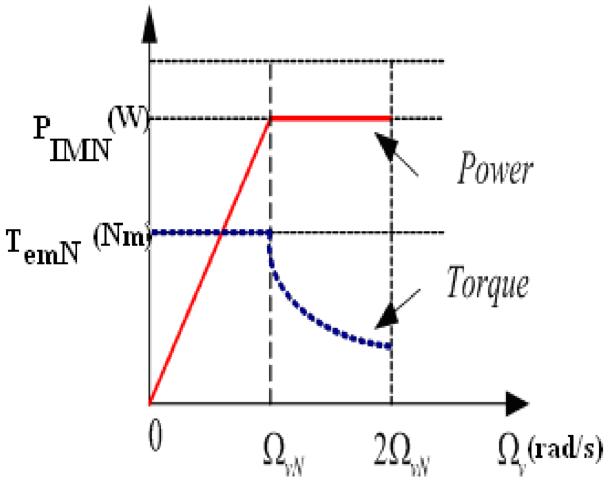
$$J_V = \frac{2 P_{masN} \Delta t}{(\Omega_{vMAX}^2 - \Omega_{vMIN}^2)} \tag{5}$$

According to equation (5) we find that when making a flywheel for an FESS, there are two initial conditions which must be considered: The maximum speed of rotation of the flywheel and the ability the flywheel. The asynchronous machine is chosen according to these benefits in terms of simplicity and robustness of the rotating parts, its model in the reference of PARK, with the rotor flux orientation (Φ_{qr}=0 and $\Phi_{dr}=\Phi_r$), can be described by the following equations:

$$\begin{cases} \frac{d\Phi_{dr}}{dt} = -\frac{R_r}{L_r}\Phi_{dr} + (\omega_s - p\Omega)\Phi_{qr} + \frac{MR_r}{L_r} i_{ds} \\ \frac{d\Phi_{qr}}{dt} = -\frac{R_r}{L_r}\Phi_{qr} - (\omega_s - p\Omega)\Phi_{dr} + \frac{MR_r}{L_r} i_{qs} \\ \frac{di_{ds}}{dt} = \frac{MR_r}{\sigma L_s L_r^2}\Phi_{dr} + \frac{Mp\Omega}{\sigma L_s L_r}\Phi_{qr} - \frac{R_{sr}}{\sigma L_s} i_{ds} + \omega_s i_{qs} + \frac{1}{\sigma L_s} v_{ds} \\ \frac{di_{qs}}{dt} = \frac{MR_r}{\sigma L_s L_r^2}\Phi_{qr} - \frac{Mp\Omega}{\sigma L_s L_r}\Phi_{dr} - \frac{R_{sr}}{\sigma L_s} i_{qs} - \omega_s i_{ds} + \frac{1}{\sigma L_s} v_{qs} \\ T_{em-ref} = \frac{pM}{L_r}\Phi_{dr} i_{qs} \end{cases}$$

(6)

Two areas of operation for the electrical machine shown in figure 4 [4,6].



- For $0 \leq \Omega_v \leq \Omega_{vN}$ the nominal torque of the machine is available, but the maximum power is variable, depending on the speed (P_{IM}=K Ω_v), and smaller than the nominal power. This area does not have much interest in FESS.
- For Ωv > ΩvN, the power is a maximum and corresponds to the nominal power of the machine, the electromagnetic torque is inversely proportional to the speed of rotation (Tem=K/Ωv). This is the area of operation used in FESS because here the power of the machine is available for any speed.

The induction machine with inertial storage will be used in the speed range below $\Omega_{vN} \leq \Omega_v \leq 2\Omega_{vN}$. Thus allowing operation at rated power constant. From a reference power P_{v-ref}, one can deduce the torque electromagnetic reference of the machine, Tem-ref, causing the flywheel by a measure of the speed of rotation, Ω_{v-mes}.

$$T_{em-ref} = \frac{P_{v-ref}}{\Omega_{v-mes}} \tag{7}$$

The electromagnetic torque reference shall be limited to nominal torque for the speed range including between 0 and the nominal speed, beyond the rated speed, the torque will decrease in order to keep the product $T_{em-ref}.\Omega_v$ constant. The torque reduction is carried out by the defluxing of the machine beyond the synchronous speed. Weakening of the law is as follows:

$$\Phi_{dr-ref} = \frac{P_{v-ref} L_r}{pMi_{qs}} \frac{1}{\Omega_{v-mes}} \quad (8)$$

The flux estimate is given by the following equation:

$$\Phi_{dr-estimé} = \frac{M}{1+\frac{L_r}{R_r}S} i_{ds-mes} \quad (9)$$

Figure 5 shows the block diagram of the control of FESS the currents ids-ref and i_{qs-ref} are determined by the flow regulator for the d-axis current, and the electromagnetic torque reference for the q-axis current. The electromagnetic torque being calculated from equation (7), the quadrature current is determined by inverting the torque equation (6).

4. Simulation Result

The simulation results shown in figures 6,7,8 and 9 illustrates the operation of the storage system inertial. The value of the inertia coefficient was calculated for a speed range between 157rad/s and 314 rad/s, and a rated power of 450kW during a time corresponding to 5s. The initial velocity of the steering wheel is fixed 157rad/s. When the storage reference power P_{v-ref}, is set at 450kW, the speed increases of 157rad/s to 314rad/s. the system stores energy. When the power is fixed to -450kW, the speed decreases of 314rad/s to 157rad/s. The system provides active and reactive energy as shown in figures 6 and 7. The components of the rotor flux direct and quadrature of the induction machine are shown in figure 8. The quadrature component is always zero, which justifies the rotor flux oriented control. The two types of PI controller and fuzzy logic are used in the control vector machine is used to display the capabilities and performance of each of them. The two regulators perfectly follow the reference trajectory with a time of rethinks picked up by the fuzzy controller better than that of conventional regulator. The electromagnetic torque is shown in figure 9, allows maintaining constant power, because the speed of the machine is greater than the synchronous speed.

The main function of the FESS is to smooth the power output of the wind generator which can cause several problems in the network. To reduce has minimum the fluctuations of this power; FESS should ensure compensation for variations in wind power. The reference power of FESS is determined by the difference between the power generated by the wind generator P_{wind} and the power it takes to deliver network or on isolated loads P_{regl}, according to the principle illustrated in figure 10.

$$P_{v-ref} = P_{régl} - P_{wind} \quad (10)$$

If the reference power is positive, is that there is a surplus of energy to be stored. If the reference power is negative, there was an energy deficit that must be covered by the stored energy.

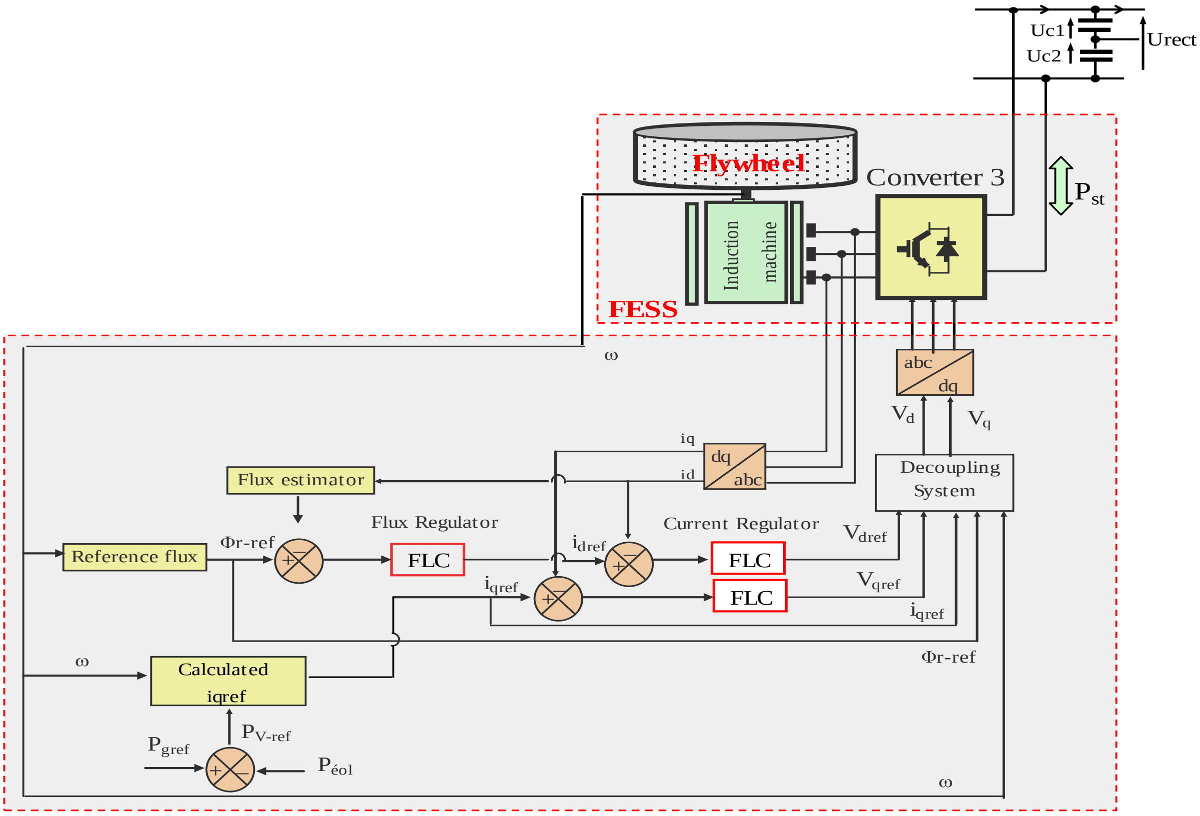


Fig. 5. Block diagram of the control system of inertial storage

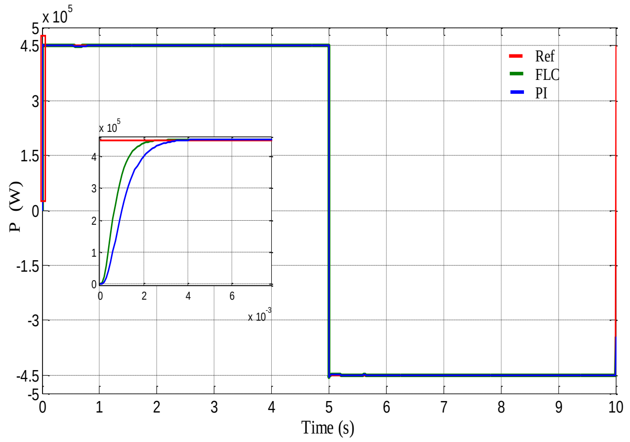


Fig. 6. The power delivered or absorbed by the IM

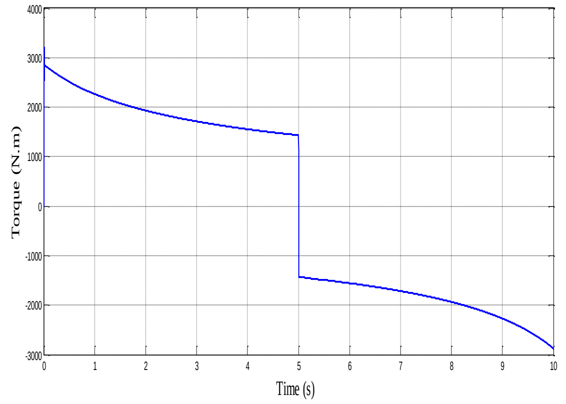


Fig. 9. The electromagnetic torque

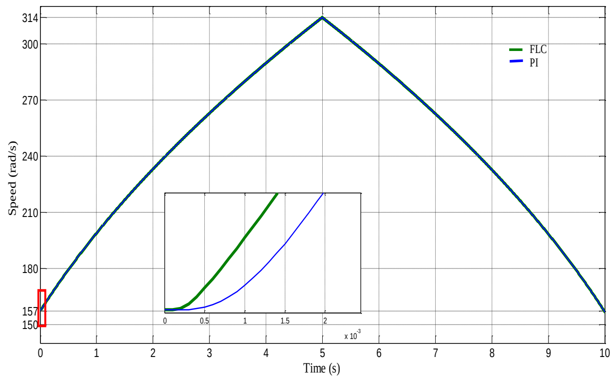


Fig. 7. Speed of the flywheel

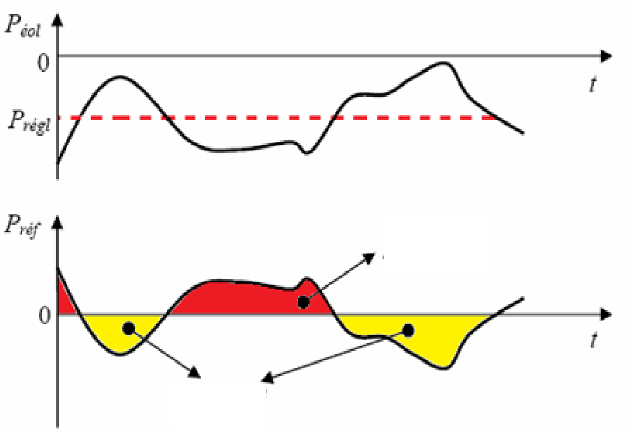


Fig. 10. Principle of FESS associated with wind generator

In what follows we showed the simulation results of the association of FESS with an induction machine of 450kW to 1.5MW wind turbine. The figures 12, 13, 14, 15 and 16 shows the simulation results when the grid requires a constant power of 1MW with the wind profile applied as shown in figure 11.

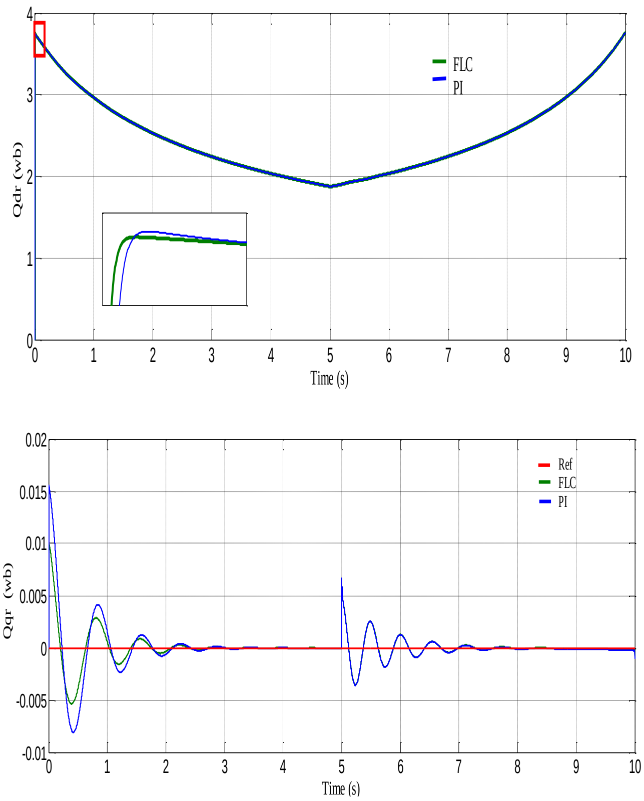


Fig. 8. The flow of direct and quadrature axis

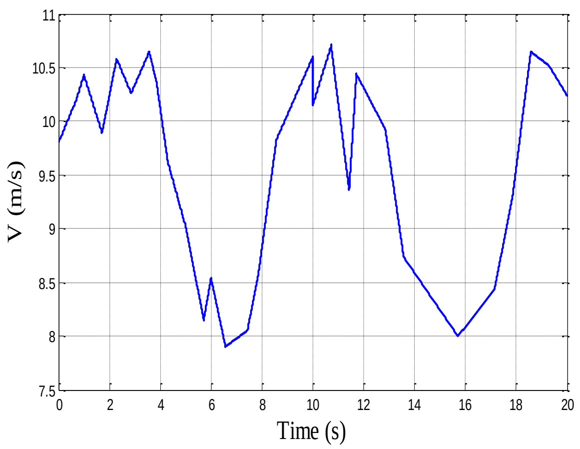


Fig. 11. Wind speed

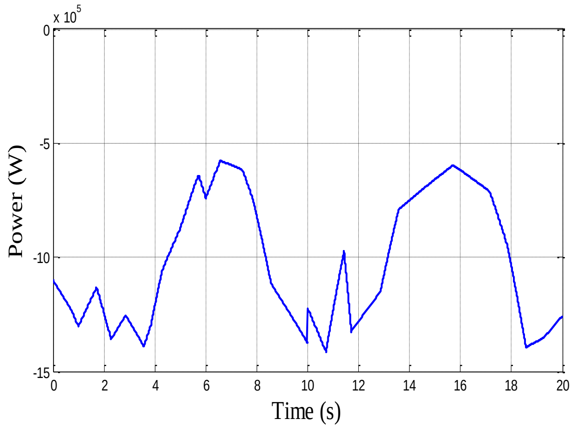


Fig. 12. Power delivered by the wind

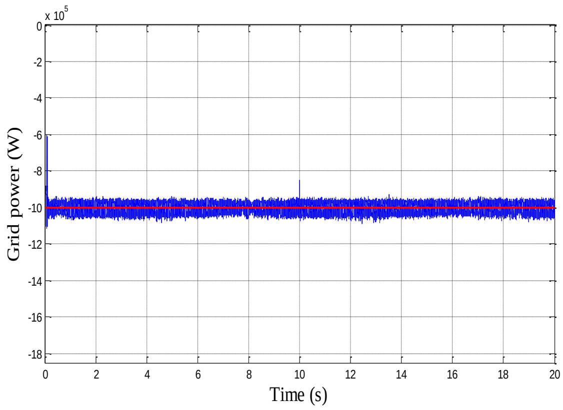


Fig. 13. Power delivered to the network

In both cases the setting of the DC bus is provided by the three-level inverter rated network is kept constant. The figure 15 corresponds to the power storage unit. This power can be positive or negative depending on wind conditions that allow the charging or discharging, it is limited to 450kW. When the reference power is positive, FESS stores electric energy the speed flywheel increases. FESS captures the electric power when the reference power becomes negative decreases the speed of the steering wheel as shown in figure 14.

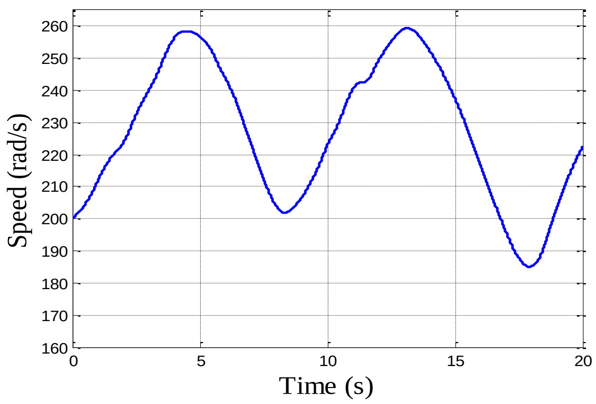


Fig. 14. Speed of the flywheel

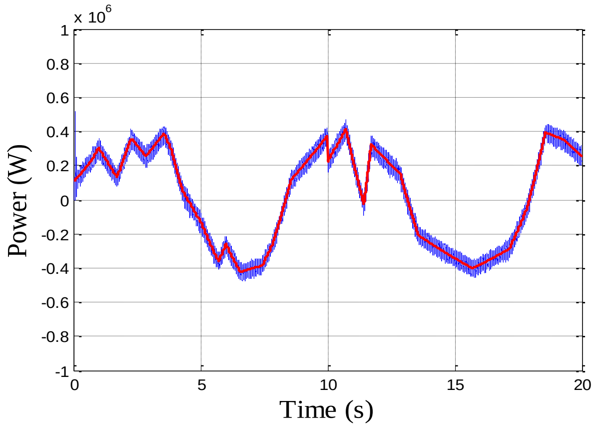


Fig. 15. Electric power of the FESS

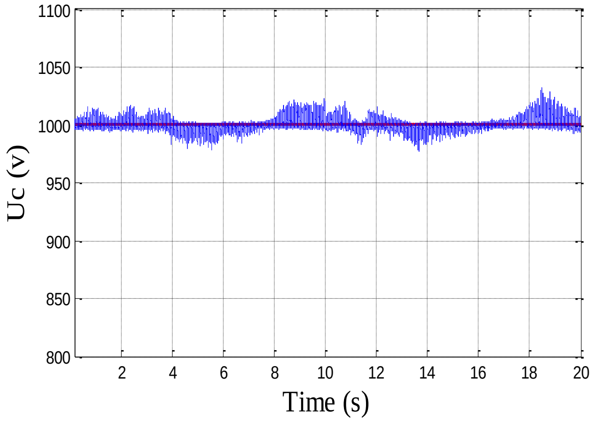


Fig. 16. The DC bus voltage

5. Conclusion

In this paper, a solution for that generation systems, based on wind associated with the inertial energy storage, can participate in the network settings is presented. The FESS is controlled by a reference power obtained as a function of the power generated and power to be sent to network constant or variable. The DC bus or are connected to the DFIG and the FESS can work with a variable speed wind turbine and decouple the interaction between machines and the network.

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