

Artificial Neural Networks Applied to a Wind Energy System



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Abstract: In this context, we are taking a close interest in the optimization of wind energy production. It consists in designing simple to implement control strategies of a wind energy conversion system, connected to the network based on the Double Fed Induction Generator (DFIG) driven by the Converter Machine Side (CSM) in order to improve the performance of Direct Torque Control (DTC) and Direct Power Control (DPC). For this purpose, the artificial neural networks (ANNs) is used. Hysteresis comparators and voltage vector switching tables have been replaced by a comparator based on artificial neural networks. The same structure is adopted to build the two neural controllers, for the DTC - ANN and for the DPC - ANN. The simulation results show that the combination of classical and artificial neural network methods permit a double advantage: remarkable performances compared to the DTC-C and DPC-C and a significant reduction of the fluctuations of the output quantities of the DFIG and especially the improvement of the harmonics rate currents generated by the machine.

Keywords: MPPT, wind energy, DFIG, Artificial Neural Network, optimization.

I. INTRODUCTION

The latest generation of wind turbines operate at variable speed. This type of operation increases energy efficiency, reduces mechanical loads and improves the quality of the electrical energy produced. Compared to fixed speed wind turbines, it is the control algorithms that allow the active and reactive power produced by the wind turbine to be controlled at all times. In this paper, we study the direct control of torque and power based on artificial neural networks (ANNs), in order to obtain a robust control that increases reliability, improves energy efficiency, and with the little interference

that it generates, limits the conventional mechanical stress. The conventional control selection table (DTC-C and DPC-C) are replaced by a simple neural controller in order to obtain a fixed switching frequency, which leads us to a considerable reduction of the harmonic rate currents in both cases proposed as the DTC-ANN and the DPC - ANN. The neural network architecture proposed for the implementation of DFIG DTC-ANN and DPC- ANN consists of a single MLP (Multi Layered Perceptron) neural network with a single hidden layer, using a Levenberg- Marquardt back-propagation algorithm to perform learning. Simulations are carried out to evaluate the proposed techniques in terms of trajectory tracking, robustness to parametric variations and reduction of the harmonic rate currents.

II. DIRECT NEURAL TORQUE AND POWER CONTROL OF THE DFIG

A. Direct Neural Torque Control (DTC-ANN)

The structure of the Direct Neural Torque Control (DTC-ANN) of the DFIG is shown in Figure 1, whose hysteresis comparators and switch table are replaced by a neural controller, and whose inputs are the torque error εC_{em} , the flux error $\varepsilon \Psi_r$, and the position (zone) of the rotor flux $Z(i)$; the outputs are the pulses S_a, S_b, S_c for controlling the inverter switches.

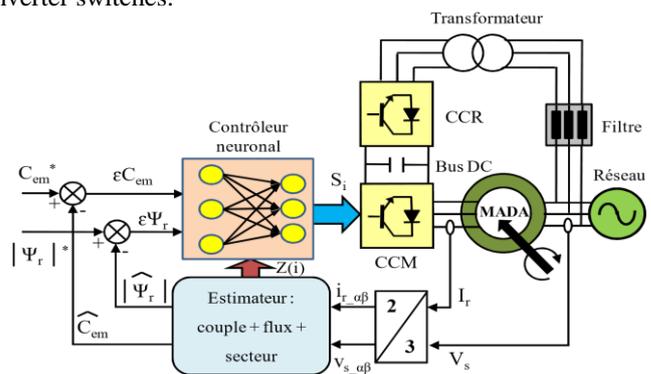


Figure 1 – Direct Torque Control of DFIG based on ANNs.

According to the tests carried out on the different structures, we found that the most judicious choice was to take a multilayer neural network architecture with a 3-35-3 structure, i.e. a MLP with 3 layers, an input layer containing 3 neurons, a single hidden layer containing 35 neurons and an output layer also containing 3 neurons, using respectively the activation functions: 'logsig', 'tansig' and 'purelin' (figure 2).

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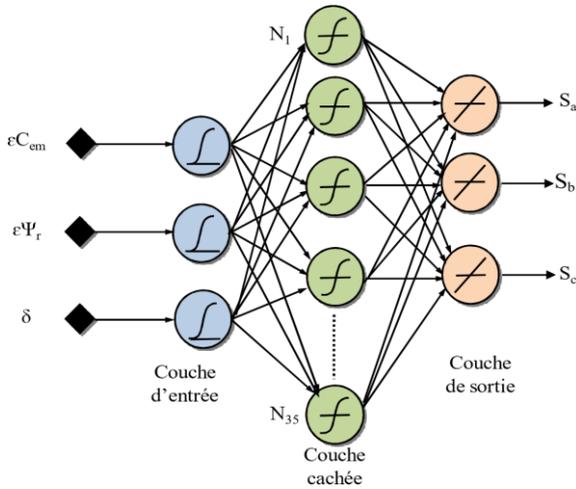


Figure 2 –The Architecture of the ANN-MLP with 3-35-3 Structure Used

Updating the weights and biases of this network is carried out by a back-propagation algorithm called Levenberg-Marquardt (LM) algorithm. In order to validate the proposed control strategy (DTC- ANN), two simulation tests are performed under the same operating conditions as the DTC-C. Figure 3 shows the simulation results corresponding to the first test. Figure 3-a shows the electromagnetic torque response of the DFIG with a significant reduction in ripple. In the transient state the torque response is very fast and in the steady state it stabilizes towards its reference value with a low static error (with precision) as shown in figure 3-b. We can also see in figures 3-c and 3-d that the rotor flux follows perfectly its reference with a significant reduction of its ripples. The stator current has a sinusoidal shape with fewer peaks at start-up as shown in figures 3-e and 3-f. The rotor current also has a sinusoidal shape with less fluctuation compared to the DTC-C, which is necessary for a good estimation of the torque. Figure 4 is used to verify the transition from hypo synchronous to hyper-synchronous mode in DFIG operation.

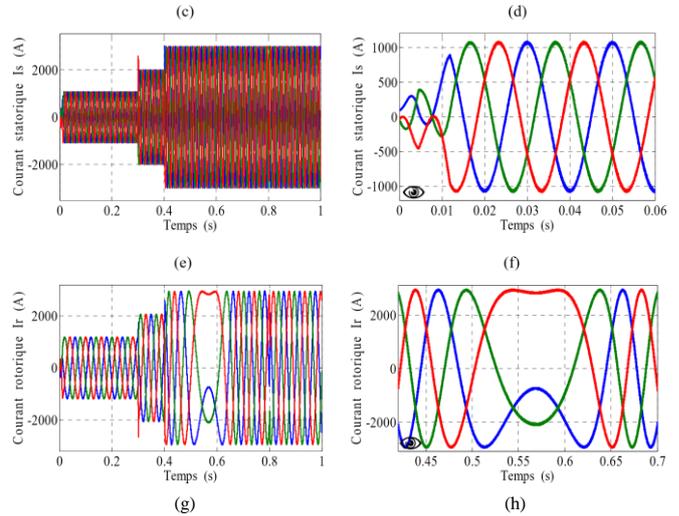
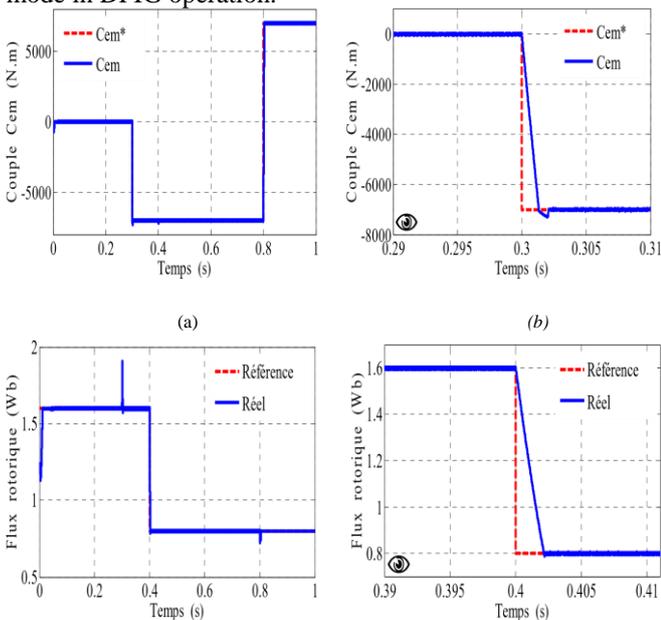


Figure 3– Simulation results of the DTC-ANN Control Applied to DFIG

The second test aims to test the robustness of the DTC-ANN control with respect to the variation of the DFIG parameters, so we will perform a simultaneous variation of 10% of the mutual inductance ($0,9 \times L_m$). The most important quantities are the electromagnetic torque and the rotor flux. Based on the results obtained, it can be concluded that the DTC-ANN has a strong robustness in the presence of the DFIG parametric variations. Despite the presence of a slight increase in the system response time, decoupling is still maintained between torque and flux, because this control strategy is less dependent on the machine parameters.

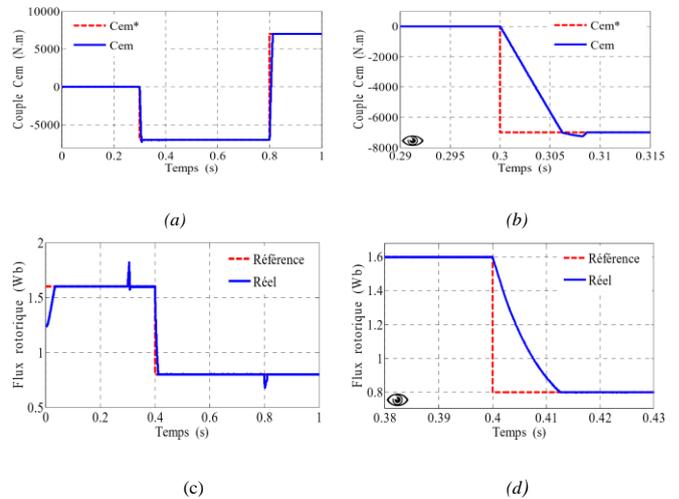


Figure 4 – DTC-ANN with respect to the Parametric Variations of DFIG.

The second goal of using the DTC-ANN strategy in the DFIG control after the robustness of the control, was the reduction of torque and flux oscillations, i.e. the decrease of the harmonic ratio of the currents. In this observation, Figure 5, gives the results obtained from the spectral analysis of the DTC - ANN strategy currents, namely the stator current (Figure 5.a), the rotor current (Figure 5.b).

These results show that the DTC-ANN provides a better quality of the waveform of the stator and rotor currents, where the harmonic ratio (THD) of the rotor current is only 30.76% compared to 78.14% in the case of DTC - C.

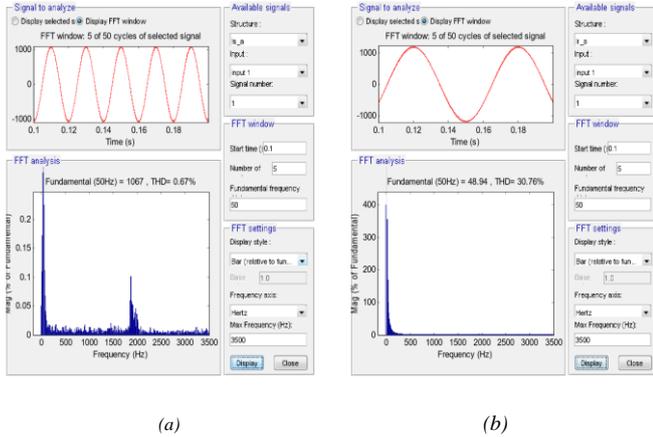


Figure 5– Harmonic analysis of current spectra: (a) stator phase, (b) rotor phase.

B. Direct Neural Power Control (DPC - ANN)

The structure of the Direct Neural Power Control (DPC - ANN) of DFIG is shown in Figure 6.

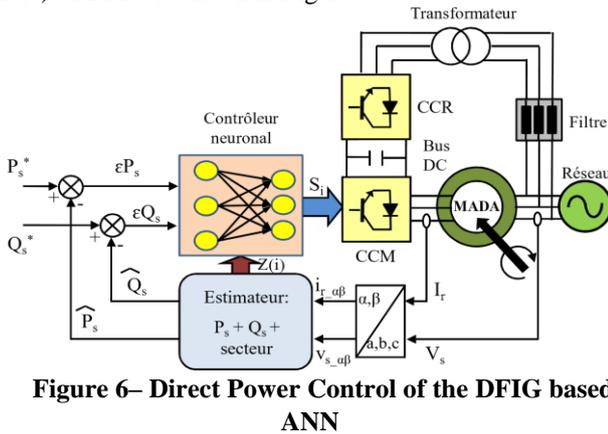
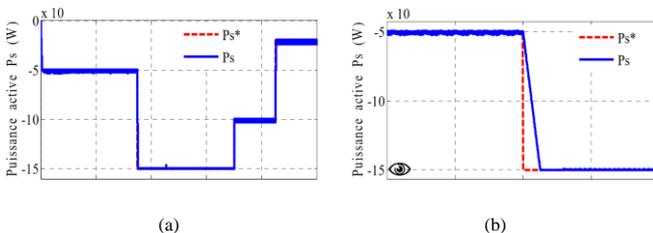


Figure 6– Direct Power Control of the DFIG based ANN

The hysteresis comparators and the switch table of the DPC-Classic (DPC-C) are replaced by a neural controller, whose inputs are the error of the active power ϵP_s , the reactive power ϵQ_s , and the position (zone) of the rotor flux $Z(i)$; and the outputs are the pulses S_a, S_b, S_c allowing the control of the inverter's switches. Adopting here the same neural network used for the DTC-RNA control strategy. In order to test the performance of this proposed control strategy, two simulation tests are performed under the same operating conditions as the DPC - C presented in chapter 5.



(a) (b)

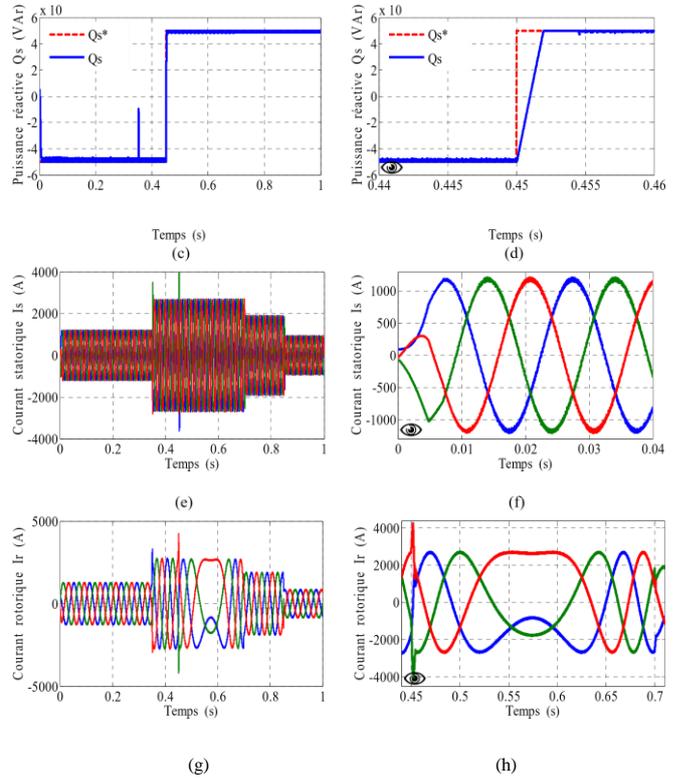


Figure 7– Simulation Results of the DPC-ANN Control Applied to DFIG.

- 1) Test of setpoint tracking
- 2) Robustness test

Hence, Figures 7 and 8 present the simulation results of the first and second tests respectively.

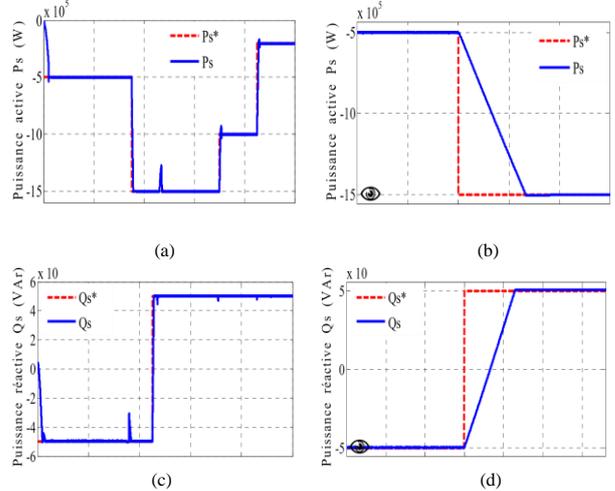


Figure 8 – The DPC-ANN vis à vis the parametric variations of DFIG

The results in Figure 7 show good dynamic and static performance, such as a very fast response time with no overshoot and minimal static error for both active power (Figure 7a and 7b) and reactive power (7c and 7d). Furthermore, the results obtained show that the stator (Figure 7e and 7f) and rotor currents (Figure 7g and 7h) have sinusoidal shapes with fewer ripples, which means a good quality of power supplied to the network.

The results of the robustness test are shown in figure 8, the most important quantities are the active reactive power. In transient states, we can notice a slight increase in the response times of both powers, but the decoupling is always kept between the two powers with a very low static error, despite the parametric variations of the DFIG. This allowed us to show the efficiency of the proposed control strategy (DPC-ANN). However, the spectral analysis of the current harmonics presented in Figure 9, shows almost the high performance, in terms of reduction of the current harmonics rate (THD). The THD of the rotor current is estimated at 68.18% for the DPC- ANN versus 68.37% for the DPC-SVM.

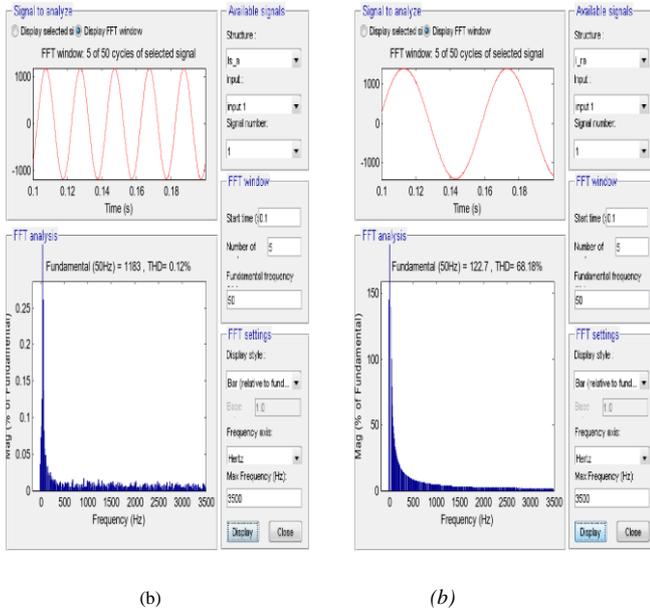


Figure 9 – Harmonic analysis of current spectra: (a) stator phase, (b) rotor phase.

III. CONCLUSION

Neural networks are powerful techniques for nonlinear data processing that have proven successful in many fields. These tools allow the computation of complex functions, adaptable to a set of examples through optimization algorithms using different learning techniques. In the first part, we have presented some essential elements that allow us to understand why, and in which cases, it is advantageous to implement artificial neural networks (ANNs). In the second part of the chapter, artificial neural networks are combined with classical DTC and DPC to obtain two new control strategies (DTC-ANN and DPC-ANN) that meet the control requirements predefined in this paper. This means robust, reliable control strategies, capable of improving the energy efficiency on the DFIG driveshaft (DTC-ANN objective); and help to improve the quality of power supplied by DFIG to the power grid (DPC-ANN objective). Simulation results have shown that the application of neural networks provides a good torque and flux response for DTC-ANN and power gives a good torque and flux response for DTC-ANN and active and reactive power for DPC-ANN. The ripples in torque and power are less compared to conventional techniques, which is reflected in the quality of the currents generated by DFIG.

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