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The DTC with ANN of a DFIG Driven by a WECS

S.Bouhafna [1], I.Toumi,[2] S. Benaggoune [3] B. Maghni [4]
[1,3]Faculty of technology, department of electrical engineering, University of Batna
street of mohamed el-hadi boukheloufe Batna –ALGERIA-
[2,4]Faculty of technology, department of electrical engineering, University of Ouargla
street of ghardia,bp.511,3000 Ouargla –ALGERIA-

Abstract:- This paper treats the modeling of a wind energy conversion system connected to the grid, which is composed of a horizontal axis wind turbine operating at variable wind speeds, a doubly- fed induction generator and two converters (AC / DC and DC / AC) controlled by direct torque control (DTC) with application of neural networks. The results of simulations of the studied system are presented in the Matlab / Simulink environment.

***Keywords*:-** *Wind Turbine; DFIG; (DTC); artificial neural networks (ANN).*

I. INTRODUCTION

To produce electrical energy using a wind energy conversion system (WECS), various control strategies should be developed in the literature The most widely used control techniques are the vector control (VC) and the direct control techniques. All these techniques aim to bring down the cost of electrical energy produced by the WECS and to converge the system for operating at unity power factor. For the rotor side converter (RSC), the VC strategy which guarantees high dynamics and static

Performance through an internal current control loops, has attracted much attention in the past few decades. However, the performance of the VC largely depends on the design of the current controllers and the tuning of their parameters. Direct Control eliminates the need for current regulators and specific modulations. DTC provides direct control of machine's torque and flux This approach achieves better steady state and transient torque control conditions, but it is penalized by the electromagnetic torque noises and the high switching frequency. The grid side converter (GSC) can also be controlled by VC technique. This method gives high static performances [2, 3]. DTC strategy is one of the interesting control strategies, as an alternative to vector control for induction machines. The advantages of this technique are the fast dynamic response, the very low use of machine parameters and fairly simple control. The schematic diagram Fig. 1 of a system composed of mechanical and electrical parts with a control which has proposed [4, 7].

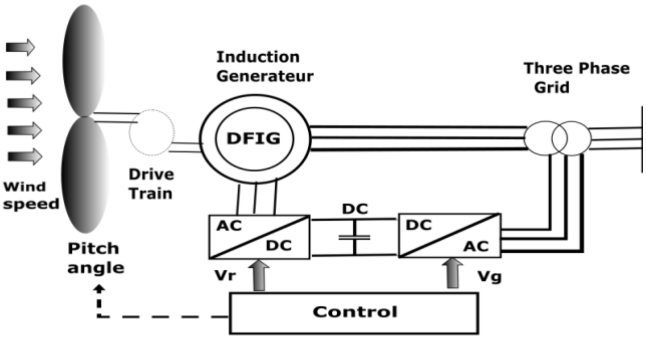


Fig 1:- Global structure of WECS

II. THE CONVERSION SYSTEM MODELING

- *Wind modeling:*

The mathematical model of wind is given by [14]:

$$V(t) = 8 + 0.2\sin(0.1047.t) + 2sin(0.2665.t) + 0.2\sin(3.6645.t) \qquad (1)$$

- *Turbine modeling:*

The mathematical model of power of wind turbine is given by : [7,4]:

$$P_{aer} = \frac{1}{2}\rho.R^2.V^3. \qquad (2)$$

The equations (3 and 4) given respectively the aerodynamic power and torque of wind turbine [1,9] :

$$P_{aer} = \frac{1}{2}\rho.R^2.V^3.C_p(\lambda,\beta) \qquad (3)$$

$$T_{aer} = \frac{P_{aer}}{\Omega_t} = \frac{1}{2}\rho.\pi R^2.V^3.C_p(\lambda,\beta).\frac{1}{\Omega_t} \qquad (4)$$

Where: ρ : $is\ a$ air density power coefficient
R: $is\ a$ radius of the turbine
V:$is\ a$ wind speed:
λ:$is\ a$ the tip speed ratio
β: $is\ a$ blade pitch angle

The power coefficient C_p of the wind turbine is given as:

$$C_p(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta. -5\right)e^{\frac{21}{\lambda_i}} + 0.0068\lambda \qquad (5)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1} \qquad (6)$$

$$\lambda = \frac{R\Omega_t}{V} \qquad (7)$$

Where Ω_t is the wind turbine speed.
The limit of BETZ:
$C_p(\lambda,\beta) = \frac{P_m}{P_{wind}} = \frac{16}{27} = 0.593$

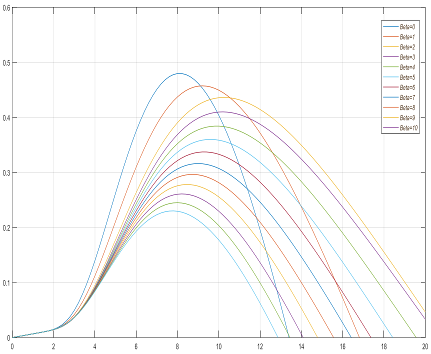


Fig 2:- The Coefficient power Cp=f(λ).

The C_{p-max} as depicted in Figure 2.We have to maintain the tip speed ratio at its optimal value, $C_p = 0.48$ and β should be equal to 0.[10,11] Fig. 2.

The gearbox is given by the two following equations:

$$T_m = \frac{T_{aer}}{G} \qquad (8)$$
$$\Omega_t = \frac{\Omega_m}{G} \qquad (9)$$

Where: T_m generator torque
T_{aer} Turbine torque

The relationship between torque and speed is written:

$$T_g - T_{em} = J\frac{d\Omega_{mec}}{dt} + f.\Omega_{mec} \qquad (10)$$

Where: J: the moment of inertia
f: the friction coefficient

- *Modeling of the DFIG:*

the stator and rotor voltage equations of the DFIG are written: [4,5,6,8,12]:

$$\begin{cases} V_{ds} = R_s.I_{ds} + \frac{d\varphi_{ds}}{dt} - \omega_s.\varphi_{qs} \\ V_{qs} = R_s.I_{qs} + \frac{d\varphi_{qs}}{dt} + \omega_s.\varphi_{ds} \\ V_{dr} = R_r.I_{ds} + \frac{d\varphi_{dr}}{dt} - \omega_r.\varphi_{qr} \\ V_{qr} = R_r.I_{ds} + \frac{d\varphi_{qr}}{dt} + \omega_r.\varphi_{dr} \end{cases} \qquad (12)$$

$$\begin{cases} \varphi_{ds} = L_s.I_{ds} + MI_{dr} \\ \varphi_{qs} = L_s.I_{qs} + MI_{qr} \\ \varphi_{dr} = L_r.I_{dr} + MI_{ds} \\ \varphi_{qr} = L_r.I_{qr} + MI_{qs} \end{cases} \qquad (13)$$

The torque T_{em}can be written as follows [6]:
$$T_{em} = -\frac{3}{2}p\frac{M}{L_r}(\varphi_{ds}.I_{qr} - \varphi_{qs}I_{dr}) \qquad (14)$$

Generator active and reactive powers at the stator side are given by the expressions:
$$P_s = \frac{3}{2}(V_{ds}.I_{ds} + V_{qs}.I_{qs}) \qquad (15)$$
$$Q_s = \frac{3}{2}(V_{qs}.I_{ds} - V_{ds}.I_{qs}) \qquad (16)$$

III. DTC PRINCILES FOR DFIG

Figure 3 shows the DTC diagram of the DFIG. in the stator is directly connected to the grid and the rotor is powered by two converters which also connected to the grid. The main objective of the DTC is to directly control the rotor flux and the electromagnetic torque of the DFIG by choosing the best voltage vector [1,6,10,13]

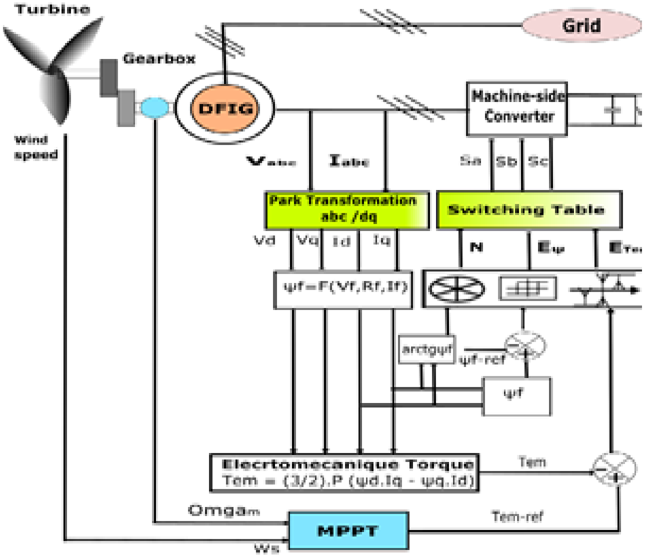


Fig 3:- The diagram DTC of the DFIG

As shown in Fig. 4, the position of the rotor flux is divided into six sectors. There are also 8 voltage vectors which correspond to possible inverter states. These vectors are shown in Fig. 3. There are also six active vectors V1, V2,…, V6 and two zero vectors V0 and V7. [1,10]

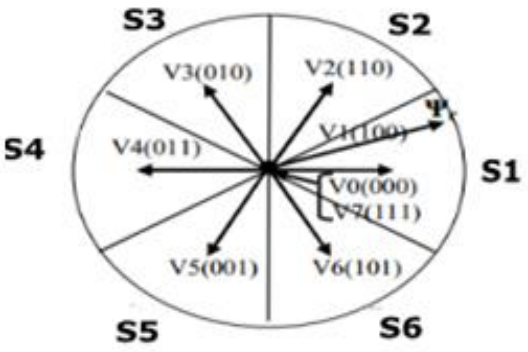
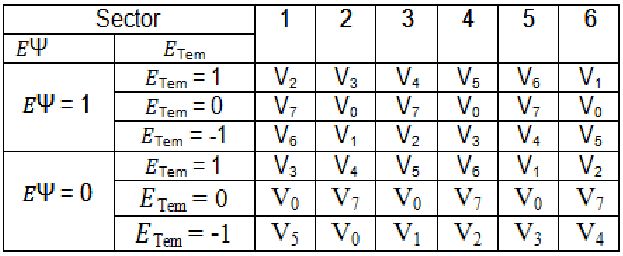


Fig 4:- Detection of vector voltage



Sector		1	2	3	4	5	6
$E\Psi$	E_{Tem}						
$E\Psi = 1$	$E_{\text{Tem}} = 1$	V_2	V_3	V_4	V_5	V_6	V_1
	$E_{\text{Tem}} = 0$	V_7	V_0	V_7	V_0	V_7	V_0
	$E_{\text{Tem}} = -1$	V_6	V_1	V_2	V_3	V_4	V_5
$E\Psi = 0$	$E_{\text{Tem}} = 1$	V_3	V_4	V_5	V_6	V_1	V_2
	$E_{\text{Tem}} = 0$	V_0	V_7	V_0	V_7	V_0	V_7
	$E_{\text{Tem}} = -1$	V_5	V_0	V_1	V_2	V_3	V_4

Table 1: Switching states

The classic DTC has drawbacks namely: the harmonics of the currents in the two regimes also a variable switching frequency and the ripples of the torque and the flux. so we proposed this command based on neural networks where the switching table is replaced by a neural controller see figure 5 [4]

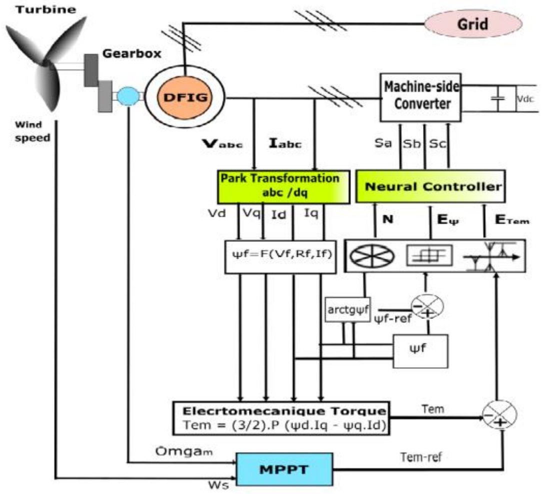


Fig 5:- DTC Neural Networks Controller scheme.

Rotor flux linkage estimation

$$\widehat{\psi_r} = \int_0^t (V_r - R_r\, i_r)dt \qquad (17)$$

The α *and* β estimates components of the ψ_r vector obtained by :

$$\widehat{\psi_{r\alpha}} = \int_0^t (V_{r\alpha} - R_r\, i_{r\alpha})dt \qquad (18)$$

$$\widehat{\psi_{r\beta}} = \int_0^t (V_{r\beta} - R_{r\beta}\, i_{r\beta})dt \qquad (19)$$

The module of the rotor flux is given by:

$$\psi_r = \sqrt{\psi_{r\alpha}^2 + \psi_{r\beta}^2} \qquad (20)$$

The phase of the rotor flux is given by:

$$\theta_r = \text{arctg}\frac{\psi_{r\beta}}{\psi_{r\alpha}} \qquad (21)$$

The torque of DFIG can be represented as a function of the angle δ between the stator and the rotor fluxes space vectors as follows [3, 6]:

$$T_{em} = \frac{3}{2} P \frac{M}{\sigma L_r L_s} |\psi_r|.|\psi_s| \sin\delta \qquad (22)$$

Where $\sigma = 1 - \frac{M^2}{L_r L_s}$ is the leakage coefficient

IV. THE NEURAL CONTROLLER

To generate a neural controller by Matlab / simulink, 30 neurons were chosen in the hidden layers and 3 in the output layers with activation functions of the <tansig> and <purelin> type respectively. The update of the weights and biases of this network is carried out by a retropropagation algorithm called the Levenberg-Marquardt (LM) algorithm. [5,6].

$$y_i = f\left[\sum_{j=1}^{ni} W_{ij}.X_j - b_i\right] \qquad (23)$$

The perceptions multi-layer (Figure 06) is a network comprising L layers, each neuron of a layer being completely connected to the neurons of the following layer. Each neuron k is a generalized linear automat whose function of activation is f_k .

ANN Program Using MATLAB/Simulink:

```
p=[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1];
%p=p';
o= [298 298 298 298 298 298 298 298 298 298 298 298
298 298 298 298 298 298 298 298 298 298 298 298 298
298 298 298 298 298 298 298 298 298 298 298];
net.numInputs=1;
net.numLayers=4;
net =newff([0360],[36,1],{'tansig','purelin'},'traingdm');
net.trainparam.lr=0.002;
net.trainparam.epochs=5000;
net.trainparam.goal=0;
net.trainParam.min_grad=1e-40;
net=train (net,p,o);
Gensim (net,-1)
```

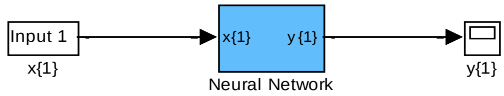


Fig 6:- Structure of ANN.

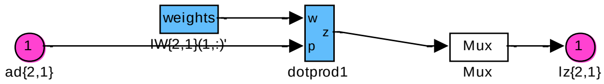


Fig 7:- Structure of layer 1.

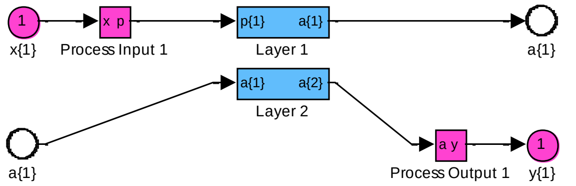


Fig 8:- Structure of layer 2.

V. SIMULATIONS RESULTS

To show the behavior of the DFIG induction generator, connected to the network through a bi-directional converter, we have introduced a variable wind profile, from which, The reference value of the torque is deduced from the regulation of the speed of the wind turbine according to the wind speed and using a PI corrector.

The results of simulations showed that the flux trajectory is circular (Fig. 9), the stator currents are sinusoidal (Fig. 10) and the estimated speed follows the reference speed (Fig. 13).

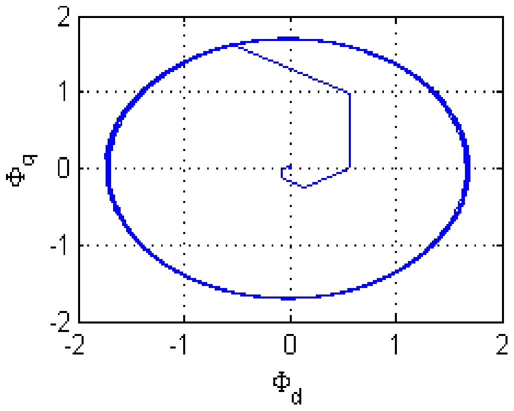


Fig 9:- The trajectory of flux

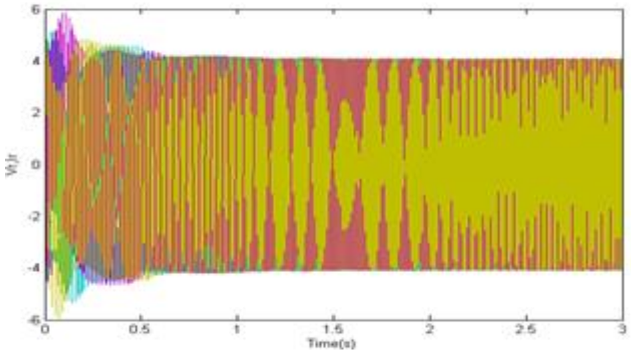


Fig 10:- The current and voltage of roto

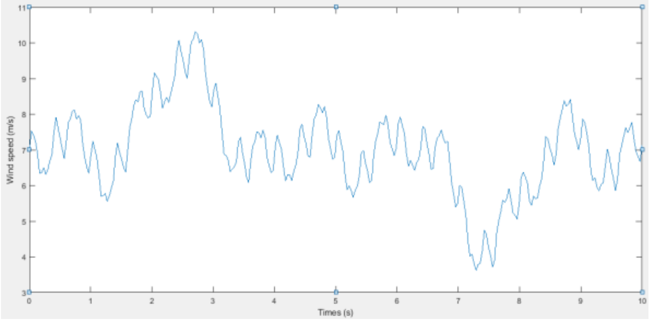


Fig 11:- The wind speed

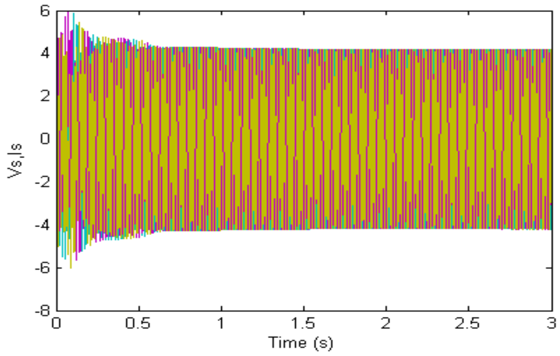


Fig 12:- The current and voltage of the stator

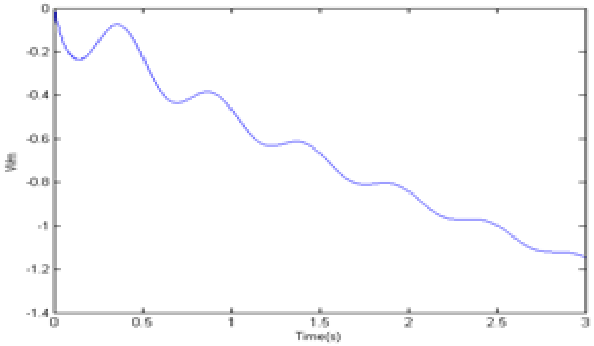


Fig 13:- The speed

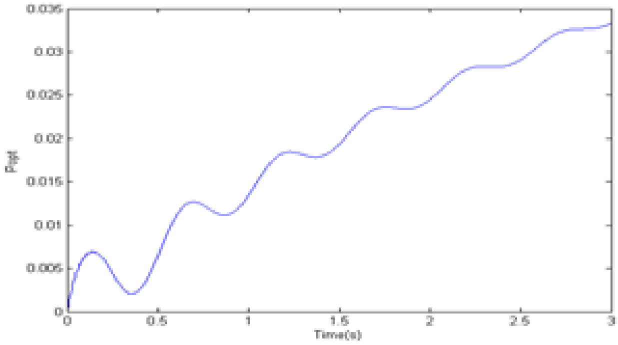


Fig 14:- The power

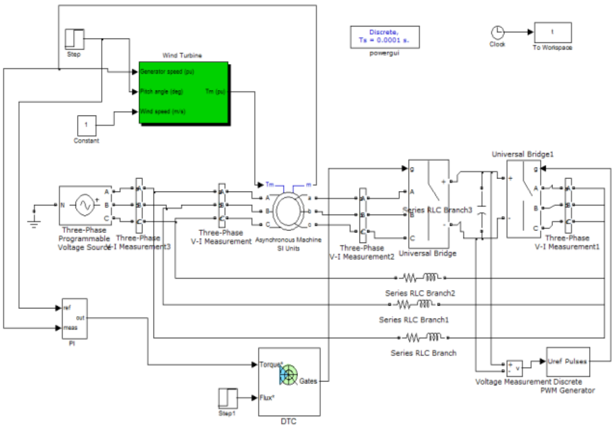


Fig 15:- Structure of the DFIG with DTC

VI. CONCLUSION

The application of DTC to the DFIG has shown that this technique responds perfectly to the variations undergone during the simulation vis-à-vis the conditions applied, which explains why the machine chosen is good performance and its simplicity, on the other hand this control technique presents drawbacks, to overcome its drawbacks, we have proposed a modified DTC technique, by the application of artificial intelligence techniques (neural network). The control of the speed of the DFIG we proposed an algorithm based on artificial neural networks (ANN) with reference model. The results of simulation under Simulink / Matlab, of the proposed block diagram have given proof of the efficiency of the proposed control techniques.

- *Appendix*

System settings
Rated power: Pn = 1.5 kW
Rated voltage: v / U = 398/660 V - 50 Hz
The nominal speed: Ωn = 1440 tr / min.
Number of pole pairs: P = 2
The parameters of the wind turbine used:
Number of blades: Np = 3
Diameter of a blade: RT = 35.25m
Inertia: J = 1000Kg. m2
Number of blades: Np = 3
Stator resistance: Rs = 0.0146 Ω
Rotor resistance: Rr = 0.0238 Ω
Stator inductance: Ls = 0.0306 H
Rotor inductance: Lr = 0.0306 H
Mutual inductance: Lm = 0.0299 H
Mechanical constants:
Moment Inertia: J = 1000 Kg. m2
Coefficient of friction: f = 0.001 N. m. S / rad
Optimal tip speed ratio: $\lambda_{opt} = 8$
Gearbox coefficient: G = 55.747
Cut-in wind speed: $V_{min} = 3m/s$
Cutoff wind speed: $V_{max} = 25m/s$

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NOMENCLATURE

WECS	Wind Energy Conversion System
DFIG	Doubly Fed Induction Generator
$V_{ds} V_{qs} V_{dr}; V_{qr}$	Stator and Rotor Voltage components in the d-q reference frame
$\varphi_{ds}, \varphi_{qs}, \varphi_{dr} \varphi_{qr}$	Stator and Rotor flux components in the d-q reference frame
$I_{ds}, I_{qs}, I_{dr}, I_{qr}$	Stator and Rotor currents components in the d-q reference frame
ω_s, ω_r	Stator frequency, rotor rotating speed
R_s, R_r	Stator- Rotor resistances
L_s, L_r	Stator and Rotor inductance
L_m	Mutual inductance
P_s, Q_s	Active and Reactive stator power
P	Number of pole pairs
T_{em}	Electromagnetic torque
P_{aer}	Mechanical turbine power
S	Section of blade
C_p	The aerodynamic coefficient power
R	Radius of the wind turbine
F	Friction coefficient
J	Inertia moment
Ω_t	Wind turbine speed
λ	Tip speed ratio
β	Blade pitch angle
ρ	Air density
V	Wind speed

Table 2