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Space Vector Modulation Control for Matrix Converter in Wind Energy

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Abstract -In this paper, the study of wind energy conversion system based on variable speed wind turbine is presented. The conversion chain mainly includes a doubly-fed induction generator fed by a matrix converter. In this matter, compared with a classical configuration it will minimize the bulk caused by the storage capacitors and to limit the harmonics.
To get to this objective, the modeling of the energy conversion system and the control strategy of the matrix converter are developed.
The simulation results and the performance of the control method are presented and discussed.
Simulation results are given to show the good performances of the adopted control strategy method.

Keywords: Wind turbine, DFIG, matrix converter, LMSE control, Simulation.

1. Introduction

In recent years, the concept of a doubly fed induction generator (DFIG), driven by a variable-speed wind turbine, equips the most wind energy conversion systems [1-3]. As a result, we have been interested in the study of a control structure of a variable-speed wind turbine converter driving a DFIG. The field oriented control has been adopted [4]. Depending on the performance of the control, the speed of the generator can follow the value predicted by power-speed characteristic curve of wind turbine for the maximum wind energy capture. Furthermore, the stator of the driven wind generator is directly connected to the grid, while the rotor is connected via conductive rings to the output of a matrix converter (MC). Indeed the MC is used in our work to replace the two power converters necessary for a conventional configuration [5, 6]. Compared to its counterpart, the MC does not require voluminous and costly energy storage elements; it uses a simpler control system than in the two levels power conversion chains.

The rest of this paper is organized as follows: the second section is devoted to the modeling of wind turbine, doubly fed induction generator and structure of the matrix converter. In the third section we have developed a method for controlling the inverter, based on the comparison of the reference and output quantities known as Least Mean Square Errors LMSE (LMSE). Finally, we validated this work with simulation results.

2. Design and modeling of the conversion chain

The figure 1 watch, essentially, the wind turbine, the doubly fed induction generator and the matrix converter .

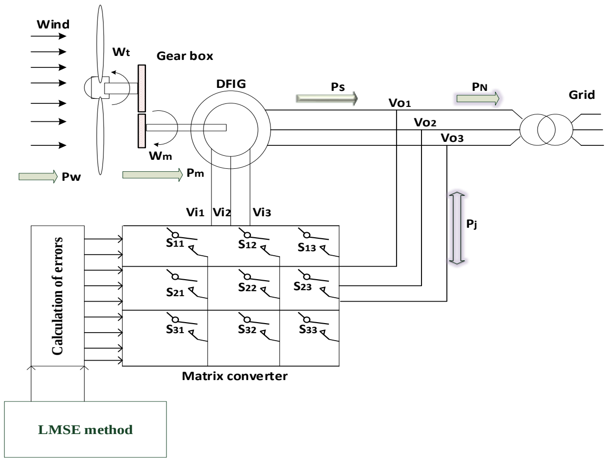

Fig. 1. Variable speed wind energy conversion system

2.1 Model of wind turbine

The mechanical power (P_m) on the rotor shaft extracted from the wind turbine can be represented by the following expression [7]:

$$P_m = \frac{1}{2} C_p(\lambda, \theta).\rho.\pi.R^3.V_v^3 \qquad (1)$$

With, ρ: Air density, approximately 1.225Kg / m^3; *R:* radius of wind generator; *Vv:* wind speed; *Cp:* aerodynamic coefficient;

The torque produced by the turbine is equal to the ratio of the mechanical power and the wind speed:

$$T_t = P_m / Vv \qquad (2)$$

The mechanical coupling between the turbine and the generator is normally provided by a gearbox (gearbox) whose gear ratio $\zeta = \omega_m / w_t$ is chosen to maintain the speed of the generator shaft in a speed range desired.

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By neglecting the transmission losses of the gearbox, the torque of the wind turbine aimed at the side of the generator can be represented by:

$$T_m = \frac{P_m}{\zeta} \quad (3)$$

Where T_m is the drive torque acting on the generator shaft and T_t is the torque of the turbine shaft returned to the generator side. Based on the equation (1), it is obvious that a wind turbine generates only a certain percentage of power when it is associated with a wind turbine. This percentage depends on the power coefficient for each wind turbine and can be defined as a function of the specific velocity λ given by the equation. (4):

$$\lambda = \frac{W_t.R}{V_v} \quad (4)$$

When the available wind power exceeds the nominal power of the generator, it is necessary to limit the input of the wind turbine. This is achieved by controlling the pitch angle (θ) for the orientation of the blades. For this, the purpose pitch angle is controlled such as the wind turbine should produce as much energy as possible and at the generator nominal power.
If the specific speed (λ) and angle of orientation of the blades are given, the aerodynamic power coefficient, Cp (λ, θ) can be approximated by:

$$C_p(\lambda,\theta) = 0.22(\frac{116}{\lambda_i} - 0.4\theta - 5)e^{-21/\lambda_i} + 0.0068\lambda \quad (5)$$

Where,

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

Figure 2 shows the computed relation between the power coefficient Cp (λ,θ) and the specific velocity λ for different angles θ. Using wind turbine parameters it is clear from this figure λ, that there is a value which ensures maximum power captured from the wind for each pitch angle. [8, 9].

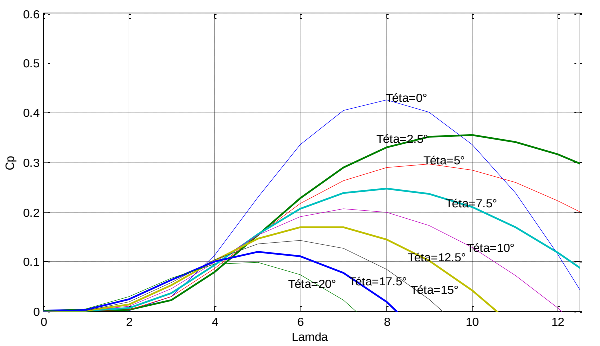

Fig. 2. Characteristics $C_p(\lambda,\theta)$ for different wedge angle values

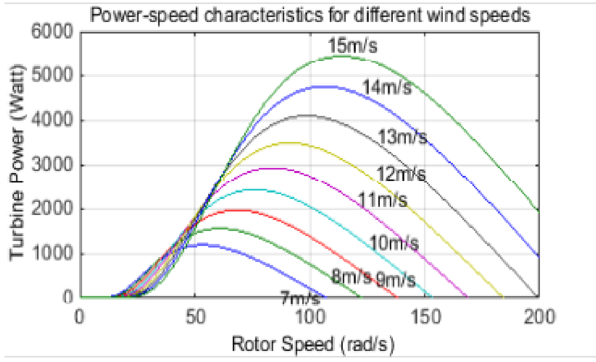

Fig.3 Power-Speed characteristics

In other words, it is asserted that for each wind speed, the machine will rotate so that it captures the maximum available power. Based on relationships (4), (5) and (6), the Power-Velocity characteristic can be plotted for different wind speeds (Figure 3). The speeds of rotation which provide an extraction of the maximum powers are calculated as a function of the optimum specific velocity λ, and the stall angle θ. These speeds are given in Table 1.

Wind speed (m/s)	Pitch angle θ (°)								
	0	2.5	5	7.5	10	12.5	15	17.5	20
0	0	0	0	0	0	0	0	0	0
2	19.2	24	21.6	19.2	16.8	14.4	14.4	12	9.6
4	38.4	48	43.2	38.4	33.6	28.8	28.8	24	19.2
6	57.6	72	64.8	57.6	50.4	43.3	43.3	36	28.8
8	76.8	96	86.4	76.8	67.2	57.6	57.6	48	38.4
10	96	120	108	96	84	72	72	60	48
12	115.2	144	129.6	115.2	100.8	86.4	86.4	72	57.6
14	134.4	168	151.2	134.4	117.6	100.8	100.8	84	67.2
16	144	180	162	144	126	108	108	90	72
	Generator Speed W_m (rd/s)								

For exploiting the characteristic of figure 3. The values of the blade orientation angle and the wind speeds are stored in a 2-dimensional table which allows the prediction of the rotational speed of the generator (see Figure4).

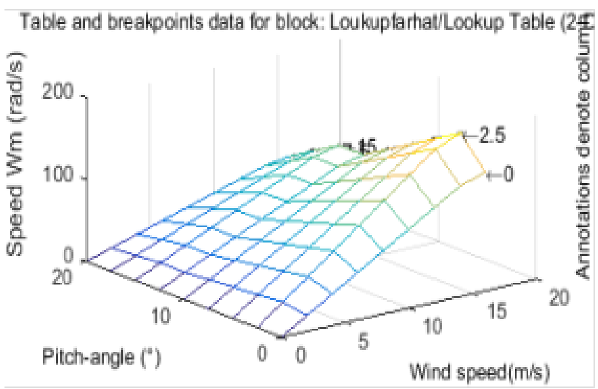

Fig. 4. Data table 2-D for the prediction DFIG speed

2.2 DFIG modeling

The mathematical model of doubly fed induction generator, in a referential linked to the rotating field, can be given the following form [8]:

$$\begin{cases} V_{ds} = R_s i_{ds} + \dfrac{d\phi_{ds}}{dt} - w_s \phi_{qs} \\ V_{qs} = R_s i_{qs} + \dfrac{d\phi_{qs}}{dt} + w_s \phi_{ds} \\ V_{dr} = R_r i_{dr} + \dfrac{d\phi_{dr}}{dt} - (w_s - w_r).\phi_{qr} \\ V_{qr} = R_r i_{qr} + \dfrac{d\phi_{qr}}{dt} + (w_s - w_r).\phi_{dr} \end{cases} \quad (7)$$

$$\begin{cases} \phi_{ds} = L_s i_{ds} + M i_{dr} \\ \phi_{qs} = L_s i_{qs} + M i_{qr} \\ \phi_{dr} = L_r i_{dr} + M i_{ids} \\ \phi_{qr} = L_r i_{qr} + M i_{qs} \end{cases} \quad (8)$$

And the mechanical dynamics of the system is governed by the following equation:

$$J\frac{dw_m}{dt} = T_e - T_m - k_f . w_m \quad (9)$$

Where, the electromagnetic torque is:

$$T_e = 3p\frac{M}{2}(i_{dr} i_{qs} - i_{qr} i_{ds}) \quad (10)$$

w_m *:* mechanical speed;
J: moment of inertia ;
k_f: coefficient of viscous friction.

And,
w_s, w_r : These are the speed of the rotating field and the electric speed of the rotor.

The strategy of control by stator flux oriented along the axis *d* gave us:

$$I_{ms} = \frac{\frac{T_s}{M}.V_{sd} + I_{rd}}{1 + T_s.p} \quad (11)$$

I_{ms}: fictitious excitation current representing the coupling of the stator flux [9].

$T_s = \frac{L_s}{R_s}$: Constant of the electrical stator time.

In addition, the following relations are obtained

$$\phi_{ds} = \phi_s = M.I_{ms} \quad \text{an} \quad \phi_{qs} = 0 \quad (12)$$

Finally, these equations are schematized by blocks (Fig.5) to give a control method of the wind turbine.

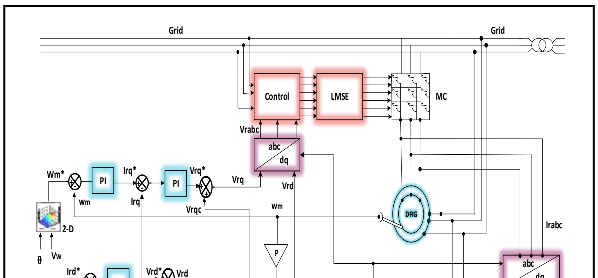

Fig. 5 Structure of the wind turbine flow direction control associated with the MC

The matrix converter is characterized by a matrix topology of nine switches (matrix [3 × 3]) (FIG. 6). Each of the three switching cells carries three switches [10].

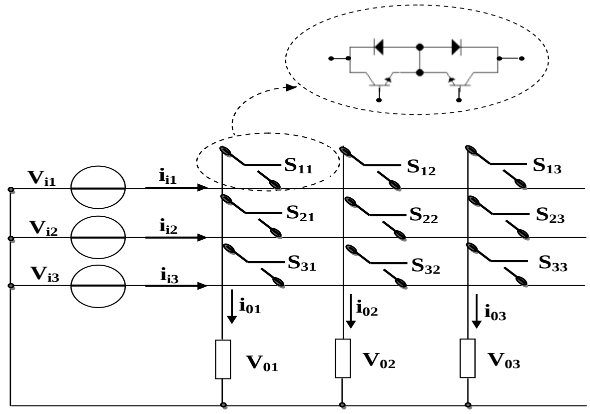

Fig.6 Block diagram of the matrix converter

3.1 Vector control of the matrix converter by LMSE modulation.

In this work the control is based on the technique of modulation of the error difference between the measured values and the desired output values (Least Mean Square errors LMSE). Two steps are required for the LMSE method [11].

Step 1

$E_1(t) = (V_{o1}(t)- V_{i1}(t))^2 + (V_{o2}(t)- V_{i2}(t))^2 + (V_{o3}(t)- V_{i3}(t))^2$
$E_2(t) = (V_{o1}(t)- V_{i3}(t))^2 + (V_{o2}(t)- V_{i1}(t))^2 + (V_{o3}(t)- V_{i2}(t))^2$
$E_3(t) = (V_{o1}(t)- V_{i2}(t))^2 + (V_{o2}(t)- V_{i3}(t))^2 + (V_{o3}(t)- V_{i1}(t))^2$
$E_4(t) = (V_{o1}(t)- V_{i3}(t))^2 + (V_{o2}(t)- V_{i2}(t))^2 + (V_{o3}(t)- V_{i1}(t))^2$
.
.
.
.
$E_{24}(t) = (V_{o1}(t)- V_{i3}(t))^2 + (V_{o2}(t)- V_{i3}(t))^2 + (V_{o3}(t)- V_{i1}(t))^2$
$E_{25}(t) = (V_{o1}(t)- V_{i1}(t))^2 + (V_{o2}(t)- V_{i1}(t))^2 + (V_{o3}(t)- V_{i1}(t))^2$
$E_{26}(t) = (V_{o1}(t)- V_{i2}(t))^2 + (V_{o2}(t)- V_{i2}(t))^2 + (V_{o3}(t)- V_{i2}(t))^2$
$E_{27}(t) = (V_{o1}(t)- V_{i3}(t))^2 + (V_{o2}(t)- V_{i3}(t))^2 + (V_{o3}(t)- V_{i3}(t))^2$

Step 2

If (min (E1, E2, E3…. E27= E1) then (S11 S22 S33) =On and (Vi1 (t), Vi2 (t), Vi3 (t))
If (min (E1, E2, E3…. E27= E2) then (S12 S23 S31) =On and (Vi3 (t), Vi1 (t), Vi2 (t))
If (min (E1, E2, E3…. E27= E3) then (S13 S21 S32) =On and (Vi2 (t), Vi3 (t), Vi1 (t))
If (min (E1, E2, E3…. E27= E4) then (S13 S22 S31) =On and (Vi3 (t), Vi2 (t), Vi1 (t))
.
.
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If (min (E1, E2, E3…. E27= E24) then (S13 S31 S32) = On and (Vi3 (t), Vi3 (t), Vi1 (t))
If (min (E1, E2, E3…. E27= E25) then (S11 S12 S13) = On and (Vi1 (t), Vi1 (t), Vi1 (t))
If (min (E1, E2, E3…. E27= E26) then (S21 S2 2 S23) = On and (Vi2 (t), Vi2 (t), Vi2 (t))
If (min (E1, E2, E3….E27= E27) then (S31 S32 S33) = On and (Vi3 (t), Vi3 (t), Vi3 (t))

4. Simulation results

The results of simulation of phase a are presented as validation (FIG. 7) in the case of a resistive-inductive load R = 20Ω and L = 40mH, an output frequency *fo* = 25 and a sequence time t_s = 0.0005s.

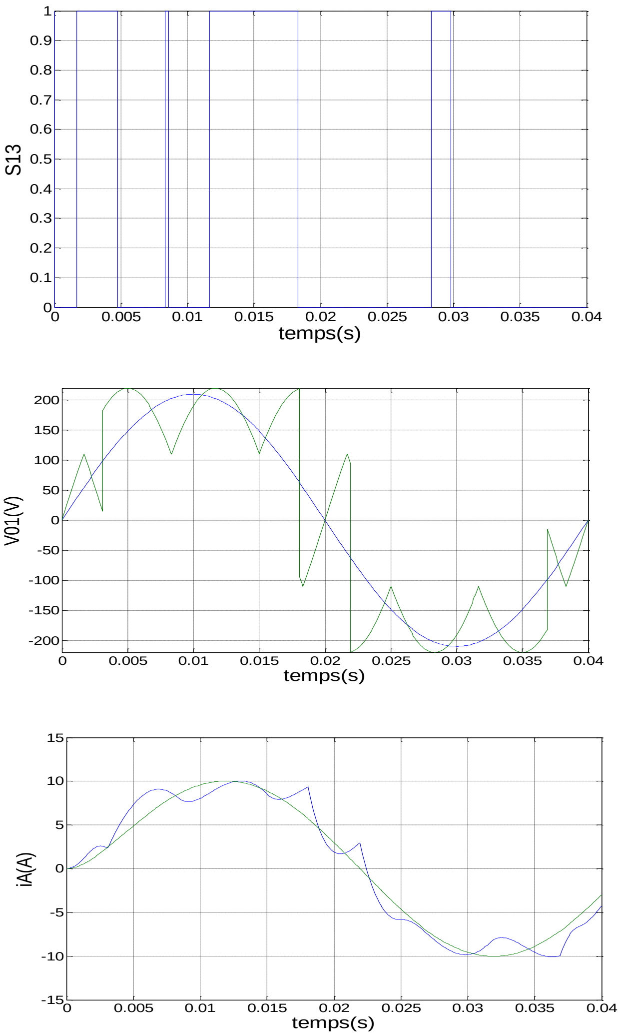

Fig.7 Simulation results: *Switch states, Outputs voltages and current references for phase.*

In all these figures, we have shown that the input and output currents are the same form. Moreover the output voltage follows their reference correctly.
Based on the modeling of the wind turbine, the DFIG and the MC which is controlled by LMSE method. The simulation results show clearly the validity of this technique adopted in a wind energy system.

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