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# INDIRECT FIELD ORIENTED CONTROL: A CONTROL STRATEGY FOR ELECTRIC WIND POWER CONVERSION

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*Abstract*— Different electric wind power conversion systems structures can be used based on the structures of converters used. The main objective in all topologies is always the same: the wind energy at varying wind velocities has to be converted to electric power with the highest performances [6,7,8,9,10]. In this paper a wind energy conversion schemes is presented based on the Indirect Field Oriented Control (IFOC)

**Keywords:** power conversion, IFOC, DFIG, control

## I. INTRODUCTION

Electric wind-power conversion technique has been developing and evolving rapidly during the last decades [1,2,3,4]. The reason is due to new opportunities of power Electronic components. While the direct line-connected generators has been used in smaller-sized plants [12], the greater of them above 500 kW require to work at higher efficiency during. Different Wind Energy conversion systems structures can be used based on the types of converters used. The main objective in all topologies is the same: the wind energy at varying wind velocities has to be converted to electric power with the highest performance

## II. CONTROL STRATEGIES

The evolution in control strategies due to the use of real time calculators has allowed for these last few years, an easier use of asynchronous machines. Most control systems use one of these two techniques:

- Constant flux control
- Vector control

It is generally accepted that field orientation, in one the most promising control method for high dynamic performance motor drives. In particular, for induction motors used in urban wind power plants. Indirect Flux Oriented Control is a simple and highly reliable scheme which has become an industry standard. This kind of control is globally asymptotically stable provided the motor rotor resistance is exactly known.

The principle of control of the electromagnetic torque by the flux oriented method is based on knowledge of the dynamic model of the machine. The choice of the Park model is commonly used because it simplifies the elaboration of control variables. This transform allows us to work in an equivalent two-phase system instead of a three-phase system.

## II.1. Equations of the machine

We consider that the reference frame is set in relation to the rotating field using mesh current analysis in the form of a matrix

$$\begin{aligned} V_{qs} &= p\phi_{qs} + \omega\phi_{qs} + R_s i_{qs} \quad (1) \\ V_{ds} &= p\phi_{ds} - \omega\phi_{qs} + R_s i_{ds} \end{aligned}$$

According to the choice of reference bases, we obtain:

$$(V_{sp}) = [R_s] (I_{sp}) + \frac{d(\phi_{sp})}{dt} + \omega_s \begin{bmatrix} -\phi_{sq} \\ +\phi_{sd} \\ 0 \end{bmatrix} \quad (2)$$

So by developing, we have the following expressions:

- For the stator:

$$V_{sd} = R_s I_{sd} + \frac{d(\phi_{sd})}{dt} - \omega_s \phi_{sq} \quad \alpha v \delta \quad V_{sq} = R_s I_{sq} + \frac{d(\phi_{sq})}{dt} + \omega_s \phi_{sd} \quad (3)$$

Equation (3) shows the couplings between  $V_{sd}$  and

$\phi_{sd}$  and between  $V_{sq}$  and  $\phi_{sd}$

- For the rotor:

$$V_{rd} = R_r I_{rd} + \frac{d\phi_{sd}}{dt} - g\omega_s \phi_{rq} = 0 \quad \alpha v \delta \quad V_{rq} = R_r I_{rq} + \frac{d\phi_{rq}}{dt} + g\omega_s \phi_{rd} = 0 \quad (4)$$

- For the fluxes:

$$\phi_{sd} = L_s I_{sd} + M_{sr} I_{rd} \quad \text{and} \quad \phi_{sq} = L_s I_{sq} + M_{sr} I_{rq} \quad (5)$$

So equation (3) becomes:

$$V_{sd} = R_s I_{sd} + L_s \frac{dI_{sd}}{dt} + M_{sr} \frac{dI_{rd}}{dt} - \omega_s (L_s I_{sq} + M_{sr} I_{rq}) \quad (6)$$

And

$$V_{sq} = R_s I_{sq} + L_s \frac{dI_{sq}}{dt} + M_{sr} \frac{dI_{rq}}{dt} + \omega_s (L_s I_{sd} + M_{sr} I_{rd})$$

$$p_e = V_A I_{sa} + V_B I_{sb} + V_C I_{sc} = V_{sd} I_{sd} + V_{sq} I_{sq} \quad (7)$$

As the Park transform used conserves the power. We can show that the expression of the electromagnetic torque  $T_e$  can take on different forms according to (7):

$$T_e = p(\phi_{sd} I_{sq} - \phi_{sq} I_{sd}) \text{ OR } T_e = p M_{sr} (I_{rd} I_{sq} - I_{rq} I_{sd}) \text{ OR } T_e = p \frac{M_{sr}}{L_r} (\phi_{rd} I_{sq} - \phi_{rq} I_{sd}) \quad (8)$$

These three expressions show that the torque results from and interaction between a flux and a current.

## II.2. Flux Oriented Control

If we take the expression of the electromagnetic torque:

$$T_e = p \frac{M_{sr}}{L_r} (\phi_{rd} I_{sq} - \phi_{rq} I_{sd}) \quad (9)$$

We can observe that the coupling between the stator current and the components of the rotor flux. However, in applications that require important dynamic performances, it is necessary to control the instantaneous value of the torque.

The principle of flow oriented control consists in decoupling the torque and the current by canceling the flux component on the axis q or  $\phi_{rq} = 0$ . We will therefore have:

$$T_e = p \frac{M_{sr}}{L_r} (\phi_r I_{sq}) \text{ with } \phi_{rd} = \phi_r \quad (10)$$

The regulation of the flux can be direct or indirect:

- Direct control: the flux is controlled by a feed-back loop. It must therefore be measured or estimated.
- Indirect control: the flux is neither measured nor estimated. It is set in an open loop.

### II.2.1 Estimations of control variables:

The objective is to express the variables to be estimated (coefficient \*) in function of the measurable variables of the stator.

- **Estimation of  $\phi_{rd}$**

Using the equations of the fluxes at the rotor:

$$\begin{aligned} \phi_{rd} &= L_r I_{rd} + M_{sr} I_{sd} \\ \phi_{rq} &= L_r I_{rq} + M_{sr} I_{sq} = 0 \end{aligned} \quad (11)$$

We can end up with:  $\phi_{rd} = \frac{M_{sr}}{1 + \tau_r S} I_{sd}$  with  $\tau_r = \frac{L_r}{R_r}$  rotor time constant and S for Laplace operator. This estimation needs the knowledge of  $\theta_s$  in order to carry out the transform.

- **Estimation of  $\omega_r$ ,  $\theta_r$  and  $\theta_s$**

Using the previous equations, we can show that:  $\omega_r^* = \frac{M_{sr}}{|\phi_{rd}|} \frac{1}{\tau_r} I_{sq}$

Then  $\theta_r^* = \int \frac{M_{sr}}{|\phi_{rd}|} \frac{1}{\tau_r} I_{sq} dt + Cte$  and it leads to  $\theta_s^* = \theta_r^* + \theta$

with  $\theta$  measurement from an encoder.

- **Estimation of the electromagnetic torque.**

The previous expression of  $T_e$  produces the following equation:

$$T_e^* = p \frac{M_{sr}}{L_r} \phi_{rd}^* I_{sq} \quad (12)$$

It is obvious that the major drawback of these estimations concerns the variations of the parameters according to the temperature, the frequency (rotor resistance), or magnetic saturation phenomena.

### II.2.2. Indirect Control principle

It is to be noted, that in this case the rotor flow is set in an open loop as a control variable.

Principle of the circuit:

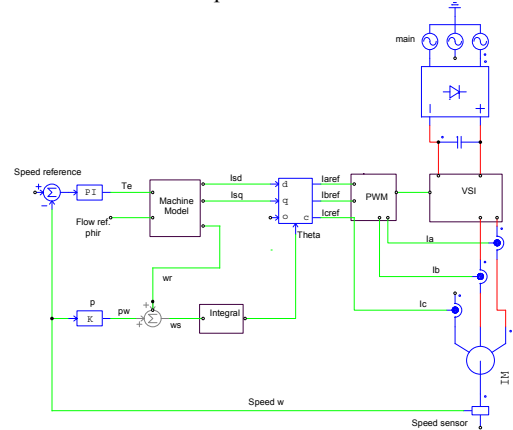


Fig. 1. Principle of Indirect Flux Oriented control

Control is ensured by controlling the stator currents (and therefore controlling  $I_{sd}$  and  $I_{sq}$ ). Using the desired value of  $T_e$  (electromagnetic torque) and the nominal value of the flux, the internal model of the machine can be used to reconstruct the currents

$I_{sd}$  and  $I_{sq}$  (respectively  $I_{sd}^*$  and  $I_{sq}^*$ ). These values are compared to the values measured in order to generate the control signals of the voltage source inverter (via inverse Park transform).

The rotor angular frequency is also reconstructed in order to ensure the self-control of the machine and the angular reference ( $\omega_s = p\Omega + \omega_r$ ).

It is to be noticed that in reality, we generally use a position sensor (resolver) that allows calibration of the rotor angle in relation to theta.

Supposing that vector control is effective :

- $I_{sd}^*$  is used to set the flux.
- $I_{sq}^*$  is used to set the torque.

With the relation:

$$T_e = p \frac{Msr}{L_r} \cdot \phi_r \cdot I_{sq} \text{ with } \phi_{rd} = \phi_r (Msr = L_m)$$

### III. Simulation Results

Simulations studies were performed using PSIM software [5,11]. The IFOC responses are presented using the following complete model:

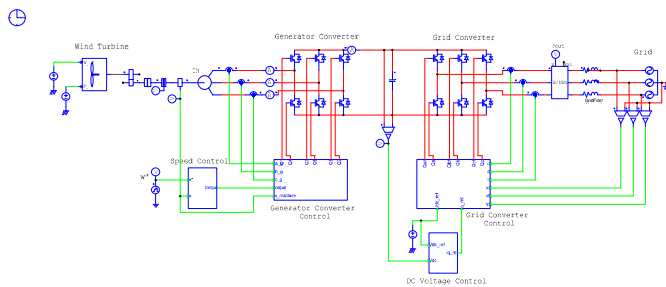


Fig. 2. complete PSIM Model

The response of the control is shown in figure 3, the graphs shown correspond to (in order of appearance):

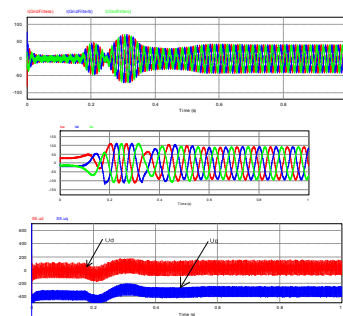
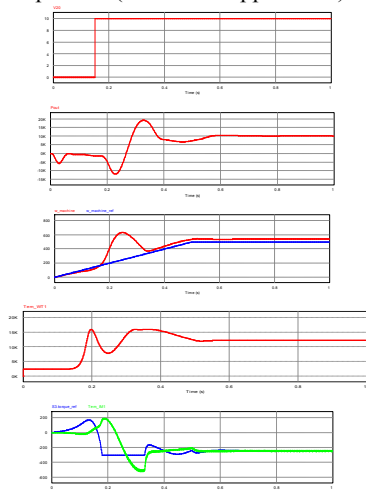


Fig.3. Response curves

Wind speed, b) Power out, c) comparison of speed machine and speed reference, d) Torque of Wind turbine, e) comparison of electromagnetic torque and the reference torque, f) filtered grid currents, g) grid voltages, h)  $U_d$  and  $U_q$  voltages.

### CONCLUSIONS:

In the technique of IFOC the following observations could be concluded:

1. The technique can keep the rotor flux constant even during changes in load torque. This indicates that decoupling control of flux and torque has been obtained.
2. It has been shown that decoupling is conditioned by the accuracy of slip calculation. The slip calculation depends on the rotor time constant, which varies continuously according to the operational conditions.

3. On the other hand, the conventional PI controller cannot compensate such parameter variations in the plant. The PI controller is not an intelligent controller. We are Currently developing other controllers and other control strategies:

a direct AC- AC converter commonly named matrix converter and a structure composed of two converters commonly termed Unified Power Flow controller (UPFC). The former structure is used with a Squirrel Cage Induction Generator (SCIG). The latter is used with a Double Fed Induction Generator (DFIG)[13].

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