Control by Compensation Magnetic Stator and Rotor Energies of the Asynchronous Generator Used WECS

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Abstract - *In this article, we propose modeling, simulation, analysis and implementation an asynchronous generator control with magnetic energy compensation. This command comes from the composition a both vector commands such as the control by orientation of the stator and the rotor fluxes. It equalizes the magnetic energy at the windings of the stator and the rotor. The advantage on this control reside in the simplicity of the current regulator when one of them is already regulated. The performance from these types' commands is simulated in MATLAB SIMULINK software*

Key words: Asynchronous machines, Vector control, Stator flux orientation, Rotor flux orientation, Magnetic energy compensation, PI control*.*

1. INTRODUCTION

The asynchronous generator (GAS) is an electric machine most used in wind turbine applications. It has many advantages like in the simplicity construction, the lower cost, its robustness, and above all its simple and economical maintenance. This generator is increasingly used for high-performance controls using DC machines. The principal problem which we meet in the control of this machine is focused on the complete absence by decoupling between the flux and the torque. These two quantities all depend on the stator current. To perform this decoupling between the torque and the flux, we often recourse with classical control: torque with slip and the flux by the ratio voltage / frequency U / f (constant). But, fault by information on the report U / f, this type the command is restricted using due to the quality of its performances. At this time, the principle from decoupling has not yet been developed, hence the appearance a new technique called "vector control" or "Orientation flux control" that made the control of the asynchronous machine possible as for DC machines [1]. But, this control studies separately the stator and rotor windings, from where we create a control by compensation by magnetic stator and rotor energies. In this study, we introduce the control of an asynchronous machines whose objective is to guarantee the performance in terms of robustness with respect the load, torque and parameters variations. The results by control are presented under start up and with load, and discussed later.

1.1 THE ASYNCHRONOUS GENERATOR MODEL

Most generators used by wind turbines are three-phase asynchronous generators. These generators have lot of advantage like robustness, cost, and have a mechanical simplicity. On the other hand, the drawbacks are located at the level of the reactive energy consumption that they draw from the network, or compensated by a capacitor bank, hence the possibility of autonomous operation.

In general, there are two types of asynchronous machine: the asynchronous squirrel cage machine and the asynchronous machine with wound rotor.

In this chapter, we are interested in the asynchronous generator with squirrel cage, because it is the most used in wind turbines rotating at a speed observed, starting from a certain number of simplifying hypotheses for the mathematical modeling of the machine.

1.2 SIMPLIFYING HYPOTHESES

The model asynchronous machine demand same number simplifying hypothesis which are:

- The stator and rotor windings are symmetrically spatial and the magneto motive force is distributed sinusoidal in the generator air gap;
- We suppose that the magnetic circuit is linear, and sufficiently flaky so that the magnetic and mechanical losses are negligible;
- The hysteresis phenomenon and the eddy currents are negligible;
- The resistance of the windings does not change with the temperature and the effect of skin is not taken into account;
- The gap is uniform thickness and the nicking effect is negligible

2. MODEL IN PARK OF THE GENERATOR

Park's transformation consists for applying to currents, voltages and fluxes, a change of variable intervenes the angle between the axis of the windings and the axes d and q. This can be interpreted as substitution, windings real, of fictitious windings ds, qs, dr, qr whose axes are connected to the axes d, q. This passage is made possible for the transformation to physical magnitudes by the Park matrix [P]. Applying Park transformation to the system, we can write:

$$V_{ds} = -r_s i_{ds} - \omega_s \psi_{qs} + \frac{d\psi_{ds}}{dt} \quad (1)$$

$$V_{qs} = -r_s i_{qs} + \omega_s \psi_{ds} + \frac{d\psi_{qs}}{dt} \quad (2)$$

For the rotor windings transformation, we use the same matrix by Park but we make $\theta_r = \theta_s - \theta$ in the expressions, therefore:

$$\frac{d\theta_r}{dt} = \frac{d\theta_s}{dt} - \frac{d\theta}{dt} = \omega_s - \omega$$

ω_r : Rotational speed of the rotor (in pu)

ω_s : Rotation speed of the d-q mark

ω_0 : The basic pulsation in rad / s

$$V_{dr} = -r_r i_{dr} - (\omega_s - \omega_r)\psi_{qr} + \frac{d\psi_{dr}}{dt} \quad (3)$$

$$V_{qr} = -r_r i_{qr} + (\omega_s - \omega_r)\psi_{dr} + \frac{d\psi_{qr}}{dt} \quad (4)$$

Electromagnetic equations are:

$$\psi_{ds} = -X_s i_{ds} - X_m i_{dr} \quad (5)$$

$$\psi_{qs} = -X_s i_{qs} - X_m i_{qr} \quad (6)$$

$$\psi_{dr} = -X_r i_{dr} - X_m i_{ds} \quad (7)$$

$$\psi_{qr} = -X_r i_{qr} - X_m i_{qs} \quad (8)$$

3. VECTORIAL CONTROL

In Object to translate the performance of the machine direct current with separate excitation to the machine asynchronous, F. Blashke and K. Hasse proposed a method vector control of the asynchronous machine [2]. The vector control also called oriented flux control of major importance since it allows to solve problems the coupling of the variables to the machine [1]. In this type of command, the flux and the torque are two variables which are decoupled and controlled independently. All research work on this topic uses two main methods:

- Direct method developed by Blaschke
- Indirect method developed by Hasse.

Most of techniques have been presented in the literature, which we can classify [3]:

According to the source of energy:

- Voltage control;
- Current control.

According to the orientation of the reference (d, q):

- Rotor flux ;
- Stator flux ;
- The air gap flux.

According to the determination by flux position:

- Direct by measure or vector observation flux (module, phase)
- Indirect by controlling the frequency of slip.
- In our case, we are interested in a voltage control with marker orientation (d-q) according to the stator flux.

3.1. CONTROL BY STATOR FLUX ORIENTATION

The asynchronous machine is a multi-variable system governed by differential equations. The utilization's Park transformation by changing landmarks, under some hypotheses, makes it possible to simplify these equations and therefore to understand a better at behavior physical of the machine. An appropriate choice to the repository (dq) is done in such a way that the stator flux is aligned with the axis d making it possible to obtain a torque expression in which two orthogonal currents (ird , irq) intervene, the first flux generator and the other torque generator [4]

$$\psi_{sd} = \psi_s \,, \psi_{sq} = 0$$

The new machine equations are:

$$\psi_{qs} = -X_s i_{qs} - X_m i_{qr} = 0 \quad (9)$$

From equation (9), we have:

$$i^s_{qs} = -\frac{X_m}{X_s} i^s_{qr} \quad (10)$$

3.2. CONTROL BY ROTOR FLUX ORIENTATION

The strategy consists independently the flux and the stator current control to impose the torque. Then we have two variables actions as in the case to the machine with DC current [5]. In this condition we have:

$\psi_{rd} = \psi_r$ and $\psi_{rq} = 0$

Which leads us to:

$$\psi_{qr} = -X_r i_{qr} - X_m i_{qs} = 0 \quad (11)$$

Only the stator quantities are accessible, the quantities rotor, they are not, so you can to estimate them from the stator magnitudes. As a result, the model of induction motor established in the field to rotor flux oriented is then given as follows:

$$i_{qr}^r = -\frac{X_m}{X_r} i_{qs}^r \quad (12)$$

3.3. MAGNETIC ENERGY COMPENSATION CONTROL

In this part, we will see the combination these two commands: "commands by orientation stator and rotor fluxes "so-called: command scalar by compensation of magnetic energy.

Consider relations (10) and (12) we have:

$$X_m = \frac{X_s i_{qs}}{i_{qr}} = \frac{X_r i_{qr}}{i_{qs}} \quad (13)$$

This equation leads us to our goal on the command scalar by compensation of magnetic energy is given by:

$$\frac{X_s i_{qs}^2}{2} = \frac{X_r i_{qr}^2}{2} \quad (14)$$

So, our control for object to equalize the energies magnets along the q-axis of the stator windings and rotor.

Starting from Equation (14), we have the relations between stator and rotor current along the q axis as follows:

$$i_{qs} = \sqrt{\frac{X_r}{X_s}}\, i_{qr} \quad (15)$$

Take us this expression in the flux ψ_{qr} we have:

$$\psi_{qr} = -\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right) i_{qr} \quad (16)$$

We follow the same steps for the axis d, we have:

$$\psi_{dr} = -\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right) i_{dr} \quad (17)$$

We bring the relations (16) and (17) in the equations of rotor voltages, we have:

$$V_{dr} = -r_r i_{dr} + (\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)\left(i_{qr} - \frac{di_{dr}}{dt}\right) \quad (18)$$

$$V_{qr} = -r_r i_{qr} - (\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)\left(i_{dr} + \frac{di_{qr}}{dt}\right) \quad (19)$$

By the Laplace transformation, we have V_{dr} and V_{qr} are the two-phase components of the rotor voltages to be imposed on the machine to obtain the desired rotor currents:

$$V_{qr} = -r_r i_{dr} + (\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)\left(i_{qr} - s\, i_{dr}\right) \quad (20)$$

$$V_{qr} = -r_r i_{qr} - (\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)\left(i_{dr} - s i_{qr}\right) \quad (21)$$

The system to be regulated is:

$$i_{qr} = \frac{(\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)}{r_r + s\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)}\, i_{dr} \quad (22)$$

4. COURRENT REGUATOR SYNTHESIS

The Proportional Integral Regulator (PI), used to command the asynchronous generator, it is simple and fast to implement all for offering acceptable performance. That's why it got our attention for a study global wind generator system, the transfer function by PI regulator is: $K_p + \frac{K_i}{p}$ [2].

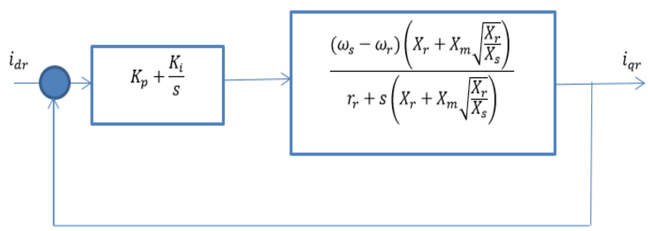

Fig -1: System regulated by a PI regulator

The transfer function with open loop is written as follows:

$$FTBO = \frac{K_i}{s}\left(s.\frac{K_p}{K_i} + 1\right).\left(\frac{\frac{1}{r_r}(\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)}{1 + s\frac{\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)}{r_r}}\right) \quad (23)$$

By pole compensation, which results in the condition:

$$\frac{K_p}{K_i} = \frac{\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)}{r_r} \quad (24)$$

Then the $FTBO$ can written by:

$$FTBO = \frac{K_i}{s} \cdot \frac{(\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)}{r_r} \quad (25)$$

In order to have a behavior to a first order system of which transfer function is:

$$G(s) = \frac{1}{1+\tau s} \quad (26)$$

So, the closed-loop transfer function (FTBF) by

Figure 1 will be:

$$FTBF(s) = \frac{1}{1 + s\frac{r_r}{K_i(\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)}} \quad (27)$$

$$\tau = \frac{r_r}{K_i(\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)} \quad (28)$$

We finally have the expressions for K_p and K_i :

$$\begin{cases} K_i = \dfrac{r_r}{\tau(\omega_s - \omega_r)\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)} \\ K_p = K_i \dfrac{\left(X_r + X_m\sqrt{\frac{X_r}{X_s}}\right)}{r_r} \end{cases} \quad (29)$$

5. SIMULATION RESULTS

5.1. SIMULATION NO LOAD FONCTION

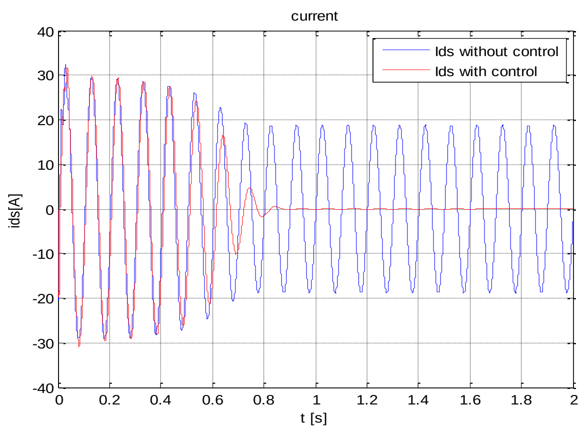

Fig-2: Response of stator current Ids with and without control

In this figure, with the starting, the stator current presente an oscillation and becomes smooth with t=0.9s. This figure allows us to say that the stator currents with command by magnetic energy compensation can follow the set point, but we have accented current call from our start-up machine, this call weakening little by little until it is canceled when the plan is established if our generator is not charging.

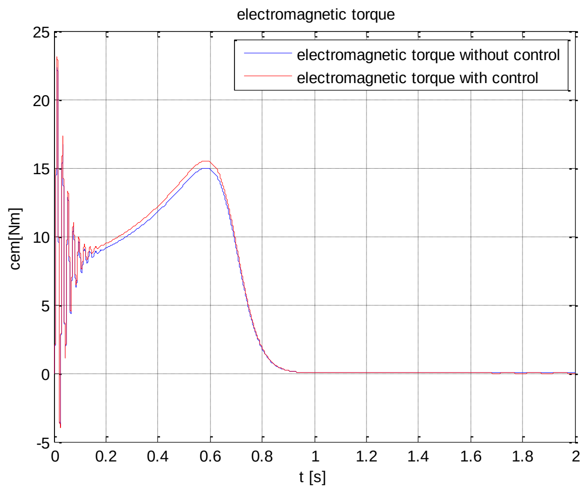

Fig-3: Response electromagnetic torque without and with control

In starting, the torque oscillation is important in this figure, since the torque (measured in Nm) rises up to over 24 Nm. It should be taken care when sizing of the machine used if we want the keep healthy. After the disappearance of the transitional regime, the torque tends to zero since the resisting torque was canceled.

5.2 SIMULATION IN LOAD FONCTIONING

In this simulation, we insert a 5 Nm load between t = 1 and

t = 1.6s.

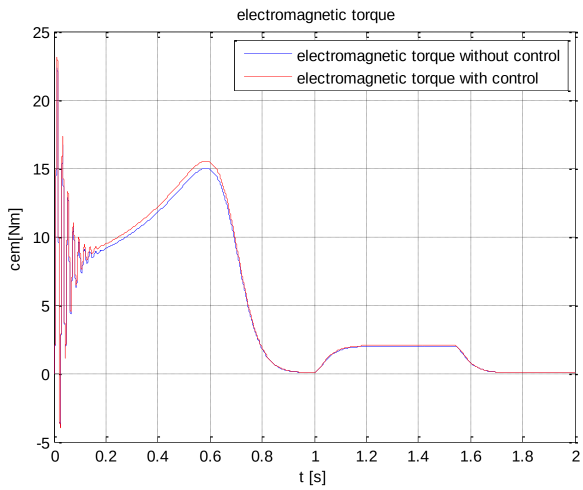

Fig.4. Response of electromagnetic torque with load control

In this figure, when a load is applied, we seen an increase in the couple the same as of the couple reference, that increase and proportional to the value of load inserer during this operation.

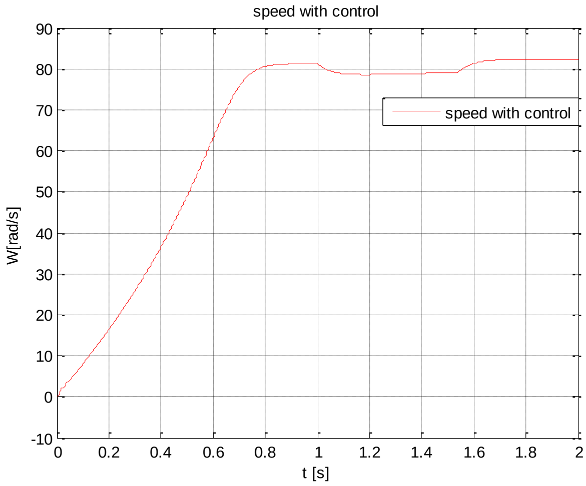

Fig-5: Response of speed with load control

This figure shows the evolution of the rotational speed when applying the load. Inserting this load at t = 0.7s marks the decrease of the speed. This last will be established after 0.6s.

6. PI SPEED REGULATOR

6.1: CLASSICAL METHOD

The transfer function among the torque and the speed of the machine is given by the equation below. This relation is deduced from the equation assuming that the resisting couple intervenes as a disturbance.

$$2H_g \frac{d\omega_r}{dt} = T_m - T_e \quad (30)$$

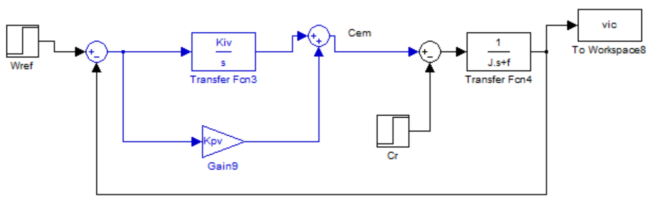

Fig-6: The PI regulator of the rotational speed

The PI regulator is the sum form given by:

$$G_R(s) = K_{pv}\left(1 + \frac{1}{T_i s}\right) \quad (31)$$

With:

$$K_{iv} = \frac{K_{pv}}{T_i}$$

following:

$$G_0(s) = \frac{K_{pv}(1 + T_i s)}{J T_i s^2 + f T_i s} \quad (32)$$

In closed loop, the transfer function is given by the following relation:

$$G(s) = \frac{G_0(s)}{1 + G_0(s)} \quad (33)$$

Which gives us:

$$G(s) = \frac{1 + T_i s}{1 + \left(\frac{f T_i}{K_{pv}} + T_i\right) s + \frac{f T_i}{K_{pv}} s^2} \quad (34)$$

By member-to-member identification denominator of the equation to the canonical form:

$$G(s) = \frac{1}{1 + \frac{2\xi}{\omega_n} s + \frac{1}{\omega_n^2} s^2} \quad (35)$$

We have:

$$\begin{cases} \frac{1}{\omega_n^2} = \frac{J T_i}{K_{pv}} \\ \frac{2\xi}{\omega_n} = \frac{f T_i}{K_{pv}} + T_i \end{cases} \quad (36)$$

Solving this system of equation we have:

$$\begin{cases} T_i = \frac{2\xi J \omega_n - f}{J \omega_n^2} \\ K_{pv} = 2\xi J \omega_n - f \end{cases} \quad (37)$$

6.2. MG METHOD (GENERALIZED METHOD)

Here the PI regulator is the product form gives by [5]:

$$G_R(s) = \frac{1 + sT_n}{sT_i} \quad (38)$$

And the transfer function of the system to be regulated can be written as following:

$$G(s) = \frac{K}{1 + sT} \quad (39)$$

With:

K=1/f and T=J/f

The transfer function for this system is written by:

$$G_0(s) = \left(\frac{1 + sT_n}{sT_i}\right)\left(\frac{K}{1 + sT}\right) \quad (40)$$

The MG method consists of compensating [5]:

$$\begin{cases} T_n = T \\ T_i = \alpha K T \end{cases} \quad (41)$$

In open loop the transfer function is reduced to:

$$G_0(s) = \frac{1}{s\alpha T_i} \quad (42)$$

In closed loop the transfer function gives a function to the first order as follows:

$$H(s) = \frac{1}{s\alpha T_i + 1} \quad (43)$$

We take α=0.1, α=0.01 and α=0.05

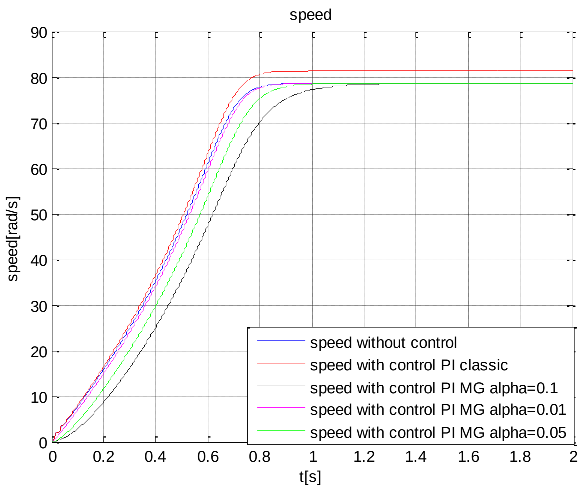

Fig-7: Response of the speed rotation without and with controlled order with classic PI and PI MG

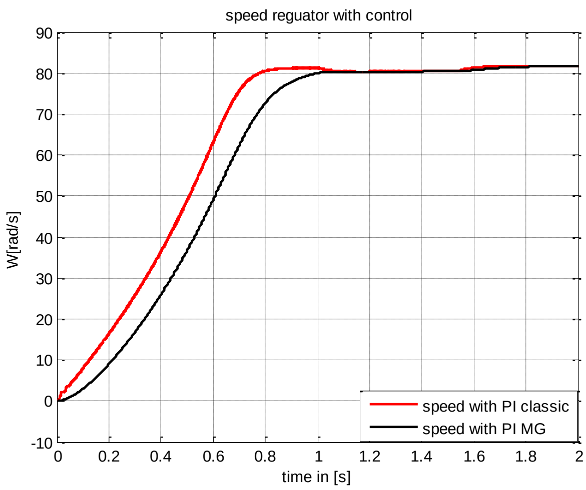

Fig-8: Response of the speed rotation without and with controlled order with classic PI and PI MG

In figure 8, that with the PI MG regulator we have better than PI classical if we choose well the constant α then the classical PI is very sensitive to load variation

7. CONCLUSIONS

To conclude, we can say that the control by compensation with magnetic stator and rotor energies of the asynchronous generator brings a lot of benefits, to know, for example, the ease of adjusting other sizes machine once one of the rotor currents is set; in addition, as it consists to add two commands vector, so it has assets on the plan economic and time. During the simulation, we see that starting regime, the stator currents are important, but they are weak in steady state, by consequent, our machine is heated less quickly and a little oscillation of speed. The rotor currents have the same amplitudes with or without start-up or steady-state control. On the axis d, these currents are merged, on the contrary the stator currents the q axis when loading without and with control are in opposition of phase. For the speed's rotation, we can say that the oscillation at startup disappears when the regime is established; moreover, the rotation of the machine is accentuated when we insert the control by compensation a magnetic energies and it decreases when applying the load to stabilize later. This decrease causes the increase the torque during the loading our machine. The figure 7,with the PI MG regulator it makes more sense to follow the set point by choosing well the constant α than classical PI and on this regulator that we can eliminate the speed oscillation in the starting time and even when inserting the load.

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