Comparison between Fuzzy logic and PI controls in a Speed scalar control of an induction machine

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Abstract. This article compares the response of a induction machine with scalar speed PI controls and with Fuzzy logic controls. The simulation has been developed using Simulink and Matlab [1]. The operation of the motor has been verified with different speed targets in form of steps.

This work allows to be seen the improvement that can be achieved by the induction machine changing controls PI into Fuzzy.

Key words: Fuzzy control, scalar control, induction machine.

1. Introduction

The Proportional Integral (PI) controller, which is widely used thanks to its versatility, discharges benefits and facility of implementation. A very common method to determine the constants of this controller is the method of Ziegler-Nichols [2].

This method gives a good response when the process to be controlled has a pair of dominant poles, but for more complex systems it is not recommended.

The best way to fit the controller's parameters is via a heuristic manual variation. The linearity of the system, in this case, is not recommended, since the operation point usually changes constantly.

The use of Fuzzy PID controller is not very common. Since it requires the use of three inputs, which causes the number of associated rules to increase sufficiently with respect to PD or PI, which makes the control design more complicated. For that reason, Fuzzy PD and PI controls are more widely used.

The PI Fuzzy control is the more practical, since the Fuzzy PD control has problems eliminating stationary errors of the system. Nevertheless, Fuzzy PI has a worse response to transitory behaviour of systems in which the order pole is higher. [3].

Therefore, the use of Fuzzy logic is very good for non-linear systems and with a very wide ranges of operation. With the Fuzzy logic, we can define the operation of the variables in a subjective way: ", small, big, etc." in a numerical form [4].

To fuzzify the variables, in this case, a decentralized "sequential" technique has been used, so each control has aligned one behind the other, so that the dynamics of the controller to be used have been considered at the time of installing the next controller in the sequence [5]. The use of this technique eliminates the need to consider too many inputs in the design.

2. Scalar control with PI controls of the induction machine

For the control of the induction machine a scalar control has been used, as it offers the advantage of its simple configuration (instead for a smaller exactitude in the speed control that offered by the vector control).

It is possible to get the reference voltage from the slip in a simple way. The slip frequency is the output of the speed controller "C1" (figure 1), and upon adding the rotor speed, the reference stator frequency is obtained.

If the stator resistance is omitted, to obtain a constant magnetic flux, the stator voltage must vary proportionally to the frequency of the stator.

Nevertheless, this hypothesis cannot be made at low speeds, since for low speeds there is no proportional variation between the flux with the voltage and the frequency. At zero speed, the voltage of the stator is only due to the voltage drop in the stator resistance.

For that reason the PI controls can work well for high and medium speeds but not for low speed, because in this zone the linearity is not fulfilled according to the set of PI parameters chosen.

In figure 1, it can be seen that there are two control loops: the inner one controls the stator current, and the outer one that controls the angular speed.

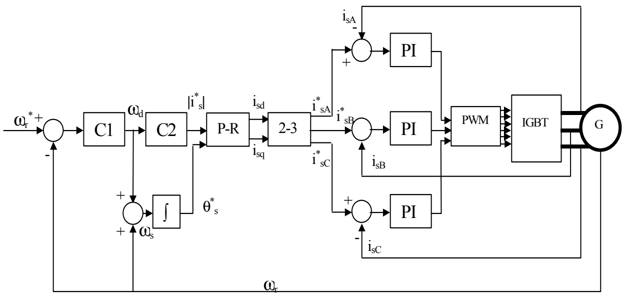

Figure 1. Classic scalar control of an induction machine.

The output of the speed control is the slip (ω_d); on adding the speed of the rotor (ω_r) we get the operating frequency of the stator (ω_s); on integrating this speed, we get the angle position of the stator currents (gives the position of the direct axis with respect to the stationary reference θ_s*).

The magnitude of the stator current with its angle, is the input to the module that transforms polar coordinates to rectangular ones, obtaining the value of the stator currents in "dq" axes in stationary reference (i_{sd}, i_{sq}). These components "dq" are then transformed into three-phase coordinates (i^*_{sA}, i^*_{sB}, i^*_{sC}).

The induction machine is fed by an inverter, controlled by PWM. which works with a 2 kHz fixed commutation, the D.C. voltage bus is 750 V.

With the general structure of a scalar speed control (figure 1), the controllers C1 and C2 are PI controls.

The result of the first simulation (case 1) are present in Figures 2 and 3. We can see the evolution of the speed and the electrical torque with regard to the target.

The controller P.I., C1 and C2, have been tuned via heuristic variation.

It is possible to see in Figure 2, that the generator speed has a big oscillation near the zone $\omega_r = 0$, due to the non linearity of this zone.

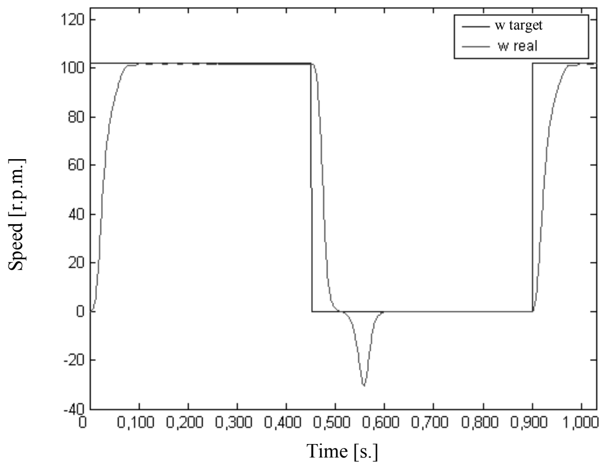

Figure 2. Target speed-mechanical speed (case1).

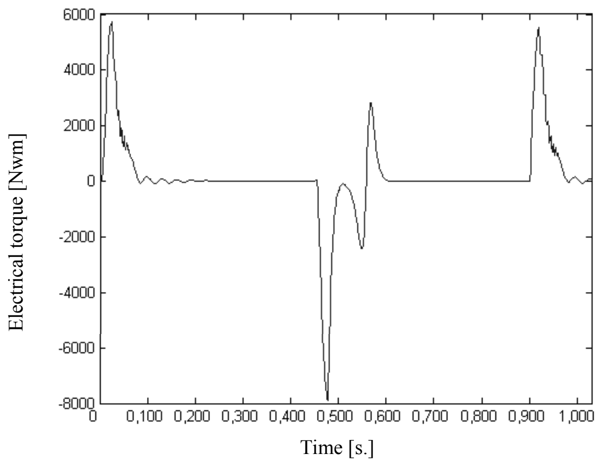

Figure 3. Electrical torque (case 1).

3. Scalar control with fuzzy logic of the induction machine

The following cases have been studied, beginning with the general structure of a scalar speed control (figure 1):

- Case 2: C1 is a PI control and C2 is a Fuzzy control.
- Case 3: C1 and C2 are Fuzzy controls.

A. Case 2

C1 control is the same as in case A, and C2 is a fuzzy control with the next characteristics: Mamdani-type, 6 rules, centroid defuzzification, one input (slip) and one output (stator current).

Those rules make the next relationship between input and output:

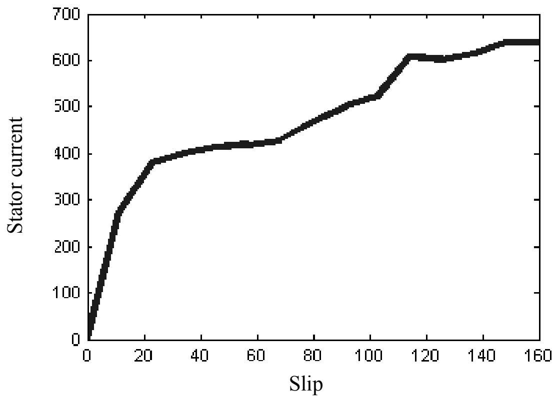

Figure 4. Rules Slip-Stator current (case 2).

B. *Case 3*

In this case two fuzzy controls has been used.

The used Fuzzy control C1 has the next characteristics: Mamdani-type, 64 rules, centroid defuzzification, two inputs (speed error "e" and speed error variation "de") and one output (slip "ω_d"). The speed error rules can see in Figure 4 and the rules of the speed error variation can see in the Figure 5.

The structure of this controller is the next:

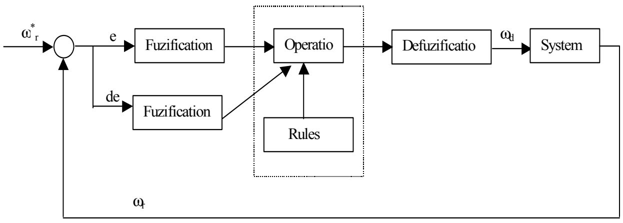

Figure 5. Fuzzy P.I..

Where the speed error "e" is defined as: $e(k) = \omega_r^*(k) - \omega_r(k)$ and the variation of the speed error "de" is the next: $de(k) = e(k) - e(k-1)$.

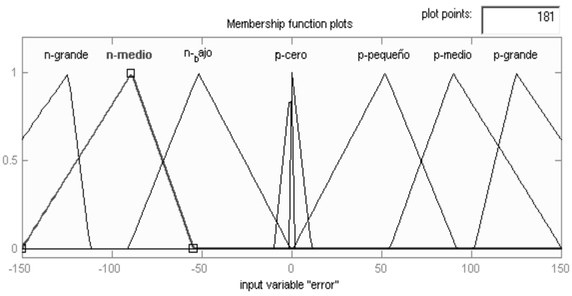

Figure 6. Rules for speed error.

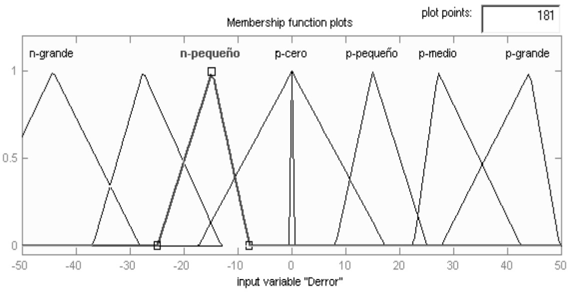

Figure 7. Rules for variation speed error.

The sensibility of the controller has been increased in order to ensure a good response for speed values near cero. The number of rules for this zone has been increased.

The discretization used time is $Ts=2\ 10^{-6}$ s.

The generating equivalent curve due to the mix of the rules and the fuzification curve is the next:

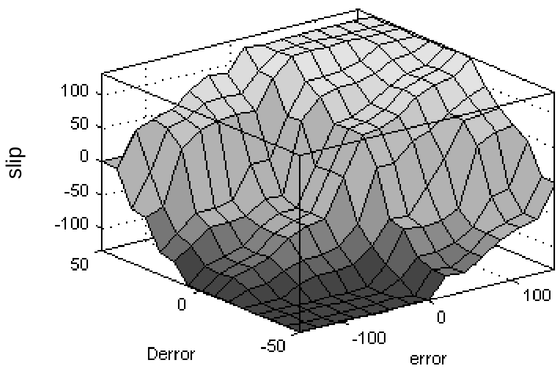

Figure 8. Surface of rules (case 3).

C. *Simulation results.*

The simulation results of the case 2 are presented in Figures 9 and 11, and the simulation results of the case 3 are presented in Figures 10 and 12.

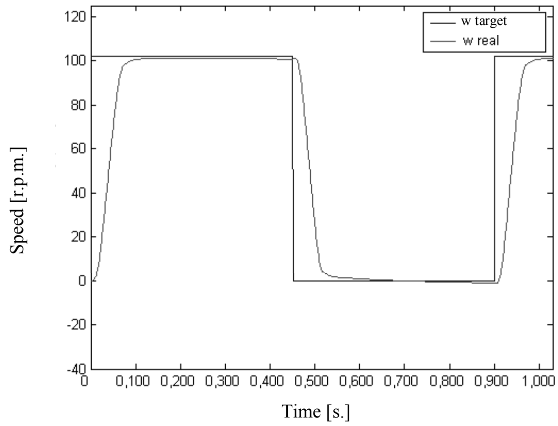

Figure 9. Target speed-mechanical speed (case2).

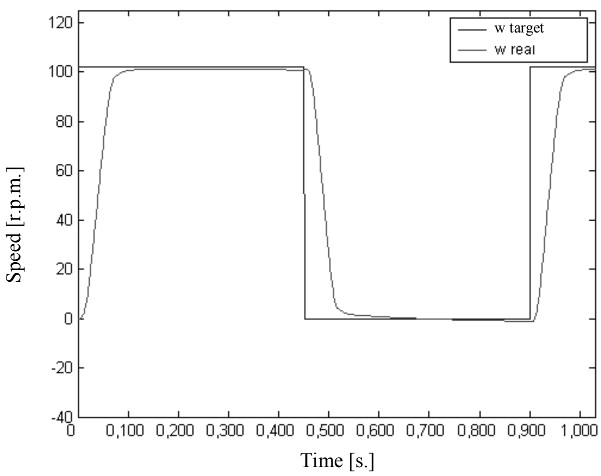

Figure 10. Target speed-mechanical speed (case 3).

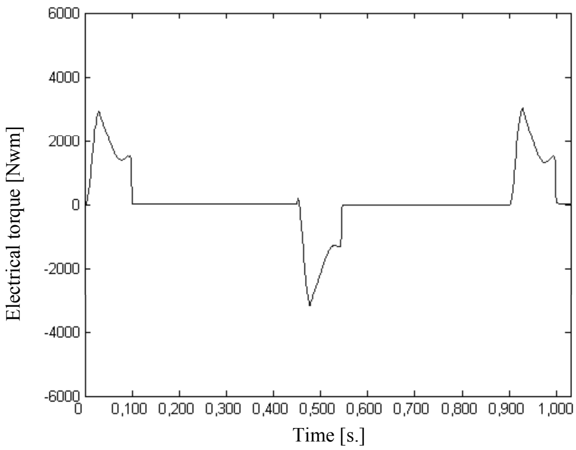

Figure 11. Electrical torque (case 2)

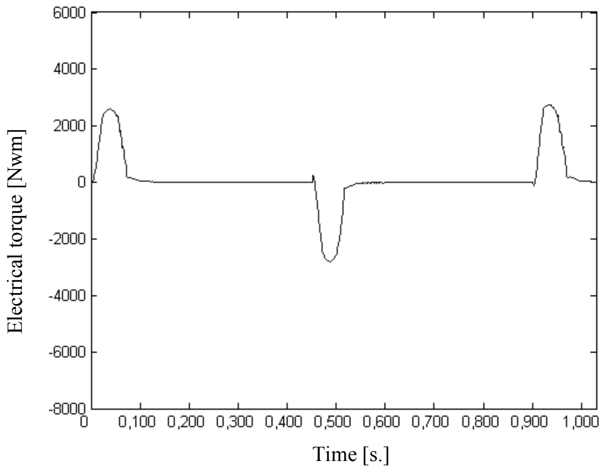

Figure 12. Electrical torque (case 3).

4. Conclusion

With this work, the following conclusions can be reached:

In spite of the easy implementation of traditional control "PI", its response is not so good for non-linear systems. The improvement is remarkable when controls with Fuzzy logic are used, obtaining a better dynamic response from the system. This is seem with clarity in the following figures that represent the machine electrical torque and the speed response, for studied case 1, case 2 and case 3.

The speed response in case 2 and case 3 is quite the same, due to the inertia effect of the motor, but the most effective torque is given in case 3.

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