An Automatic Setting on Soft-Starters for Induction Motors using Fuzzy Control Techniques

José Álvaro de Paiva*, Andrés Ortiz Salazar, André Laurindo Maitelli

LECA, DEE, Universidade Federal do Rio Grande do Norte
CEP: 59.072-970, Natal-RN-BRAZIL

*Centro Educacional Federal de Ensino Tecnico do Rio Grande do Norte,.
CEP: 59001-970, Mossoró – RN – Brazil
jalvaro@leca.ufrn.br, andres@leca.ufrn.br, maitelli@leca.ufrn.br

***Abstract* – This paper describes the development of a microcontrolled soft start system to induction motors, where the start parameters adjustment process of the conventional systems are adjusted automatically by the fuzzy technique. This adjustment is accomplished taking as base to the phase current of the machine and its variation in the time. It is present theoretical and experimental results with conventional induction machine and AC-AC converter. It is showed the good performances of the started automatic fuzzy technique.**

I - Introduction

The Soft-Start systems for induction motors is becoming more presents in the industry. In function of this considerable use, new technologies are appearing in search of an optimization in the motion and in the energy consumption, as it is the case of the soft start and stop with fire angle continuous control,[1]. One of the control techniques is the fuzzy logic control technique, due to its great adaptation and flexibility for different operation condition of the system in general,[2]. The fuzzy logic is a technique based on rules that will define the controlled system operation, establishing conditions and necessary parameters to the desired behavior to the system dynamics.

The main objective of this work is the accomplishment of the parameters adjustment in an automatic way, applying the fuzzy technique to simplify the operator action and to eliminate the need of successive starts to the empiric adjustment of these parameters. In most soft starters systems the microprocessors is used now, the starter parameters are adjusted in a manual way through keys (dip switches) or precision potentiometers. The selection of these parameters is made with base in successive machine starts to obtain a satisfactory behavior in the start and stop, timing initial start angle, the angle variation and maximum current limit.

II - Model and Responce of The Induction Motors

The induction motor is modeled and studied using the " T " model and *d-q* transformation, referred to the rotor flux , as showed in Fig. 1.

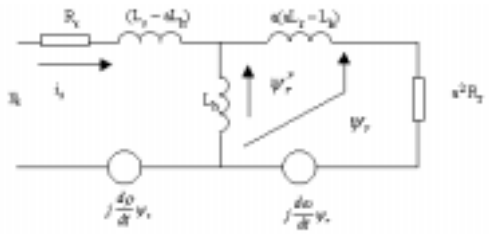

Figure 1 – General model of induction motor

The electric equations of the machine with the rotor parameters referred to the stator are described below:

$$\frac{di_{sd}}{dt} = \frac{u_{sd}}{k_1} - \frac{L_h}{L_r k_1}\frac{d\psi_{rd}}{dt} + \frac{d\rho}{dt} i_{sd} \tag{1}$$

$$\frac{di_{sq}}{dt} = \frac{u_{sq}}{k_1} - \frac{R_s}{k_1} isq - \frac{d\rho}{dt} isd - \frac{L_h}{L_r k_1}\frac{d\rho}{dt}\psi_{rd} \tag{2}$$

$$\frac{d\psi_{rd}}{dt} = \frac{L_h R_R}{L_r} isd - \frac{L_h}{L_r}\frac{d\rho}{dt}\psi_{rd} \tag{3}$$

where i_{sd}, i_{sq}, u_{sd} and u_{sq} are the currents and voltages of the model *dq*,[3], r is the angular position of the rotor in relation to the estator, ψ_{rd} is *dq* component of the rotor flux with reference in the rotor, R_s, R_r is the estator and rotor resistances, L_s, L_r, L_s the estator, rotor and air-gap inductances and $k_1 = (L_s - L_h^2 / L_R)$.

$$T_e = \frac{3}{2} n. \frac{L_h}{L_r} i_{sd}\psi_{rd} \tag{4}$$

$$T_c = D.\omega_{ele} \tag{5}$$

$$\omega_{ele} = n.\omega_{mec} \tag{6}$$

$$\frac{d\omega_{mec}}{dt} = \frac{T_e - T_c}{J} \tag{7}$$

$$\frac{d\rho}{dt} = \omega_{ele} + \omega_{mr} \tag{8}$$

$$\omega_{mr} = \frac{L_h R_r}{L_r} \frac{i_{sq}}{\psi_{rd}} \qquad (9)$$

where T_e is the electric torque, T_c is the load torque, ω_{ele} it is the angular speed for a machine of two poles, ω_{ele} is the mechanical speed, ω_{mr} it is the angular speed of the rotor flux , n it is the number of pair of poles, J it is the moment of inertia and D it is the friction coefficient.

In the Figures 2 and 3 we can observe, respectively, the behaviour of the phase current in direct start and the rotor speed. For the accomplishment of computational simulations, we used an induction motor with the following parameters:

- *2.2 CV, 220V, 60Hz, 4 poles;*
- R_s=1.63 Ω , R_r =0.74 Ω, L_{lr}=2.1mH , L_{ls}=4.7mH, L_h = 85mH
- J_m=4.5.10^{-3} Kg.m^2 ;T_n =8.144N – m , ω_n = 1725 RPM

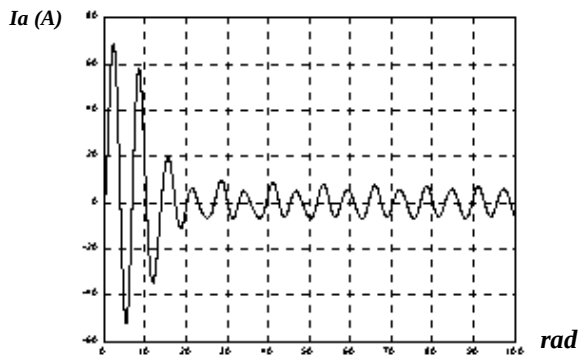

Figure 2 – Behavior of the phase current for the direct start (*20 A/DIV*)

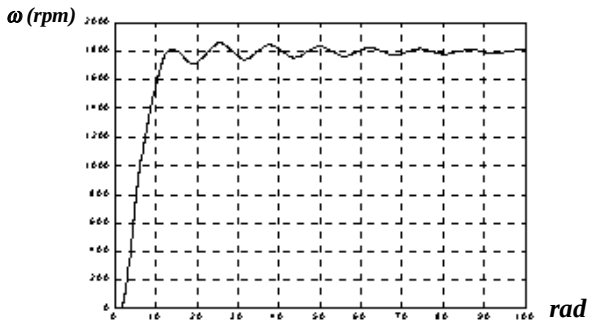

Figure 3 – Behavior of the speed machine in the direct start (*200 rmp/DIV*)

As we can observe, for a direct start the phase current assumes values above the nominal during the transitory and, depending on the load, these currents can reach of five to eight times the value of the nominal current. For this reason, it makes necessary the application of a technique that controls the current levels in the machine.

III – System Description

The microcontroller soft-start system has as main objective allow a progressive aceleration for induction machines, controlling tyristor angle of the three-phase bridge that feeds the machine, limiting the level of current in the system.

The representative scheme of the system is showed in the Fig. 4:

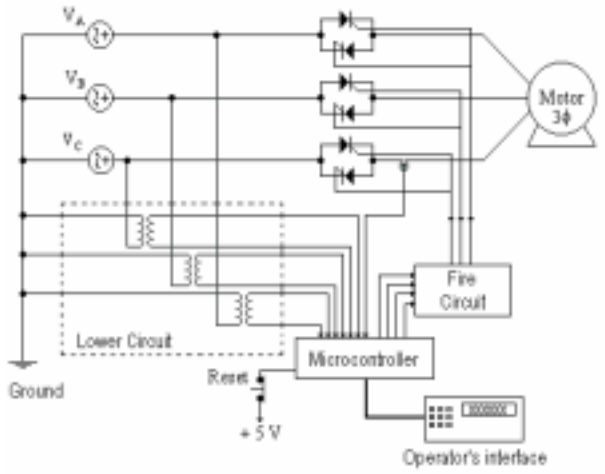

Figure 4 – Representative scheme of the system

For the assembly of this system, we established the following conditions:

- Considered the three-phase sign of the net balanced.
- Accomplished fittings in the three-phase sign lowered inside of the limit from 0 to 5V for the perfect synchronism in the A/D conversion .
- Squared the sign input three-phase for we obtain the synchronism.
- Discarded the effects of the load on the microcontroller operation .

When beginning the system, the fire angle of tyristors it is placed in 180° and, depending on the current value in the winding machine, this angle is reduced until a minimum value, increasing the effective value of tension. The start is made by system operator through a keypad and a display, according to the control program recorded in a FLASH memory existent in the microcontroller.

To make compatible the signal levels for the microcontroller and motor, three interface circuits were built, that are:

- *Lower Circuit* - has the purpose of lowering the sinusoidal tension of 220 Volts for 5 Volts;
- *Fire Circuit* - high level of power of the pulses from the microcontroller.
- *Sensor Circuit* - that is responsible for the reading of the current level.

The microcontroller used is the Motorola® 68HC16Z1, that it operates for 16.78 MHz with 16 bits of

data and 10 bits in the conversion A/D. This microcontroller has 8 channels A/D and 34 programmable digital channels.

The control program is being developed in the Micro-C language, [4], that it is similar to the language C pattern, but it possesses specific functions for the mentioned microcontroller. The algorithm includes sampling functions, zero crossing detection, load current monitoring, keyboard reading and shipping of pulses. For the accomplishment of the sampling of the sign three-phase of the net, we used the interruption resource, and all the temporisation made by the internal variables of the program based on accountants of interruptions.

In the conventional method of soft start, the operator should program some input parameters in the system, in a way to establish the angle variation. The parameters of input the healthy system are:

- *Start Time (ts)* - Time that is fastened in the system so that the angle leaves it a maximum value (established by operator) and be decreased until the minimum value for the system to enter in regime.
- *Pedestal Voltage (Pd)* - Minimum Level of tension so that the soft start is guaranteed and it holds.
- *Maximum Current (Imax)* - Maximum of the limit current so that the increase of the effective tension is enabled in the start.

The fuzzy logic control accomplishes the adjustment of the parameters in an automatic way, eliminating the need of successive starts for the empirical adjustment of these parameters.

III.1 - Theoretical Aspects of the Fuzzy Logic Control

The theory of fuzzy logic is an alternative to the classic method of control and has as the main purpose, to supply a behavior wanted for the system in subject without the need of its mathematical model knowledge, facilitating like this, the control in non linear systems.

The rules are established with base in the range of variation of the variable and range will compose the membership set or Fuzzy Set, that it will count the pertinence degree of the numeric value of the variable in the universe of the rules. The Fig. 5 illustrates block diagram of the idealized control system with fuzzy controller:

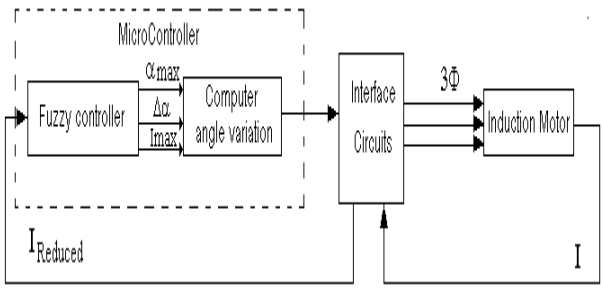

Figure 5 – Block diagram of the idealized system

The fuzzy controller divides in three different parts that are: Fuzzifier, Inference's machine, and Defuzzifier.

The controller that uses fuzzy logic processes linguistic variables instead of numeric variables, through rules defined by the planner, considering the previous knowledge of the system behavior.

For the controller's project it is necessary that is executed the following steps,[5]:

- Selection of the input and output variables;
- Definition of the rules and membership functions;
- Development of the inference mechanism;
- Selection of the defuzzification strategy;

Before the project it is important that the operator to be interrogated to take knowledge of the system characteristics, observing the actions of this, with the purpose of setting up the model of the system with the fuzzy controller.

The control algorithm will execute the following tasks:

- Reading of tension and current of only a phase for temporizing the thyristor's fire in the subsequent phases.
- Digital Reading of square tension, synchronized with net tension in the first ones 90° and reading of square current, synchronized with the phase current in the 90° remaining, for temporization of the thyristor's fire .
- Continuous reading of phase current levels.
- The controller use fuzzy logic for determination of parameters associates to start: initial angle of having left α_{max}, the angle variation ($\Delta\alpha$) and the maximum current(I_{max}).

III.2 - Description of the Controller Using Fuzzy Logic to the Soft Start System for Induction Motors

The implemented controller is taking in consideration the knowledge of dynamics in the conventional system, that is to say, the project takes as base the acting wanted for the system soft-starter for different conditions of machine operation.

For the controller's development we use the modifications proposals in the previous section. The input variables will be the current(I) and its variation in the time(ΔI), and the output parameters be α_{max} (pedestal) , the angle variation ($\Delta\alpha$) during the start process and the current limit (I_{max}) for the variation of the effective tension given to the motor. The Figures 6, 7, 8, 9 and 10 show the membership functions of the variables mentioned above,

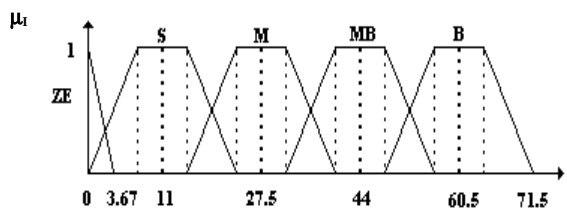

Figure 6 – Membership function for I

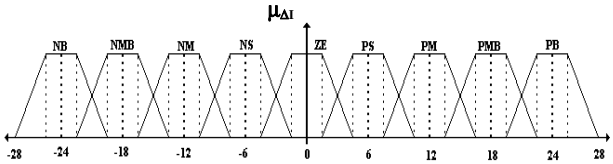

Figure 7 - Membership function for ΔI

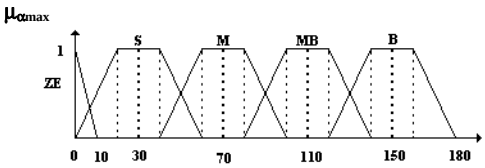

Figure 8 – Membership function for α_{max}

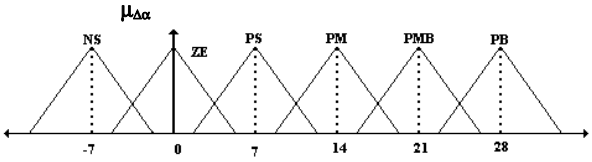

Figure 9 - Membership function for Δα

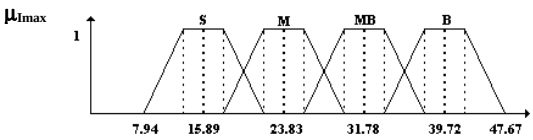

Figure 10 - Membership function for Imax

where the linguistic terms of fuzzy sets are: ZE - Zero; S – Small; M - Medium; MB - Medium Big; B - Big; NS - Negative Small; NM - Negative Medium; NMB - Negative Medium Big; NB - Negative Big; PS - Positive Small; PM - Positive Medium; PMB - Positive Medium Big ; PB - Positive Big .

The fuzzy Rules that relationship the input variables I and ΔI with the output variables α_{max}, Δα and I_{max} can be expressed through tables 1, 2 and 3:

Table 1 – Rules for determination of α_{max}

ΔI \ I	ZE	S	M	MB	B
NB	S	S	S	M	MB
NMB	S	S	S	M	MB
NM	S	S	S	M	MB
NS	S	S	S	M	MB
ZE	S	S	M	MB	MB
PS	S	S	M	MB	B
PM	M	M	M	MB	B
PMB	M	M	B	B	B
PB	M	MB	B	B	B

Table 2 – Rules for determination of Δα

ΔI \ I	ZE	S	M	MB	B
NB	PB	PB	PMB	M	M
NMB	PB	PB	PMB	M	M
NM	PMB	PMB	PM	M	M
NP	PMB	PM	PM	M	M
ZE	PM	PM	PS	ZE	ZE
PS	PS	PS	ZE	ZE	ZE
PM	PS	PS	ZE	NS	NS
PMB	ZE	ZE	NP	NS	NS
PB	ZE	ZE	NP	NS	NS

Table 3 – Rules for determination of I_{max}

ΔI \ I	ZE	S	M	MB	B
NB	S	S	M	M	M
NMB	S	S	M	M	M
NM	S	S	M	M	M
NP	S	S	M	MB	MB
ZE	S	M	MB	MB	MB
PS	M	M	MB	MB	MB
PM	M	MB	B	B	B
PMB	M	MB	B	B	B
PB	M	MB	B	B	B

There are several defuzzification methods. In our case, the method TVFI (Truth Value Flux Inference),[6] is used,

$$\overline{u} = \frac{\sum_{i=1}^{n} u_i \mu_i}{\sum_{i=1}^{n} \mu_i} \qquad (10)$$

where, n is the number of rules and u_i the value of the centroid corresponds to the fuzzy group of the conclusive part of the rule i, μ_i it represents the minimum value of the membership functions of the conditional part of the rule i and $\overline{u}$ is the deffuzifier value.

IV – Flow Diagram of the Control Program

The control program is projected following flux diagram shown in Fig. 11.

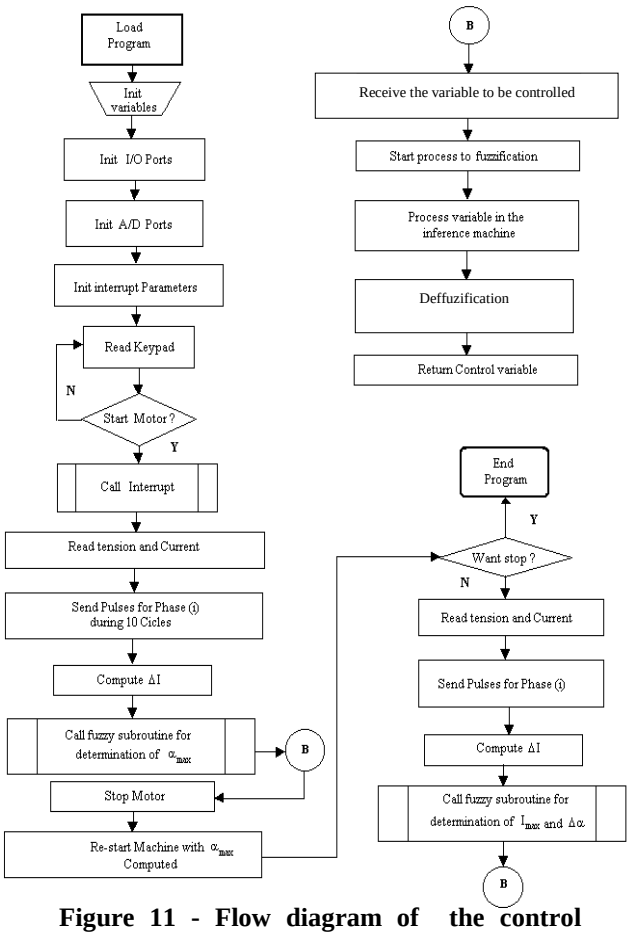

Figure 11 - Flow diagram of the control program

V – SIMULATIONS RESULTS

For the study of the induction motor driving behaviour with fuzzy control, we considered the same machine mentioned in the item II. We accomplished simulation for different loads and start angles. The Figures 12 and 13 show the behaviour of the phase current (I_a) and the rotor speed (ω), respectively for a start at 135° with minimum load torque. Several experiences were doing with different loads from 0 to 100% of the nominal value, getting to start the machine without the high over current value of the conventional methods.

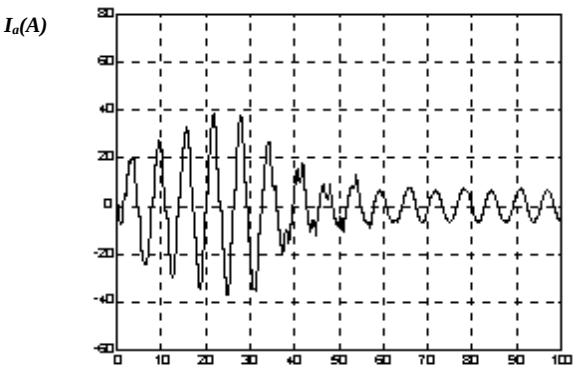

Figure 12 – Phase Currente at 135° with minimum load torque *(20 A/DIV)*.

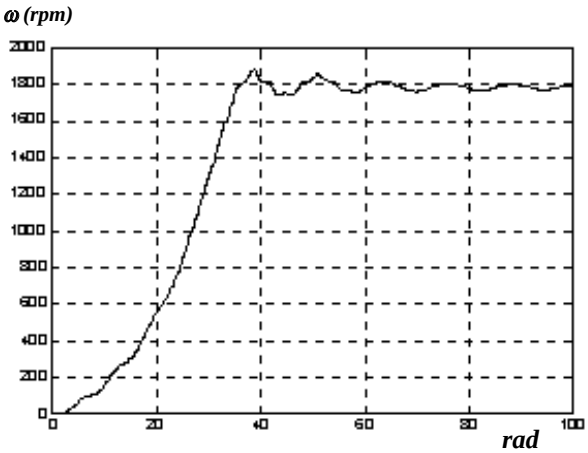

Figure 13 – Angular Speed with minimum torque *(200 rmp/DIV)*.

VI – EXPERIMENTAL RESULTS

The Figures 14 e 15 shown the phase current behaviour of the induction motor in direct start and the start with Fuzzy controller in real time, respectively.

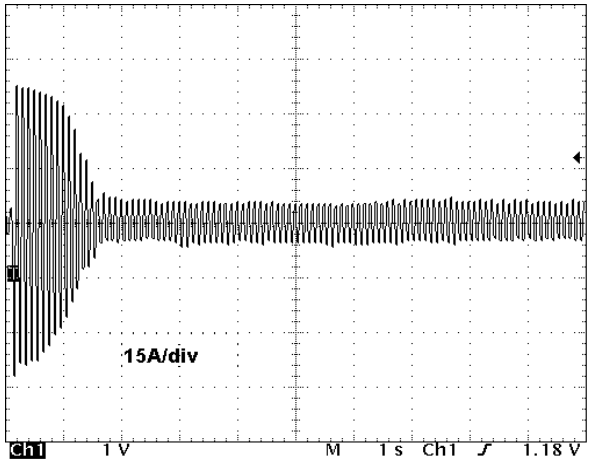

Figure 14 – Phase Currente at direct start

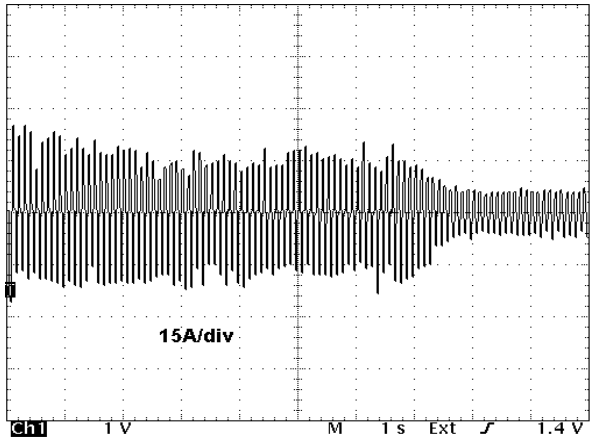

Figure 15 – Phase Currente with fuzzy controller

As we can observe, in the direct start we have a maximum level of current in the order of 36 A, and in the start controlled by the fuzzy technique we obtain to 28 A. This maximum limit of current can be decreased through the manipulation of the membership functions and also of the matrix of fuzzy rules. Another important aspect, is that the controller is self adjustable to different load conditions.

VII - CONCLUSIONS

The search of improvements in systems in the technological area is very important, considering that the technology is in constant development, and a system that assists to several applications has to adapt to these changes. Observing the existent limitations in the conventional method of soft start for induction motors, if became necessary to research in a new control way.

The control technique for fuzzy logic appeared as a simple alternative and adapted to our application.

The objectives intended with this study line can be described as:

- The search of a better use of the microcontroller resources .
- The research and assimilation of knowledge of new control strategies in the field of power electronics with the use of Fuzzy Logic technique.
- The improvement of the system motion and automation of the process of soft start for induction motors.

After simulations in the system controlled by fuzzy logic for different conditions, the behaviour of the motor model was satisfactory, considering that the preset current limits were respected and the speed reached its nominal value quickly. These results will be of great importance for the implementation of the control program in real.

VII. ACKNOWLEDGMENT

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