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Implementation Fuzzy ADRC Controllers for an RLC Circuit in Harmonic Detection

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Abstract. This article presents an LCR Circuit in an induction motor as a second-order system. Thus, the first part implements the active disturbance rejection control (ADRC), and then the implementation of the Fuzzy ADRC controller will be simplified by the tuning technique. The article also presents the LCR circuit in an induction motor that uses the plant transfer function. The response of the simulations is shown in the Bode diagram.

Keywords. Control ADRC, Control Fuzzy ADRC, RLC circuit, Second Order Differential Equation.

1 Introduction

A pronounced frequency-dependent behavior of an equivalent inductance in a three-phase induction motor (IM) has been analyzed several times. Generally, the equivalent the inductance of an IM, i.e., the leakage inductance seen from the stationary stator side, is sometimes determined as the sum of the stator and rotor inductances, both constant [1], [2]. An active disturbance rejection control (ADRC) serves as a low-pass filter (LPF) in the APF harmonic detection algorithm. The

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tracking Differentiator (TD) in active disturbance rejection control (ADRC) serves as a low-pass filter (LPF) in the APF harmonic detection algorithm. Compared to traditional harmonic detection algorithms, the improved strategy resolves the contradiction between speed, accuracy, and excess filtering. The traditional $i_p - i_q$ harmonic detection algorithm uses a Butterworth filter to filter out AC components. Although the Butterworth filter has better-filtering effects, it will have a large overshoot. The paper referenced in [5] presented a new approach for active disturbance rejection position fuzzy controller of bearingless induction machine. On the other hand, in the article, [4] was proposed as a control variable for the radial position problem, in which ADRC control is used to improve the dynamics of the closed-loop system when a load change occurs at the output of the system. The article describe study the implementation of an ADRC control in the RLC circuit in induction motor. In the section 2, present model mathematical. In the section 3 present the ADRC controller. In the section 4, present Fuzzy ADRC controller. In the section 5, with the conclusions are made.

2 Mathematical model

The RLC circuit consists of a resistance R (ohm), an inductance L (henry), and a capacitance C (farad). To simulate the RLC circuit in Figure (1) and apply the PID, ADRC and fuzzy-ADRC controllers, it is first necessary to mathematically model the entire system to obtain the system transfer function of plant.

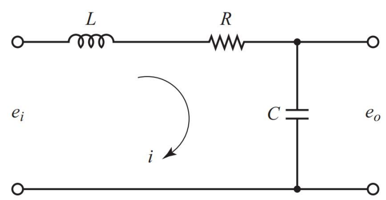

Figure 1: RLC circuit in induction motor. Source: Own

$$L\frac{di}{dt} + Ri + \frac{1}{C}\int idt = e_i \tag{1}$$

$$\frac{1}{C}\int idt = e_0 \tag{2}$$

Since equations (1) and (2) are a system that represents the circuit in Figure (1), it is possible to apply the Laplace transform to obtain a transfer function model of the circuit, assuming that the initial conditions are null. The plant transfer function is classified as the ratio of output and input, thus taking e_i as the system input and e_0 being the system output, it has the following plant transfer function:

$$P(s) = \frac{1/LC}{s^2 + \frac{R}{L}s + \frac{1}{LC}} \tag{3}$$

It is also possible to observe this system in a state space model as follows:

$$\ddot{e}_0 + \dot{e}_0\frac{R}{L} + e_0\frac{1}{LC} = e_i\frac{1}{LC} \tag{4}$$

Where the state variables are $x_1 = e_0$ and $x_2 = e_0$. The input and output variables are given by: $u = e_i$ and $y = e_0 = x_1$. In this way it is obtained:

$$\begin{aligned} \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} &= \begin{bmatrix} 0 & 1 \\ -\frac{1}{LC} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{LC} \end{bmatrix} u \\ y &= \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \end{aligned} \tag{5}$$

According to [3] for any second order system it is possible to associate a transfer function in terms of natural frequency (ω_n) and damping coefficient (ϵ) we have:

$$H(s) = \frac{\omega_n^2}{s^2 + 2\epsilon\omega_n s + \omega_n^2} \tag{6}$$

where $\omega_n = \sqrt{\frac{1}{LC}}$ and $\epsilon = \frac{R}{2L\omega_n}$

3 ADRC Controller

The article describe a LCR Circuit in an induction motor is characterized as a second-order system, is given as:

$$\ddot{y} = f(y, \dot{y}, d, t) + bu \tag{7}$$

Where y is the position, u is the input parameter, b is a constant, d is an unknown parameter (external perturbation) and $f(y, \dot{y}, d, t)$ is known as the generalized perturbation of the system and its knowledge not required for controller design and implementation. The only information needed is its real-time estimated value. Let $\tilde{f}$ be the estimate $f(y, \dot{y}, d, t)$ at a time t, then the control law proposed by the ADRC control method is as follows:

$$u = \frac{-\tilde{f} + u_0}{b} \tag{8}$$

The controller implementation can be simplified, so that when applied to equation (7), makes the closed-loop system equal to $\ddot{y} = u_0$.

4 Fuzzy ADRC Controller

In this part, the ADRC controller adopts a nonlinear state error feedback strategy, which can significantly improve the efficiency of feedback control. Considering nonlinear state error feedback is based on the principle of "small error, big gain, big error, small gain," appropriate selection of parameters and linear range for segmentation, and using different gain controls in different ranges can achieve the effect of the fast adjustment.

Under the condition of position sensor, ω is the known quantity, its the differential is also a known quantity and the state equation of position loop is available:

$$\begin{aligned} \dot{x}_1 &= x_2 = \frac{d\theta}{dt} \\ \dot{x}_2 &= \frac{d^2\theta}{dt^2} = h(x_1(t), x_2(t), w(t)) + bu(t) \\ y &= x_1 = \theta \end{aligned} \tag{9}$$

According to rotational transformation is obtaining parameters $\beta_0, \beta_1, \beta_2$. Finally, with the principles of tuning Fuzzy ADRC parameters, we can obtain Fuzzy-ADRC. Its structure is shown in Figure (2), and its structure with rotational transformation is shown in Figure (3).

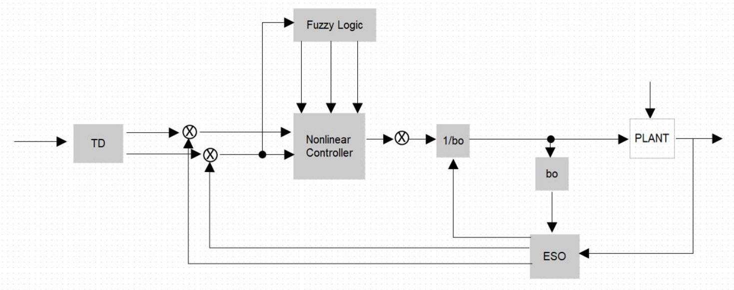

Figure 2: Fuzzy-Self-adapted ADRC structure. Source: Own

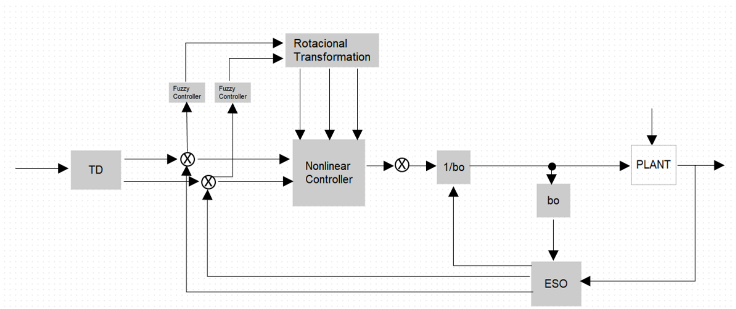

Figure 3: Fuzzy-Self-adapted ADRC structure with rotational transformation. Source: Own

It is said to see that each piece of the position Fuzzy-ADRC controller is construed, Its entire control frame is demonstrate in Figure (2). The x_1 is the monitoring signal of θ^* , x_2 is the differential signal of θ^* , z_1 is the monitoring signal of θ , z_2 is differential signal for z_1, z_3 is system observation of the incertitude piece of the perturbance that is $w(t)$ as the observation for the certain part, where the differential is different from the differential signal in a controller, its effect is not amplified, but disincentive to the noise signal.

4.1 Fuzzy controller model

This article introduces the fuzzy logic controller, according to the input of , e_1, Δe_1, e_2, Δe_2 and using fuzzy control rules to change the ADRC parameters $\{\Delta i_x, \Delta i_y\}$, with rotational transformation is obtained approaching the optimal parameters $\{\beta_0, \beta_1, \beta_2\}$. To meet the requirements of the $\{e_1, \Delta e_1, e_2, \Delta e_2\}$ parameters of the Fuzzy ADRC, in the controller, the fuzzy variables are e_1, e_2, $\{\Delta i_x, \Delta i_y,$, in your domain, seven language sets defined such as { (NNB), (NNM), (NNS), (QQZ), (PPS), (PPM), (PPB) }. In the select the input variables e_1, e_2 for the Gaussian association function, output variables $\{\Delta i_x, \Delta i_y\}$ for triangular membership function. In this article, the basics e_1, domains are $[-20, +20]$, a range variation of $[-1, +1]$ and e_2 domains are $[-20, +20]$ for a range variation of $[-1, +1]$. Thus the variables $\{\Delta i_x, \Delta i_y\}$, with rotational transformation is obtained $\{\Delta\beta_0\}$ $\{\Delta\beta_1\}$,$\{\Delta\beta_2\}$ domains are $[-12, +12]$, $[-12, +12]$, $[-1.2, +1.2]$. Fuzzy reasoning using the Mamdani type and defuzification is the weight average method. According rules of the human

Table 1: Linguistic labels adopted to describe fuzzy sets.

Label	Signification
NNB	Negative Big
NNH	Negative Huge
NNM	Negative Medium
NNS	Negative Small
QQZ	Quasi- Zero
PPH	Positive Huge
PPS	Positive Small
PPM	Positive Medium
PPB	Positive Big

mind, diffuse control rules are devised by summarizing the technical knowledge of the engineering team and practical experience. The adjustments gave rise to the error and the change in the error pertinence functions illustrated in Figures (4), (5) and the output pertinence functions represented in Figure (6) and the rules summarized in Table (2). For $\{\Delta i_x, \Delta i_y\}$ parameter configuration, a fuzzy control table is formed, as demonstrated in Tables (2) and (3) .

Table 2: Rules for x-axis fuzzy controller.

d f	NNB	NNM	NNS	QQZ	PPS	PPM	PPB
NNB	NNH	NNH	NNH	NNB	NNM	NNS	QQZ
NNM	NNH	NNH	NNB	NNM	NNS	QQZ	PPS
NNS	NNH	NNB	NNM	NNS	QQZ	PPS	PPM
QQZ	NNB	NNM	NNS	QQZ	PPS	PPM	PPB
PPS	NNM	NNS	QQZ	PPS	PPM	PPB	PPH
PPM	NNS	QQZ	PPS	PPM	PPB	PPH	PPH
PPB	QQZ	PPS	PPM	PPB	PPH	PPH	PPH

Table 3: Rules for y-axis fuzzy controller.

g h	NNB	NNM	NNS	QQZ	PPS	PPM	PPB
NNB	NNH	NNH	NNB	NNB	NNM	NNS	QQZ
NNM	NNH	NNB	NNB	NNM	NNS	QQZ	PPS
NNS	NNB	NNB	NNM	NNS	QQZ	PPS	PPS
QQZ	NNB	NNM	NNS	QQZ	PPS	PPS	PPM
PPS	NNM	NNS	QQZ	PPS	PPS	PPM	PPB
PPM	NNS	QQZ	PPS	PPS	PPM	PPB	PPH
PPB	QQZ	PPS	PPS	PPM	PPB	PPH	PPH

According to the table of allocation of members of fuzzy set Tables (2) and (3). and the fuzzy control model of parameters, and with diffuse synthetic reasoning to project diffuse matrix, then defuzzification and correction parameters found $\{\Delta i_x, \Delta i_y\}$, with rotational transformation is obtained $\{\Delta\beta_0, \Delta\beta_1, \Delta\beta_2\}$ and replaced it in the equation:

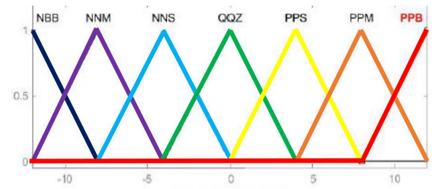

Figure 4: Membership functions of input variables (e). Source: Own

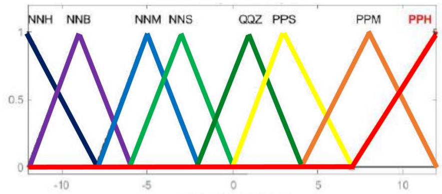

Figure 5: Membership functions of input variables $(\Delta)e$. Source: Own

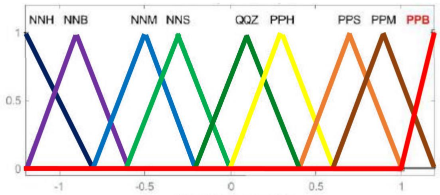

Figure 6: Membership functions of output variables. Source: Own

$$\beta_0 = \beta_0^{'} + \Delta\beta_0 \tag{10}$$

$$\beta_1 = \beta_1^{'} + \Delta\beta_1 \tag{11}$$

$$\beta_2 = \beta_2^{'} + \Delta\beta_2 \tag{12}$$

Where variables $\beta_0, \beta_1, \beta_2$ is the nonlinear controller initial value. With $\beta_0^{'} = 0$, $\beta_1^{'} = 0$, $\beta_2^{'} = 0$, $\{\Delta\beta_0\}$ $\{\Delta\beta_1\}$,$\{\Delta\beta_2\}$ domains are $[-12, +12]$, $[-12, +12]$, $[-1.2, +1.2]$. Thus $\beta_0 = \Delta\beta_0$, $\beta_1 = \Delta\beta_1$ and $\beta_2 = \Delta\beta_2$. The fuzzy ADRC controller is well optimized because there is a good tuning of the fuzzy ADRC controller. The controller that obtained the best performance concerning the step response was the fuzzy-ADRC controller, as it eliminates the overshoot completely. However, even with excellent results, the step response is slower than the system response with the controller PID. Below Figure (7) shows the response of the simulations in the Bode diagram for all transfer functions.

5 Conclusions

This article aimed to present an LCR circuit in an induction motor as a second order system. Thus, in the first part, an active disturbance rejection control (ADRC) was implemented, and then an implementation of the Fuzzy ADRC controller was obtained, which was simplified by the tuning technique. The simulation responses were presented in the Bode diagram.

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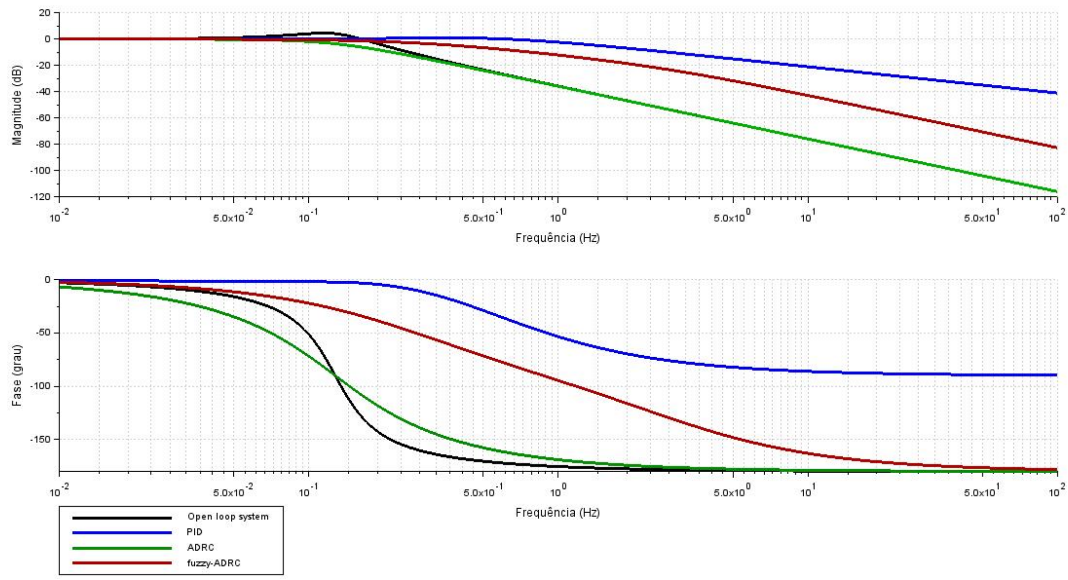

Figure 7: Bode diagram. Source: Own

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