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Article

Speed control of 3 phase induction motor using an RC circuit as a start signal

Control de velocidad de un motor trifásico de inducción usando un circuito RC como señal de arranque

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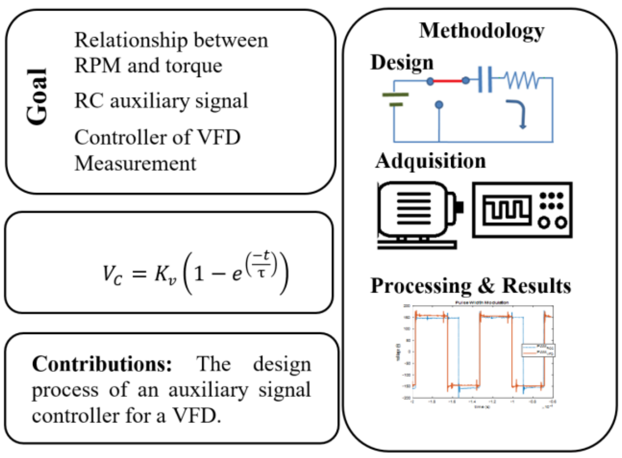
Abstract

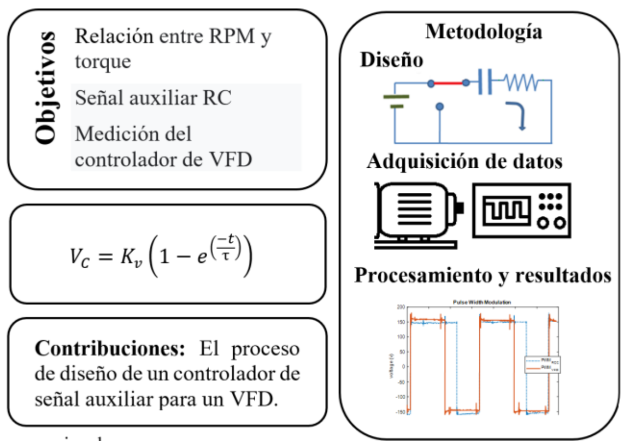
rcoming Resistance of the initial condition in three-phase electric motors is essential in applications where it's had high initial consumption demand, such as HVAC Systems, pumps or compressors, higher torque ensures reliable operation even under varying conditions of load. These motors can provide efficient operation for heavy loads or when starting under load conditions. In this work an RC circuit is used for starting signal of a 3-phase induction motor, advantages of using an RC circuit against a conventional variable frequency controller are shown in the article



Torque, Circuito Aplicaciones

Resumen

Superar los valores resistivos en la condición inicial de los motores eléctricos trifásicos es esencial en aplicaciones donde necesitan una alta demanda de consumo inicial, como sistemas HVAC, bombas o compresores, un par más alto garantiza un funcionamiento confiable incluso en condiciones variables de carga. Estos motores pueden proporcionar un funcionamiento eficiente para cargas pesadas o al arrancar en condiciones de carga. En este trabajo se utiliza un circuito RC para la señal de arranque de un motor de inducción trifásico, en el artículo se muestran las ventajas de utilizar un circuito RC frente a un controlador de frecuencia variable convencional.



Torque, Circuito Aplicaciones

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Introduction

Detailed examination of motor starters, advances in torque control algorithms and the evolution of electric motor controllers emphasize the importance of integrating sophisticated technologies for efficient and reliable operation of motors.

Since the start of the design and development of AC motors, classical theories have emphasized the significance of effective control for electric motors in industrial environments, which heavily depends on the utilization of electric motor starters (Anderson J., 1922). Another example is the use of electric motors in large-scale farm irrigation systems, which are powered by a single-phase grid supplemented by solar photovoltaic energy and battery storage. The system employs TS-fuzzy based direct torque control to enhance robustness during load variations (Sareddy, et al., 2024). Also, it is essential to meticulously examine the components of these starters and carefully select the principles governing their operation. However, this involves exploring the array of starter types available and carefully assessing their applicability across diverse contexts. Such thorough scrutiny is paramount to ensuring the seamless functionality of electrical systems.

Many studies have examined the potential for generalizing speed algorithms of starting and integrating them into a comprehensive. (Abbas, et al., 2024). Nevertheless, in the control of adjustable speed drives, the reliable performance of inexpensive digital integrated circuits is nearing a point where traditional control procedures may be supplanted by novel algorithms and methods that better leverage their speed and functional capabilities. (Ilic-Spong, et al., 1987).

Several recent papers have explored sophisticated technologies concerning to design of electric motor drives, examining their evolution in structure, converters, heat dissipation, volume optimization, and electromagnetic interference. (Zhang B, et al., 2022) and (Bolognani S, et al., 2009).

In numerous industrial and commercial scenarios, the initial surge experienced by electric motors, particularly those operating on three-phase systems, however, presents significant hurdles due to its detrimental impact on both power grids and equipment. Start the electric motor study delves into the electrical traits and practical advantages associated with optimizing electric motor startups, shedding light on its efficacy in reducing strain on electrical systems and enhancing overall performance. (Hardine Linkha, et al., 2022).

Variable Frequency Drives (VFD) have become an essential technology for controlling electric motors; Many studies explore the benefits of VFDs, their main advantages include energy savings, better process control and longer equipment life. Synthesizes recent scientific research findings to provide a comprehensive overview of the importance of VFDs. (Almeida, et al., 2005)

VFDs enhance process control by allowing precise adjustments to motor speed, leading to improved product quality of the manufacture. This is particularly important in applications requiring specific speed profiles or frequent speed changes. Nevertheless, each innovative electrical apparatus for industrial applications must be thoroughly tested, both during the development process and for compliance testing. The development of a new electrical system should be accompanied by the parallel design of a customized measurement system, with performance specifications tailored to the features of the system under test. (Fiorucci, et al., 2013)

Most motors are designed to operate at a constant speed and provide a constant output; however, modern technology necessitates variable speeds in many applications where electric motors are used. This growing interest has led to extensive research and development aimed at optimizing VFD performance and integrating them more effectively into various industrial processes. Consequently, understanding the energy-saving potential and economic benefits of VFDs has become a critical focus (Saidur, et al., 2012).

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Variable frequency drives have significantly influenced the improvement of global energy consumption. Accordingly, the widespread adoption of variable frequency drives (VFDs) to replace traditional non-adjustable or single-speed variable frequency drive systems could result in significant energy savings globally. For applications that demand high-performance VFDs and precise speed control, ensuring accurate rotor speed information is essential, so installing a reliable speed sensor is necessary. (Ibrahim M. et al., 2013).

Complementary studies could include research where the AMB study enhances rotor speed and stability using a dual-loop control mechanism, while the VFD study optimizes starting torque and energy efficiency in AC motors through the use of auxiliary signals and advanced control algorithms. Both studies share a common focus on improving control and efficiency in motor systems (Pachuau, J., et al., 2023).

In certain industrial applications, it is necessary to start motors with heavy loads, requiring speed control to initiate these systems. However, this presents a challenge because these motors typically start at with linear speed increment. The primary focus of this paper is to provide an account of the design process of an auxiliary signal controller for a VFD. This paper reviews the current state, and trends of measurement techniques and instruments applied for the experimental characterization of variable speed drives using Resistive-Capacitive (RC) Circuit signal for starting condition.

Methodology

The methodology of this paper combines theoretical model of RC circuit with practical analysis to explore the advantages of using RC signal to start three-phase induction motors, providing comprehensive information on how to improve motor starting performance.

Circuit RC

Resistive-Capacitive (RC) circuit is a fundamental component in electrical engineering, The circuit is widely used because it is possible to predict its state behaviour.

The RC Circuit serving critical roles in various applications such as filtering, timing, and signal processing. (Grigorescu et al., 2008). Some studies introduce and analyse innovative applications using the RC circuit as a source of information generation, demonstrating its great reliability for their application. (Hidalgo., 2023).

An RC circuit's primary function is determined by the relationship between resistance (R) and capacitance (C). When a voltage is applied, the capacitor charges or discharges through the resistor, governed by the time constant τ (tau), defined as

$$\tau = RC \quad [1]$$

This time constant determines the rate at which the capacitor charges or discharges, influencing the circuit's behavior in filtering and timing applications.

Box 1

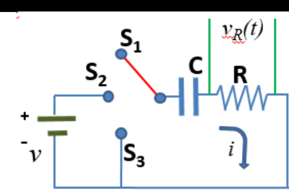

Figure 1
RC Circuit

Source: Own elaboration

The RC circuit in Figure 1 consists of a voltage that charges a capacitor, and a resistor has been connected in series with the capacitor to make the charge/discharge process slower. The switch has three positions (see table 1):

Box 2

Table 1
Capacitor Status

Switch status	Capacitor Status
S_1	initially downloaded
S_2	Loading via R
S_3	downloading via R

Source: Own elaboration

To find the dynamic behavior of the system in the resistance i.e. ($v_R(t)$) with the switch in positions S_2 and S_3.

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As can be seen in figure 1, if the switch changes to S_2, the voltage across the resistor v_R varies in time and the source voltage is divided into voltage of the capacitor and the voltage of the resistance. Using the voltage relationship, the differential equation that describes the behavior of the simple mesh is

$$v = \frac{1}{C}\int i\,dt + Ri \quad [2]$$

If the current is known, we can directly determine the voltage. Using the change to the Laplace domain we can rewrite the equation in the following form.

$$v = \frac{I_s}{CS} + R\,I_s \quad [3]$$

By factoring I_s and ordering we can determine the following transfer function

$$\frac{I_S}{V_S} = \left(\frac{C\ S}{R\ C\ S+1}\right) \quad [4]$$

To determine the current *i* over time it is necessary to apply the Laplace inverse, as shown below.

$$i(t) = \frac{K_v}{R} e^{\left(\frac{-t}{\tau}\right)} \quad [5]$$

Where K_v represents the constant source magnitude in volts. Finally, the voltages are:

$$\begin{cases} V_R = K_v\ e^{\left(\frac{-t}{\tau}\right)} \\ V_C = K_v\left(1 - e^{\left(\frac{-t}{\tau}\right)}\right) \end{cases} \quad [6]$$

Case Study

To carry out the work, a Siemens brand frequency converter was used due to the easy adaptation of the proposed methodology.

A 47 kΩ resistor and a 330 µF capacitor are used to create the motor start signal (see figure 2). The voltage of alimentation of the start signal circuit is 9.5 v.

The principal characteristics of the induction motor are: Rated power 0.246 KW, Rated voltage 220 v, Rated current 0.9 A, Rated Speed 2840 RPM, Efficiency 0.66 and Frequency 60Hz. Figure 2 shows the components used.

Box 3

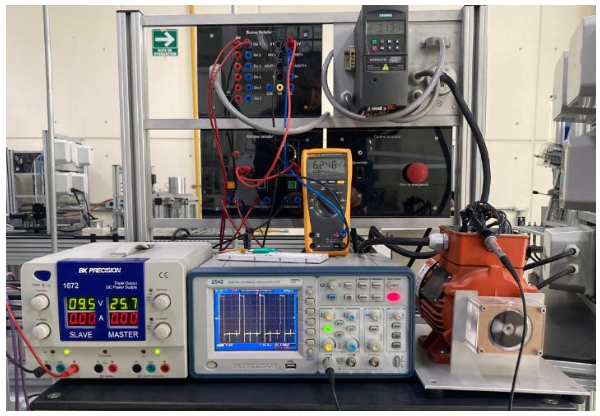

Figure 2
Measuring equipment used in the laboratory
Source: Own elaboration

Results

Solution is presented in three ways:

- **VFD:** corresponds to the measurement curve generated directly by the frequency converter without any external signal, i.e. they are the linear outputs of conventional VFDs.

- **RCC:** It is the measurement response obtained by incorporating RC circuit as an auxiliary signal to start the motor.

- **SIM:** For the signal corresponding to the voltage values resulting from the use of the simulator in Figure 3, it was obtained from equation (6). MATLAB was used for floating point interpolation to simulate the frequency and speed responses for Figures 3 and 4 respectively.

Box 4

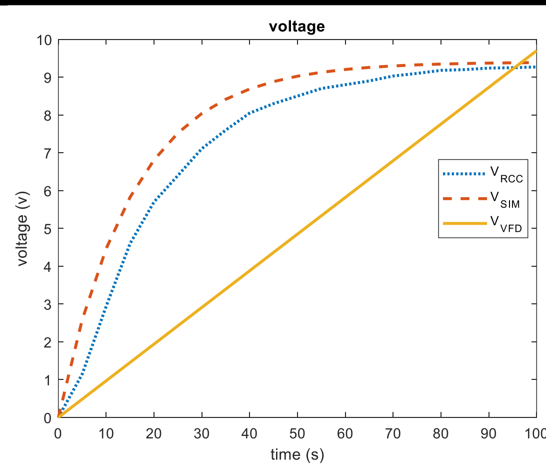

Figure 3
Voltage response
Source: Own elaboration

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Using a simple MATLAB floating point interpolation routine. we can get the following result for simulation frequency and speed Simulation of figures (4 & 5), while the V_{SIM} voltage of simulation in figure 3 is obtained using equation 6.

Box 5

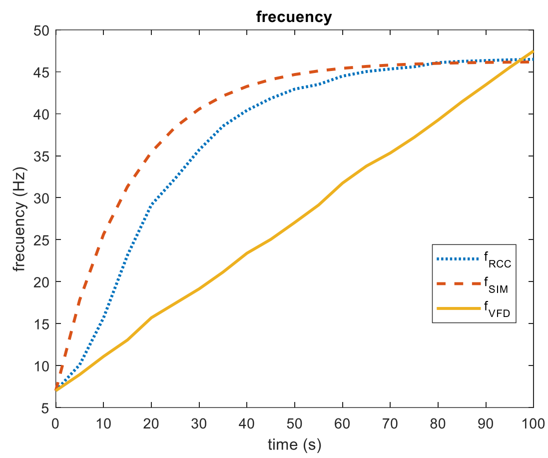

Figure 4
Frequency response

Source: Own elaboration

Numerous studies have concentrated on enhancing power electronics technology, and advancements in semiconductor electronic devices have increased reliability and reduced costs. This progress has led to the development of modern solid-state of the VFD. VFDs are electronic devices that control the speed of induction motors by varying the frequency, offering increased efficiency, reliability, and low maintenance costs. However, they still utilize linear signals for motor starts. (Enemuoh, et al., 2013).

Box 6

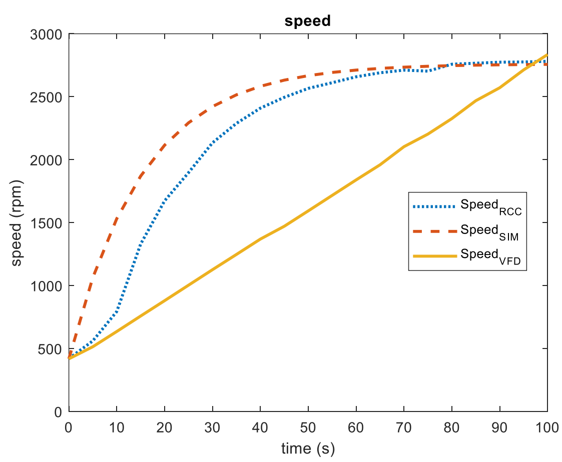

Figure 5
Speed response

Source: Own elaboration

It is evident that the voltage, frequency, and speed outputs of conventional VFDs are linear, which is not optimal for generating sufficient starting torque when the motor is under extreme load. The variations in voltage, frequency, and speed for conventional VFDs are illustrated in the figures 3-5.

When an auxiliary voltage signal is incorporated into the analog input of the frequency converter, the original linear signal from the VFD is changed to a signal with a higher speed at first. This is desirable when the motor is under stress and needs a higher torque to break the moment of inertia.

Box 7
Table 2
Frequency of five times constants τ

time constant	Time (s)	F. VFD (Hz)	F. RCC (Hz)
τ_1	15.51	13.0500	23.1500
τ_2	31.02	19.1400	35.7000
τ_3	46.53	25.0400	41.8300
τ_4	62.04	31.7400	44.4900
τ_5	77.55	35.3300	45.3400

Source Own elaboration

Table 2 shows that the frequency obtained in the laboratory using an RC circuit is higher than the conventional VFD system for the five τ values $[\tau_1, \ldots, \tau_5]$.

The ideal electric motor drive for traction applications in electric vehicles should deliver high torque at low speeds for acceleration and demanding conditions, and low torque at high speeds for regular driving (Ehsani M, et al., 2003).

The relationship between engine power, speed (RPM) and torque is fundamental in the design of electric motors. The instantaneous torque of an angular speed is the power times the angular velocity. Future work will aim to clarify these interrelated concepts and their practical implications. The relationship between frequency and Pulse Width Modulation (PWM) in induced electric motors is fundamentally connected to the concept of speed. The figure 7 below illustrates speeds for different frequency values, corresponding to time τ_1 of Table 2.

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VFDs are amply used in industrial applications because they provide an efficient means of varying the speed and torque of three-phase motors. A VFD utilizes a diode bridge to convert AC voltage to DC, and then reconverts it from DC to AC at a specific frequency used to control the motor's speed. Figure 7 shows the variation in the period of voltage pulses. The data of figure 7 are directly obtained using an oscilloscope by selecting the three different frequency values of time τ_1 (15.51s) on the Siemens frequency converter.

Box 8

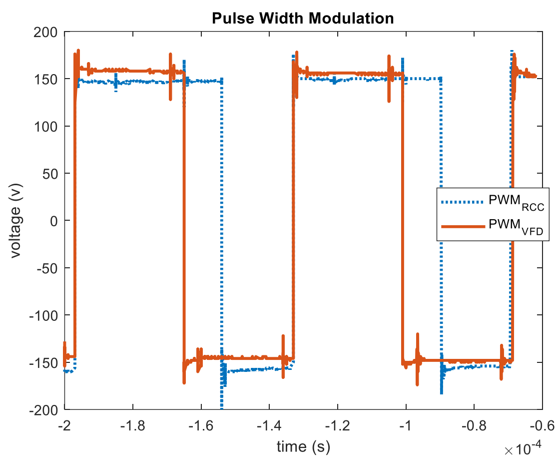

Figure 7
Pulse Width Modulation of time τ_1
Source: Own elaboration

Figure 7 shows the variation in the voltage pulse widths, where the most significant was the pulse width for 23.115 Hz corresponding to the RCC signal, and the smallest was for 13.05 Hz corresponding to the conventional VFD, this method provides a reliable way to adjust the frequency of the three-phase motor to vary the speed.

Conclusions

The use of VFDs has demonstrated benefits for AC motors, including energy savings, enhanced industrial process control, and extended equipment life. However, conventional VFDs typically provide limited, linear starting torque, which is inadequate for motors under excessive starting load conditions.

Advancements in speed control of AC electric motors have necessitated novel improvements in motor starters, including the integration of torque control algorithms, reflecting the evolution of AC motor controllers.

Accordingly, our analysis examines the incorporation of a start signal into a commercial VFD to improve the efficiency and reliability of AC motors, particularly in scenarios where they face high initial starting torque.

The experimental results presented in this paper confirm the effectiveness of using an RC circuit as an auxiliary power signal for VFDs, demonstrating higher starting power and torque under heavy loads. This notwithstanding, this methodological approach leverages the predictability and reliability of RC circuits, presenting a promising direction for future enhancements in AC motor starting control technology.

The paper emphasizes the importance of understanding the relationship between PWM and speed in motor design, particularly for applications requiring high torque at low speeds. Future research will focus on further clarifying these interrelated concepts and their practical implications.

This research focuses on more advanced starting torque solutions that can better protect motors under initial load conditions using a RCC auxiliar signal. Accordingly, the application of more aggressive auxiliar signals, such as antilogarithmic signal through an instrumentation op-amp, can produce an output frequency response antilogarithm. These techniques are currently used in analog computing and signal processing and will be explored in future research.

The implementation of artificial intelligence introduces new possibilities for addressing complex problems (Guedes 2024). Looking ahead, the integration of neural networks is anticipated to facilitate more precise control mechanisms.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

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Author contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

Juárez Toledo Carlos: Contributed to the project idea, method, and research technique. Conducted data analysis and systematization of results.

Carrillo-Martinez, Irma: Provided advice on systematization and background for the state of the art and development of the proposed method. Supported the design of the mathematical model.

Hernández-Epigmenio, Miguel Angel: Assisted with data analysis and systematization of results and wrote the article.

Camacho-Altamirano, Ulices: Worked on the application of the field instrument, data collection, and systematization of results.

Availability of data and materials

The data were collected and analyzed in the automation laboratory at the Autonomous University of the State of Mexico.

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Abbreviations

AC	Alternating Current
VFD	Variable Frequency Drives
SIM	Simulator Response
τ	tau
RCC	Resistive-Capacitive Circuit
PWM	Pulse With Modulation
op-amp	operational amplifier

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