Article **Journal of Technological Operations**
December 2022, Vol.6 No.18 12-19

Interharmonic currents generated by soft starters in induction motors

Corrientes interarmónicas generadas por arrancadores suaves en motores de inducción

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DOI: 10.35429/JTO.2022.18.6.12.19 Received July 25, 2022, Accepted, December 30, 2022

Abstract

The presence of non-linear loads, as well as the use of induction motors cause the generation of harmonic pollution, which includes frequency components that are not multiples of the fundamental frequency referred to as interharmonics and subharmonics, causing disturbances in the network, being parameters of importance for the evaluation of power quality. Soft starters have shown electrical energy savings for induction motors; however, the present investigation shows a higher generation of interharmonics during starting. The method used for the time-frequency analysis is through the Wavelet Synchrosqueezing Transform, the measurements were made with non-invasive current sensors SCT-013. The results show that the current amplitudes during starting to depend on the load moment of inertia and the phase control according to the type of soft starter, being one of the main causes of interharmonic generation.

Interharmonics, Power quality, Induction motors

Resumen

La presencia de cargas no lineales, así como el uso de motores de inducción ocasionan la generación de contaminación armónica, donde se incluyen componentes de la frecuencia que no son múltiplos de la frecuencia fundamental referidos como interarmónicos y subarmónicos causando perturbaciones en la red, siendo parámetros de importancia para la evaluación de la calidad de energía. Los arrancadores suaves han demostrado un ahorro de energía eléctrica para motores de inducción, sin embargo, la presente investigación demuestra una mayor generación de interarmónicos durante el arranque. El método utilizado para el análisis tiempo-frecuencia es mediante la transformada Wavelet Synchrosqueezing, las mediciones se realizaron con sensores no invasivos de corriente SCT-013. Los resultados demuestran que las amplitudes de corrientes durante el arranque dependen del momento de inercia de carga y el control de fases según el tipo de arrancador suave, siendo una de las principales causas de generación de interarmónicos.

Interarmónicos, Calidad de energía, Motores de inducción

Citation: GUDIÑO-OCHOA, Alberto, OCHOA-ORNELAS, Raquel and JALOMO-CUEVAS, Jaime. Interharmonic currents generated by soft starters in induction motors. Journal of Technological Operations. 2022. 6-18:12-19.

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Introduction

In the industrial sector, induction motors are considered a fundamental part for carrying out various processes (Liang & Ilochonwu, 2010). The use of electrical machines is very important, given that their respective performance is determined from their construction and those components that make it up, however, different conditions of this equipment could reduce the quality of energy, resulting in equipment failures and vibrations (Delgado-Arredondo et al., 2019).

It has been found that they cause certain harmful effects of disturbances such as interharmonics and subharmonics, components that are not integer multiples of the fundamental frequency, due to the speed fluctuations that they can present, torque pulsations, and additionally, network disturbances and premature damage to the equipment (Gnaciński et al., 2021).

These disturbances, in addition to causing the flicker effect (Testa et al., 2007), in induction motors tend to cause local saturation in the magnetic circuit, torque reduction, overheating and temperature in the windings (Gnaciński & Pepliński, 2014). The incorporation of renewable energy sources that include double conversion systems, including a DC link can generate harmonic disturbances, these can also occur at the inverter voltage output (De Rosa et al., 2005).

The main source of generation of interharmonics ranges from non-linear loads and such as frequency inverters, which have been used to control the speed of asynchronous machines, however, they generate a harmful effect on the network in addition to acoustic noise in the equipment (Gnaciński et al., 2019). Going deeper, this is mainly due to having a conversion stage based on a DC link, based on a conversion stage based on IGBT devices (Shen et al., 2016). Various investigations have shown that symmetrical subharmonic and interharmonic components, having the same magnitude, cause effects in voltage fluctuations, being some phase angles in the torque pulsations triggering certain undesirable vibrations which can cause damage to the machine and corresponding torque pulsations to the natural frequency of the first elastic mode (Gnaciński et al., 2022).

Soft starters

Soft starters are very common devices in the industrial sector and control the voltage applied to the motor using thyristor semiconductors (Riyaz et al., 2009), or better known as SCRs. The starting pair carries current in only one direction; therefore, an antiparallel arrangement is required for each phase. By reducing the voltage applied to the motor, its torque is reduced, mechanical wear and savings in electrical energy are achieved, one of its main advantages being less motor wear (Ferreira & Almeida, 2017). One drawback, however, is its reduced starting torque. Figure 1 shows the common architecture of these devices.

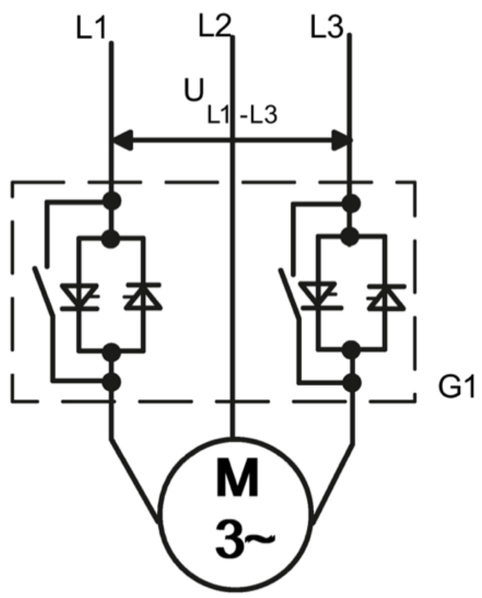

Figure 1 Soft starter with 2-phase control

The control by phase cutting is shown in Figure 2, it is observed that the control exerted by the electronic soft starter on the motor voltage also regulates the starting current consumed and the starting torque generated in the motor during the process. Therefore, unlike the frequency-controlled start and stop of a frequency converter, the frequency remains constant during this process and corresponds to the mains frequency.

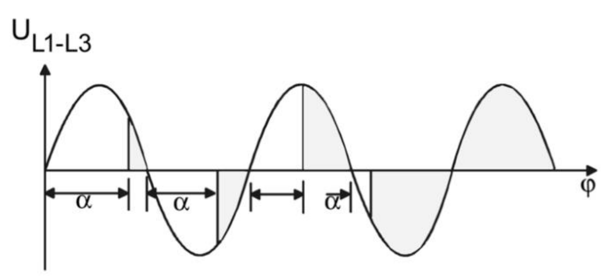

Figure 2 Phase clipping control

ISSN: 2523-6806

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It has been found that soft starters produce a wide range of frequency components, which could cause overvoltages, being the starting process one of the main conditions, depending on the number or configuration of the thyristors, there are leakage currents to earth. when controlling only two phases and a direct line to the motor (Meshcheryakov et al., 2017).

Load and moment of inertia of a motor

When starting and stopping a motor, the relationship that includes the inertia and load inertia of an induction motor affects the performance of the system (Andoh, 2007). The moment of inertia refers to the rotational inertia of a body, it is used to determine the motor torque necessary to achieve a desired speed within a given time.

During the starting of squirrel cage induction motors, the motor torque must exceed the mechanical load torque, the rotor inertia torque, mechanical load, and friction (Verucchi et al., 2005). The equation that describes these behaviors is the following:

$$\mathrm{T} = \mathrm{T}_L + \frac{d}{dt}([j + j_L] \cdot \omega) + B \cdot \omega \qquad (1)$$

Where T is the motor torque, $\mathrm{T}_L$the resistant torque of the mechanical load, j is the moment of inertia of the induction machine, j_L is the moment of inertia of the mechanical load, B the coefficient of friction and ω the angular velocity of the axis.

It has been shown that when there is also a mechanical load in induction motors, current interharmonics are generated in synchronous and asynchronous motors, which induces oscillations in the load torque (Li & Wang, 2014).

In other studies, the effect of the moment of inertia and certain speed-load characteristics were corroborated as the main cause of interharmonics, likewise depending on the type of load in the torque, therefore, fluctuations in the rotational speed are also generated, which could be suppressed for a large value of moment of inertia (Gnaciński et al., 2019).

Asynchronous inertia in motors has also revealed certain effects on the system response, being the sensitivity of the electromagnetic torque to slip, the sensitivity of the mechanical load torque to motor speed and their respective inertia (Chen et al., 2020).

Therefore, it is important to determine the main causes of interharmonic generation, even in devices commonly used for starting electrical machines, and to propose solutions to mitigate harmful effects that impair the evaluation of power quality, as well as affect the efficiency to electrical machines connected to the network.

Signal processing: wavelet synchrosqueezing

The Wavelet Synchrosqueezing Transform (SSWT) is a method for the analysis of signals in the time-frequency domain, it is based on the CWT, which has been useful for the analysis of signals with multicomponents or with non-stationary characteristics (Franco et al., 2012). It has shown to be useful for the detection of power quality disturbances, especially for each frequency component, which, compared to other methods (Chang et al., 2021), has anti-noise characteristics and better resolution, without presenting spectral leaks. The following equation expresses the sum of the added components:

$$s(t) = \sum^{k}{}_{k=1} \; A_k(t) cos\left(2\pi\phi_k(t)\right) \qquad (2)$$

Where $A_k(t)$corresponds to the amplitude of the signal, ϕ_k is the phase, the SSWT is based on the continuous Wavelet transform, it is defined as the following expression established by Daubechies et al. (2011):

$$s(b) \; = \; \Re e \left[C_{\psi}^{-1} \sum_k W_s(a_k, b) a_k^{-\frac{3}{2}} (\Delta a)_k \right] \qquad (3)$$

Methodology

For this study, two triphasic motors of the ABB and Siemens brands were considered respectively, the first corresponds to an induction motor ABB MBT ARM 71 A(48).

ISSN: 2523-6806

No. M97F-25924 coupled to a DC generator and tachometer, the second, a decoupled induction motor GP10-1LE22011AB214AA3 without torque load. The characteristics of these machines are presented in Table 1.

Motor	Rated Power	Poles	Rated Speed	Rated Voltage	Rated Current
ABB	0.75 kW	4	1610 RPM	220 Δ	1.0 A
GP10	0.746 kW	4	1750 RPM	220 Δ	3.2-3.0 A

Table 1 Parameters of the motors

The hypothesis proposed is that the relative moment of inertia of the load affects low power motors, the lower the inertia of the machine and a load at its torque is considered constant, the higher the production of components that are not multiples of the fundamental frequency, they will be reflected in the current of the motor and in the network. This analysis has not been addressed in previous research or studies, only those that determine that speed fluctuations have a direct relationship with interharmonics (Zhang et al., 2005).

The soft starter used to start each motor is from SIEMENS, model SIRIUS 3RW30. The connection is shown in Figure 3.

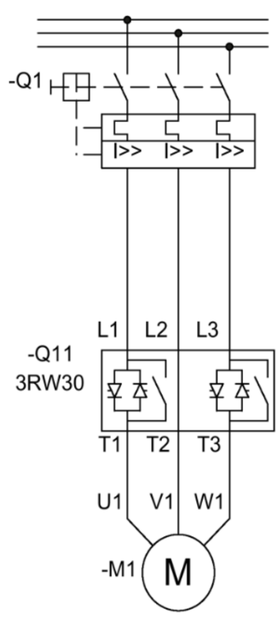

Figure 3 Siemens SIRIUS 3RW30 soft starter schematic

For the respective measurements and data acquisition, SCT-013 non-invasive current sensors were used to obtain the phase currents of the motors, previously calibrated. Data acquisition was by means of a National Instruments DAQ MyRio for data capture, the established sampling time was 500 Hz, this to avoid aliasing problems (Costa & Boudreaux-Bartels, 1999). Subsequently, the data obtained were imported into the Matlab workspace and subsequently the signal processing was applied with the SSWT. Figure 4 shows the established methodology.

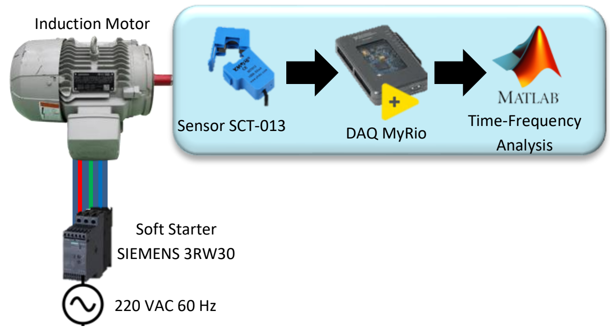

Figure 4 Signal measurement flowchart

The moment of inertia (j) of the motor coupled to the DC generator is 0.01, while the uncoupled motor is 0.1535. For the start of the coupled motor, a starting voltage of the motor was established at 40% to produce a lower start, with a ramp time of 10 seconds, since this influences the motor to reach its nominal speed in that time, if it is a very short time, high currents may appear, and the soft starter may be damaged. The waveform generated during startup for the coupled motor is shown in Figure 5, which presents non-stationary characteristics.

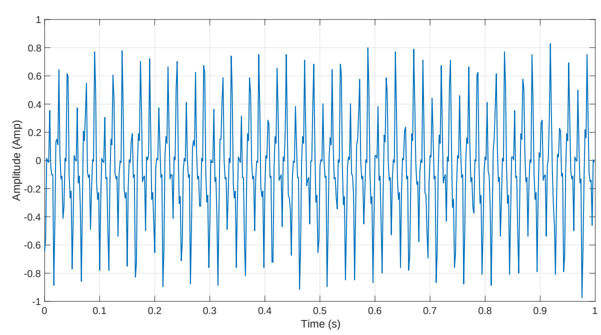

Figure 5 Coupled motor current waveform

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To have an analysis prior to processing with the SSWT, the FFT was applied to detect the most significant frequencies. Figure 6 shows notorious interharmonic content after the even harmonics of 101, 141, 157, 222 and 262 Hz, as well as the presence of 20 Hz subharmonics.

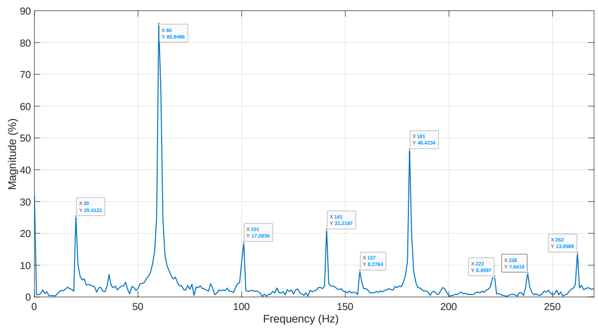

Figure 6 Spectrum with FFT of coupled motor signal

For the SIEMENS motor with no load in its torque, it presented the same non-stationary characteristics only in the first sample just after the start-up, the harmonic and interharmonic content being significant, since the speed was constant, the disturbances were reduced compared to the motor coupled to the torque. DC generator containing up to the fifth sample interharmonic content. Figure 7 corresponds to the signal generated when starting the motor.

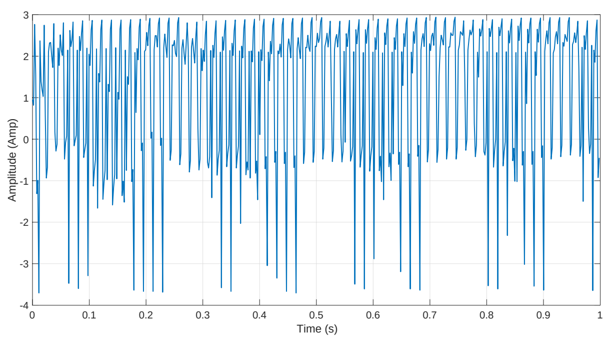

Figure 7 Decoupled motor current waveform

Figure 8 shows interharmonics that exist very close before and after the odd and even harmonics.

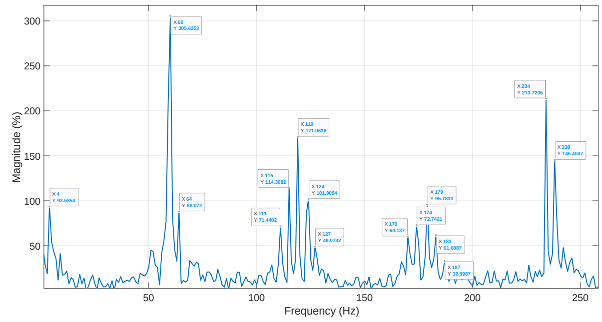

Figure 8 Spectrum with FFT of decoupled motor signal

Results

Once the measurements were obtained, the SSWT function was executed in Matlab, establishing 'bump' as the mother wavelet defined for the spectral analysis, with the sampling frequency defined according to the number of samples, in this case 500 Hz.

In the spectrogram of Figure 9, the presence of significant interharmonics is observed only in the first sample when the motor starts uncoupled, given that when it reaches its maximum speed there are no fluctuations in the nominal speed of the machine, therefore, there is no interharmonic contamination when the nominal speed is reached.

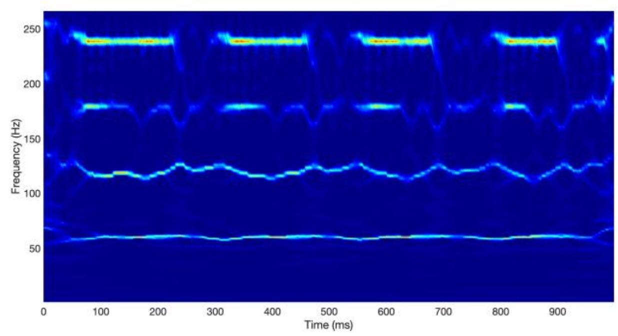

Figure 9 Decoupled motor SSWT spectrogram with interharmonic and subharmonic content

The time-frequency analysis for the motor coupled to the DC generator shows that during starting there is interharmonic and subharmonic content that can be harmful to other equipment connected to the network. The figure 10 shows the definition in which these harmonic disturbances oscillate, which suggests being motors of low power and with a lower moment of inertia, being more damaging than other induction motors with load to their torque, but a moment of inertia much older.

ISSN: 2523-6806

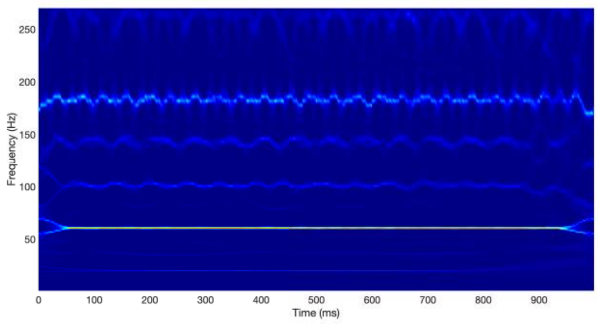

Figure 10 Spectrogram with SSWT of coupled motor with interharmonic and subharmonic content

Gratitude

Addressed to TecNM, Instituto Tecnológico de Ciudad Guzmán campus, for providing everything necessary for the development of this work. Thanks to the CONACYT National Quality Postgraduate Program for the financial support used in part to carry out the experiments.

Conclusions

The results obtained corroborate that induction motors with properties with a lower moment of inertia, with a constant load when started through soft starters that only contemplate two voltage lines for their control, foster interharmonic generation, which could be harmful to equipment connected to the network or other electrical machines. For an induction motor with no load, but with a lower moment of inertia, this phenomenon is still visible, so more research should be carried out in this regard and other types of starts in motors that present lower inertia characteristics of their own in their model and load. applied in torque.

In the case of soft starters, being devices commonly used in the industrial sector, it is important to review the effects that it would have on the quality of energy and efficiency of the machines if it is desired to establish a control strategy for its respective mitigation.

Likewise, time-frequency analysis carried out with the SSWT method guarantees better results for harmonic analysis in the presence of non-stationary signals and with oscillations that could make their visualization difficult.

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