Article **Journal Computational Simulation**
June 2023, Vol.7 No.17 17-23

Eleven level multi-level inverter simulation platform

Software para simulación de inversores multinivel de 11 niveles

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DOI: 10.35429/JCS.2023.17.7.17.23 Received: January 20, 2023; Accepted June 30, 2023

Abstract

Finding the optimal firing angles that minimize the amount of harmonics in a multilevel inverter is an optimization problem. However, since these values are available, testing them in an inverter is not something that can always be done since there is not always a physical inverter to carry out the tests. This paper proposes the development of a Simulink script that allows, from the input angles, to determine the typical ladder output waveform, as well as the harmonic content of an 11-level triphasic multilevel inverter. This will be done by designing the inverter by implementing Simulink IGBTS modules in a configuration of 5 H-bridges in series per phase. Furthermore, Fourier analysis of these waves is carried out in order to characterize the harmonic content of the generated signals.

Multilevel Inverter, Simulation, Harmonics

Resumen

Encontrar los ángulos de disparo óptimos que minimicen la cantidad de armónicos en un inversor multinivel es un problema de optimización. Sin embargo, ya que se tienen estos valores, el probarlos en un inversor no es algo que siempre se pueda realizar ya que no en todo momento se tiene un inversor físico para efectuar las pruebas. En este trabajo se propone el desarrollo de un script de Simulink que permita a partir de los ángulos de entrada, determinar la forma de onda típica de salida en escalera, así como el contenido armónico de un inversor multinivel trifásico de 11 niveles. Esto se realizará mediante el diseño del inversor mediante la implementación de módulos IGBTS de Simulink en configuración de 5 puentes H en serie por fase. Además, análisis de Fourier de estas ondas se lleva a cabo para, caracterizar el contenido armónico de las señales generadas.

Inversor Multinivel, Simulación, Armónicos

Citation: PEÑA-DELGADO Adrián Fermín, JOERS-DELGADO, Carlos, GONZALEZ-MORALES, Amparo, ROMÁN-RIVERA Anette Michel. Eleven level multi-level inverter simulation platform. Journal Computational Simulation. 2023. 7-17:18-23

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Introduction

Multilevel inverters "MLI" are circuits capable of synthesizing an alternating voltage with low harmonic content from one or more direct current sources. They are mostly used in medium and high power industrial applications (Athimoolam & Balasubramanian, 2023).

Generally speaking, MLIs can be classified into two groups according to their power sources. The first one makes use of constant current power supplies "CSMLI" and the second one uses constant voltage power supplies "VSMLI", it should be emphasized that the latter is the most popular within the industrial sector (El-Hosainy et al., 2017). We will base the analysis for the development of the software for the simulation of an 11-level multilevel inverter on the latter. The most prominent feature that has positioned the multilevel inverter as the most attractive option in the industrial sector is its ability to achieve high voltage levels by employing low-cost power semiconductor devices (Shehu et al., 2016) (Atar et al., 2023). Among the most widely used VSMLI topologies are those based on cascaded H-bridge circuits (Colak et al., 2011).

Even though the MLI is capable of providing a voltage with low harmonic content, without the proper selection of a modulation technique, the proper use of modulation techniques guarantees an AC voltage with particular characteristics in THD, VRMS, just to mention a few (Reddy & Narayana, 2020).Figure 1 shows the three-phase cascaded multilevel inverter of "n" levels, where, the number of cells is given by S, VCD represents the supply voltage per cell, and A, B and C represent the phase voltages (Routray et al., 2018).

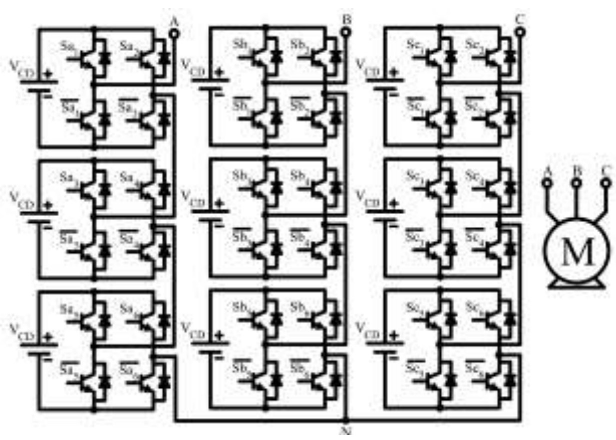

Figure 1 Typical diagram of a multilevel inverter consisting of H-bridges and their switching devices

The correct switching control of the MLI semiconductor devices lies in the use of modulation techniques for their operation (El-Hosainy et al., 2017). Figure 2 illustrates how the typical output shape of the multilevel inverter can be generated by switching the different dc power supplies at specific angles.

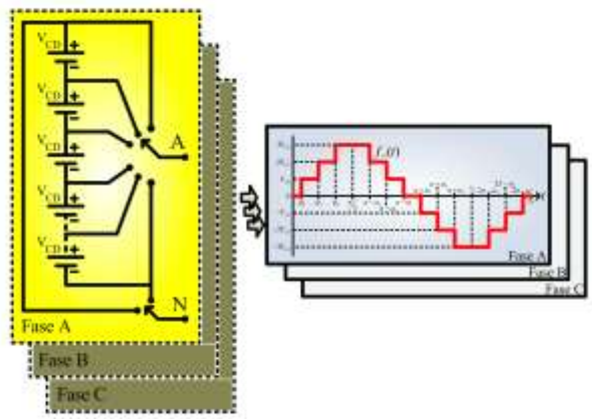

Figure 2 Generation of the staircase output waveform of a three-phase multilevel inverter

The solution of the mathematical formulation of the modulation technique is not relevant in this paper. Here it is assumed that the correct angles needed to produce the inverter output waveform are already known, taken from the literature, or previously calculated.

The interest of this article lies in the fact that once the switching angles have been defined, we will proceed by means of a simulation to obtain the output waveform of the 11-level multilevel inverter.

Although in the literature there are studies to find better ways to obtain the firing angles of multilevel inverters, there is no specific article where they focus on the development of a simulation platform to make use of the angles, determine the waveforms of phase voltage, line, as well as the harmonic content of the output waves of a multilevel inverter, see Figure 3 (Dahidah et al., 2008; Etesami et al., 2018; Reddy & Narayana, 2020). In study we will focus on performing this simulation for 11-level three-phase multilevel inverters.

ISSN 2523-6865

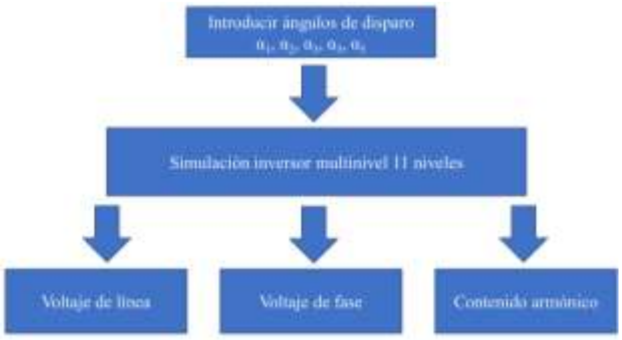

Figure 3 Experimental Methodology

Methodology to be developed

1. Establish the firing angles.
2. Implement 5 H-bridges per phase, using the IGBTS modules included in Simulink, see Figure 4.
3. Program the control logic that allows from the 5 input angles to establish the PWM signals for the switching on and off of the IGBTS per phase.
4. Establish the carrier and reference signals.
5. To record the line and phase voltages.
6. Determine the harmonic content of the phase voltage, as well as the total harmonic distortion.
7. Verify the simulator operation for 3 modulation indexes, 0.6, 0.8 and 1.

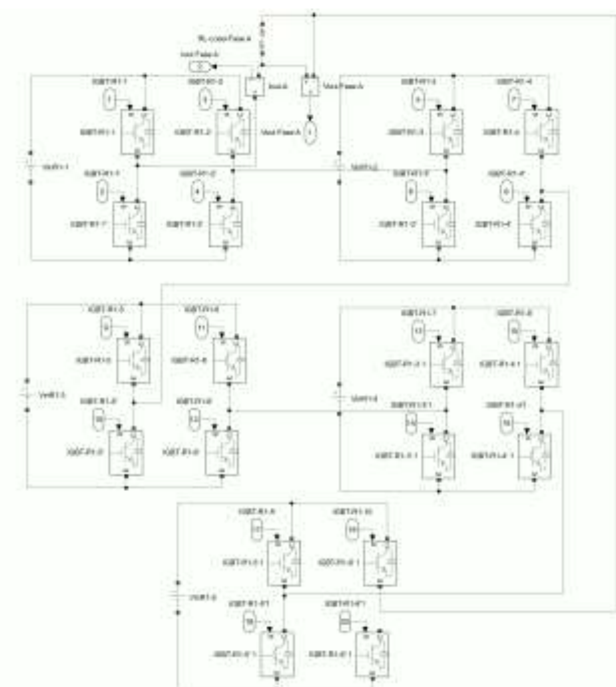

Figure 4 H-Bridges implemented with IGBTS in Simulink

Figure 4 shows the configuration of 5 H-bridges connected in series for one phase. It is important to note that the IGBTS gates have a unique label that differentiates them from the others. These are necessary to make use of them within the simulation. On the other hand, Figure 5 shows the complete simulation with the carrier signals and references for the 3 phases, as well as the PWM generators. Even though the H-bridges are not directly observed, they are found in the part where the IGBT gate labels are referenced, as previously described.

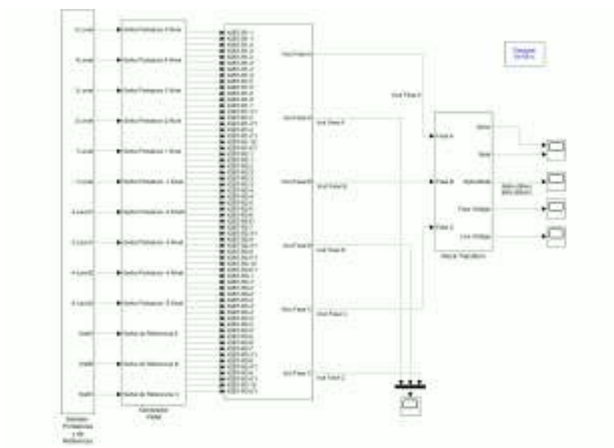

Figure 5 Simulation in Matlab Simulink

The firing angles implemented in this paper for 3 different modulation indices were calculated using a genetic algorithm "GA" following the methodology described in (Memon et al., 2018). It should be emphasized that for all calculations, in the proposed methodology, the fifth, seventh, eleventh and thirteenth harmonics were sought to be minimized. Table 1 refers to these angles, as well as their modulation index "mi". In addition to the Fourier analysis, the total harmonic distortion of the phase voltage is calculated.

m_i	α_1	α_2	α_3	α_4	α_5
0.6	35.34	46.95	58.58	72.67	87.84
0.8	22.34	39.28	52.69	59.32	70.97
1.0	7.86	19.37	29.65	47.68	63.21

Table 1 Angles used for the simulations with their respective modulation indices

Results

The results of the simulations of the line and phase voltage waveforms, in addition to the harmonic distortion of the phase waveform of an 11-level multilevel inverter can be observed in the following figures. Specifically, Figures 6, 7 and 8 show the three-phase output phase voltages.

|While figures 9, 10 and 11 include only the phase A voltage. Figures 12, 13 and 14 show the line voltages obtained in the simulation. On the other hand, the harmonic spectrum of a phase wave for modulation indices of 0.6, 0.8 and 1.0 are illustrated in figures 15, 16 and 17. In addition, these figures graphically illustrate the correct elimination of the fifth, seventh, eleventh and thirteenth harmonics, as previously established in the methodology section.

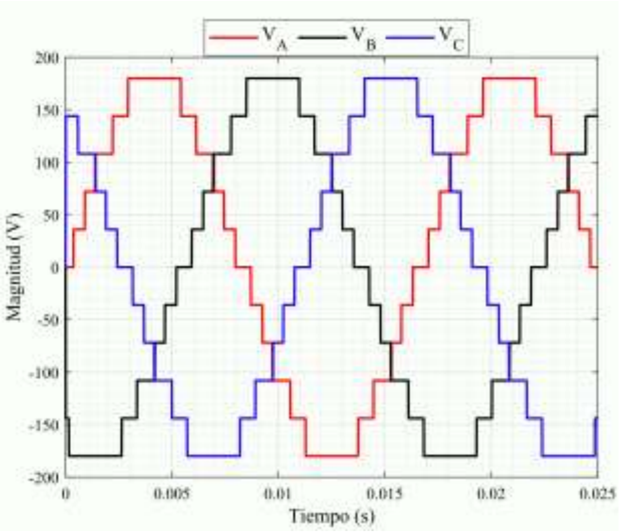

Figure 6 Three-phase phase voltages for a modulation index of 1.0

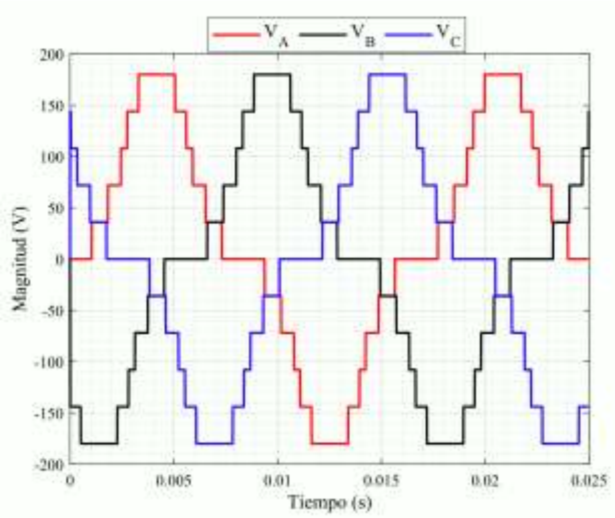

Figure 7 Three-phase phase voltages for a modulation index of 0.8

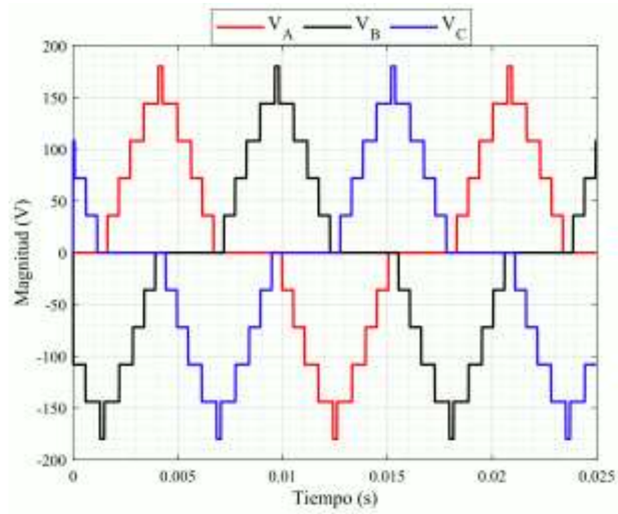

Figure 8 Three-phase phase voltages for a modulation index of 0.6

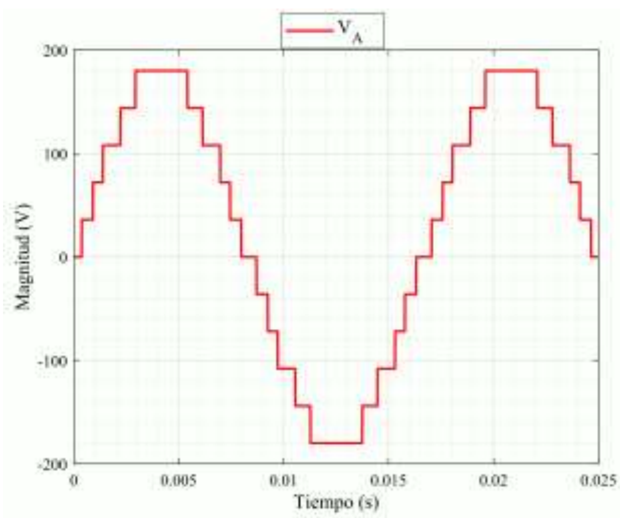

Figure 9 Phase voltage at a modulation index of 1.0

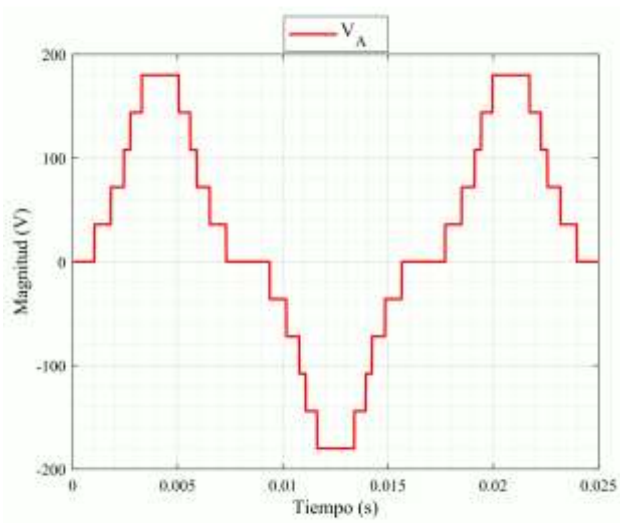

Figure 10 Phase voltage for a modulation index of 0.8

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June 2023, Vol.7 No.17 17-23

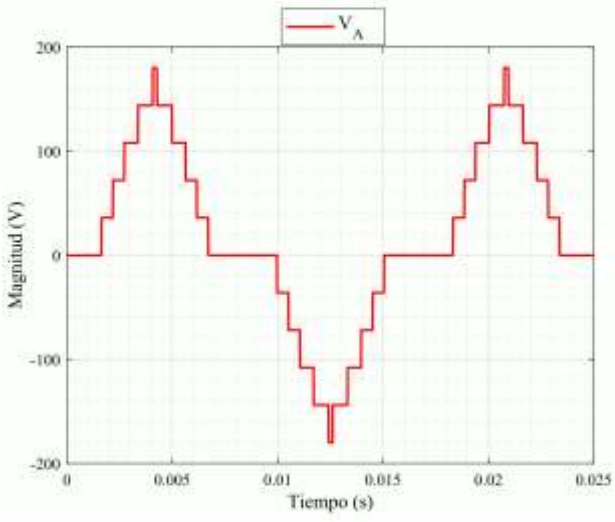

Figure 11 Phase voltage for modulation index 0.6

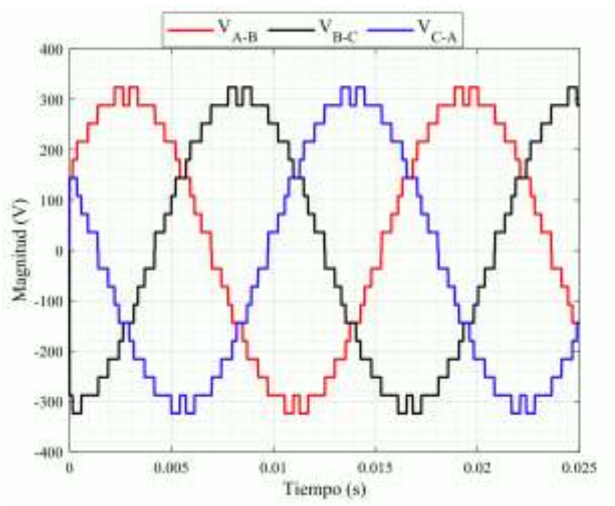

Figure 12 Line voltage for modulation index of 1.0.

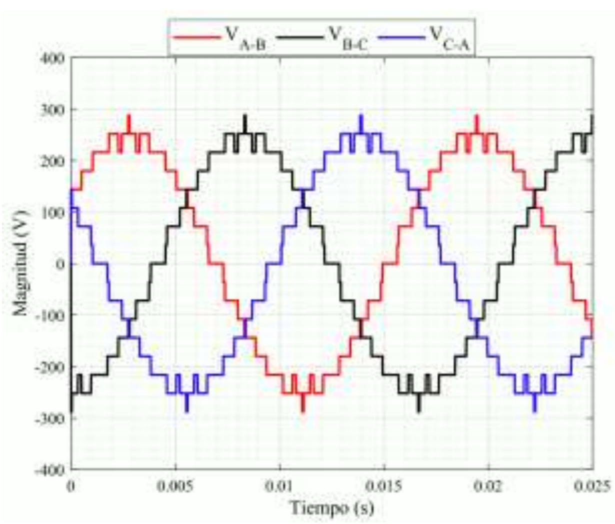

Figure 13 Line voltage for modulation index 0.8

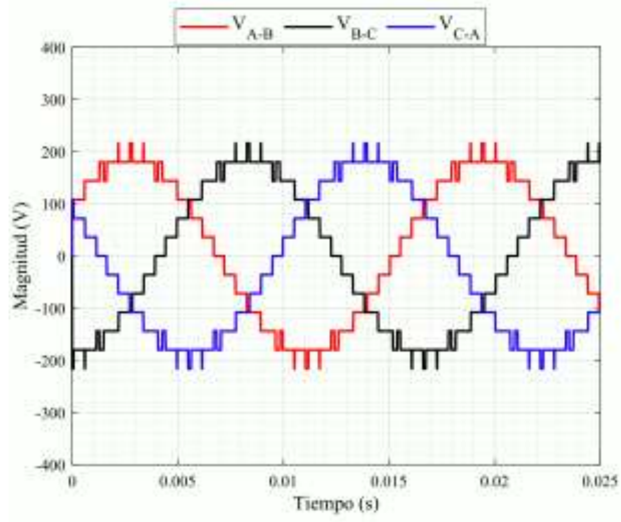

Figure 14 Line voltage at a modulation index of 0.6

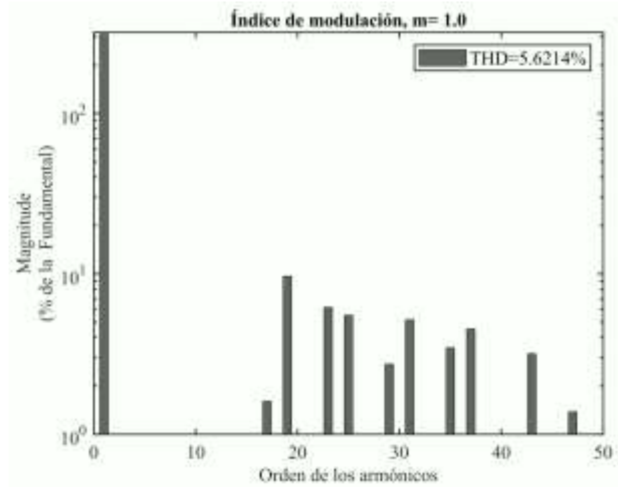

Figure 15 Harmonic content of the phase voltage for a modulation index of 1.0.

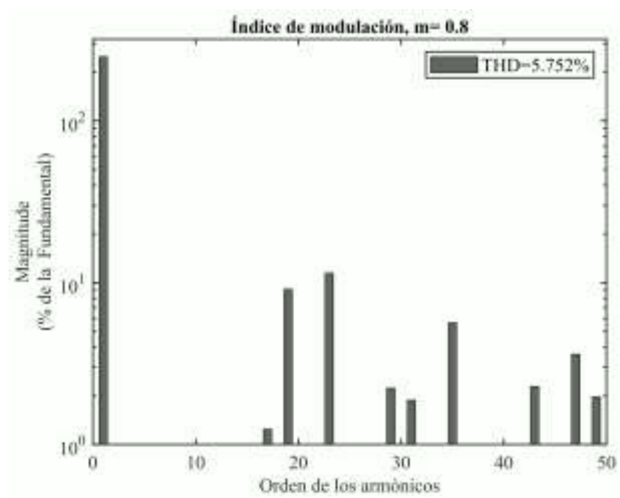

Figure 16 Harmonic content of the phase voltage for a modulation index of 0.8.

ISSN 2523-6865

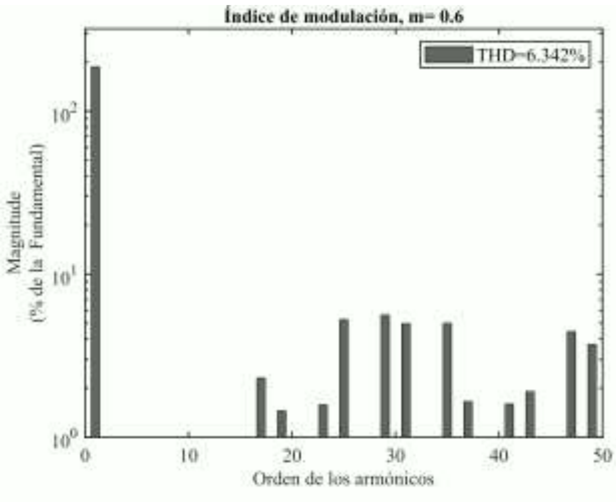

Figure 17 Harmonic content of the phase voltage for a modulation index of 0.6

Conclusions

In this paper, a simulation of an 11-level multilevel inverter is presented. This proved that in terms of the inverter output voltages the typical staircase signal is obtained for both line and phase voltages. Additionally the simulation platform proved to be sensitive to variations in the modulation index and how this manifests itself in the output voltages.

On the other hand, it was also considered from the voltage waves generated in the simulation, the calculation of the harmonic component of these, as well as its total harmonic distortion, obtaining satisfactory results by demonstrating graphically the elimination of the fifth, seventh, eleventh and thirteenth harmonics.

Financing

This research work has been financed by the Universidad Tecnológica de Altamira.

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