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Design and simulation of techniques for mitigation of harmonic distortion in a three-phase rectifier

V M Garrido-Arévalo[1], W J Pérez-Camargo[1], and J G López Quintero[2]
[1] Universidad Tecnológica de Bolívar, Cartagena de Indias, Colombia
[2] Universidad Tecnológica de Pereira, Pereira, Colombia

E-mail: vgarrido@utb.edu.co

Abstract. Rectifiers are electrical devices that receive an alternating signal and deliver a direct current signal at their output, this process by which they transform one type of energy to another is known as rectification. This type of device incorporates a phenomenon called harmonic distortion into the electrical network, which consists of malformations presented in the waveform of the alternating signal from which it feeds, which generate unwanted effects on electrical systems. Because of this, this work presents the combination of two harmonic distortion mitigation strategies (12-pulse multilevel converter and harmonic frequency tuned filtering stage) in order to reduce total harmonic distortion levels generated by a three-phase rectifier.

1. Introduction

The development of new topologies and functionalities of alternating current - direct current (AC-DC) power converters go naturally with the evolution of electronic power devices. The great proliferation of these converters, as a continuous voltage power supply of most modern electronic devices of multiple applications, in all power ranges, makes it necessary to publish regulatory regulations on the disturbances that are generated in the supply network electrical and especially in the industrial field [1].

The increasing presence of non-linear loads in modern electrical systems causes distortion of the waveforms of voltages and currents, which translates as the existence of harmonics and inter-harmonics in those systems. International standards recommend the permissible limits of distortion in electrical networks to reduce the harmful effects of harmonic circulation through those networks and their components [2]. This work focuses on the design of a passive filter to mitigate harmonic distortion in a three-phase AC-DC converter. The computational model of the converter will be extracted from sample templates located in Matlab-Simulink's library. Variations are applied in the original structure of the template to obtain improvements in total harmonic distortion (THD) levels, reducing the negative effects described in [3].

In the available literature, various proposals for harmonic mitigation solutions are found [4-8]. In [9] the number of pulses of the converter is doubled to obtain low distortions in the AC signal, in [10] a passive filter is applied, reducing harmonic distortions in the network. However, there is no evidence in the literature where several techniques are used together. Therefore, this work focuses on combining two of the techniques to reduce the aforementioned effects, comparing the results obtained with the levels required by the standard Institute of Electrical and Electronics Engineers (IEEE) 519 [11].

On the other hand, in [12] a high-voltage direct current (HVDC) system is modeled using the dynamic phasor concept, which is based on an averaged method that describes the waveform using the Fourier series expansion coefficients, obtaining reduced use computing of the device where this model will be carried out. Similarly, in [13] the implementation of the DC converters for an HVDC interconnection is proposed, which consists of several wind power plants connected to the grid, consisting of 100 individual 200 W generators, in the plant 25 converters are used source converter voltage (VSC) which will be connected to a common DC bus, simulating the system confirms that despite the disturbances there will be an optimal coefficient of performance, leaving out synchronization problems.

2. Methodology

This work is based on a three-phase six-pulse rectifier which is connected to the network through a Y-Y transformer, this rectifier model taken from the Matlab Simulink library, which is useful as a starting point. Measurements are made corresponding to the THD in order to check compliance with the IEEE 519 Standard [11]. If it is verified that the percentages of harmonic distortion in the network exceed the limits established by current regulations, the harmonic reduction techniques described below are carried out:

2.1. Multilevel converter technique

The model described in [6] is made, taking into account the correct selection of the transformers to be used. Two test scenarios are selected for the same technique, testing its effectiveness. The necessary simulations are carried out in Matlab 2017b licensed by Universidad Tecnológica de Bolívar. The results obtained with respect to the base converter are analyzed.

2.2. *Tuned filter technique*

In [2] a general procedure is proposed for the calculation of passive harmonic filters and to determine the equations corresponding to the different types of filters. The procedure described is taken as a reference for the design and calculation of the filter used in this work. Two test scenarios are taken equal to the previous ones. Simulations are performed in conjunction with the prior art. THD levels achieved in the system are compared against those obtained in the base converter.

3. Scenarios simulations and test systems

3.1. Scenarios simulations

This section presents three test scenarios in an AC-DC converter, the first corresponds to the base case and will serve as a reference for comparison with the other two scenarios, which include the proposed modifications.

- Scenario 1. In this scenario, a six-pulse converter “Base” is simulated.
- Scenario 2. For the second scenario, a modification is applied to the first scenario, creating a twelve-pulse converter.
- Scenario 3. Finally, this scenario consists in applying a passive filter to the 12-pulse converter.

All scenarios, the following variables will be measured: Harmonic distortion, AC waveform and DC value.

3.2. Test systems

3.2.1. Test system I. It is considered a six-pulse AC-DC conversion system shown in Figure 1, which consists of an YY transformer, a three-phase power supply and an arrangement of six semiconductors which are responsible for transforming alternating current into direct current.

3.2.2. Test system II. In this scenario, a three-phase 12-pulse rectifier is simulated. The system shown in Figure 2 consists of a three-phase power supply, a tri-winding transformer where the two secondary

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windings are out of phase with the other 30 electrical degrees where it is connected to two six-pulse rectifiers, which are connected in series from the DC side indicated in the green circle.

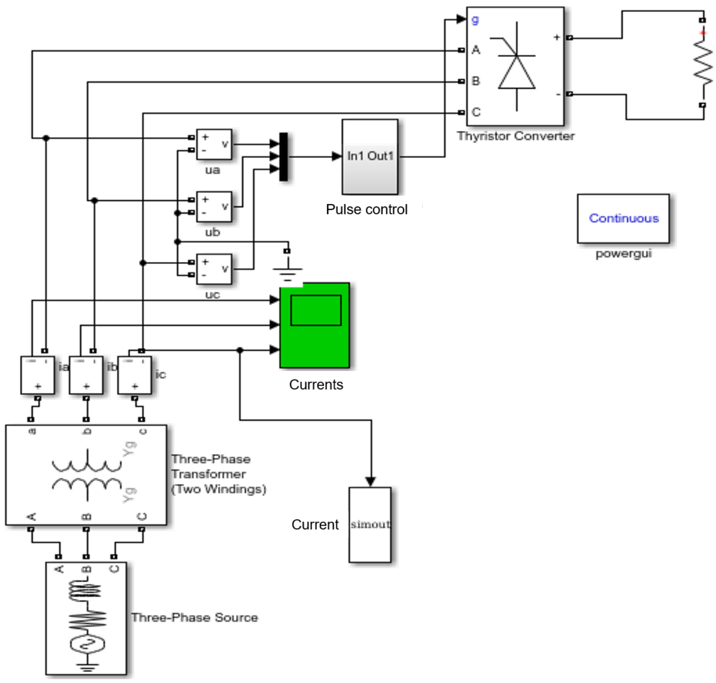

Figure 1. 6-pulse AC-DC converter circuit.

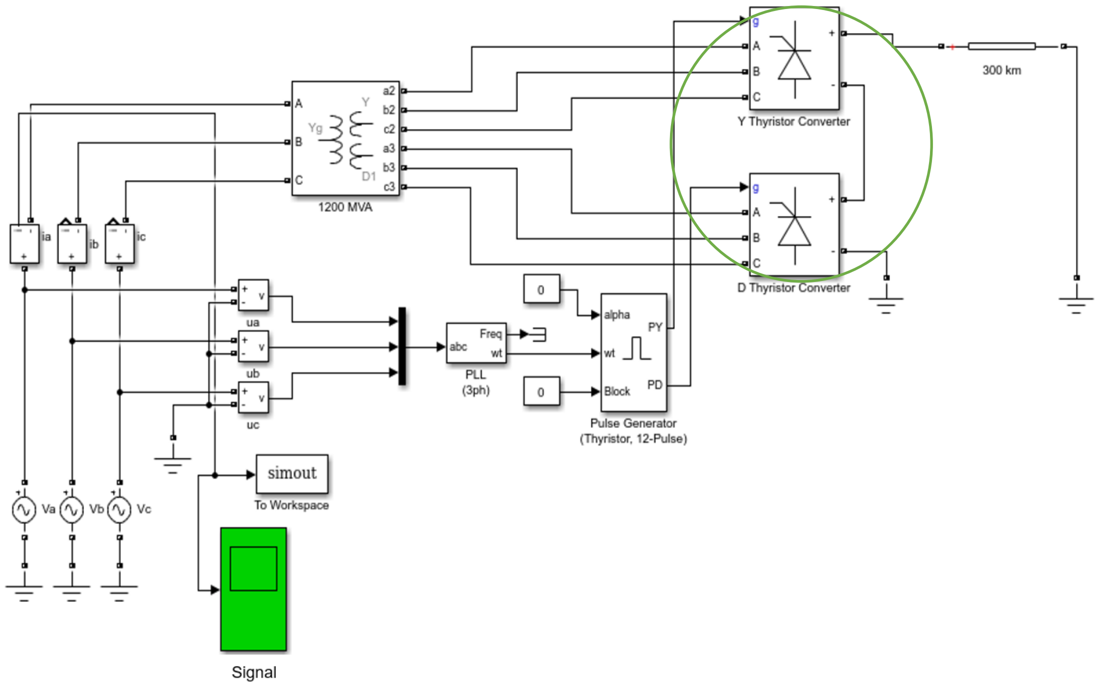

Figure 2. 12-pulse AC-DC converter circuit.

3.2.3. Test system III. In this test system two harmonic mitigation strategies are combined. In the first instance a passive tuned filter is implemented which is connected to the 12-pulse converter built in Test System II. The aim is to compare the THD obtained in this scenario against test systems I and II, waiting for a decrease in the harmonics of the network. This test system is presented in Figure 3.

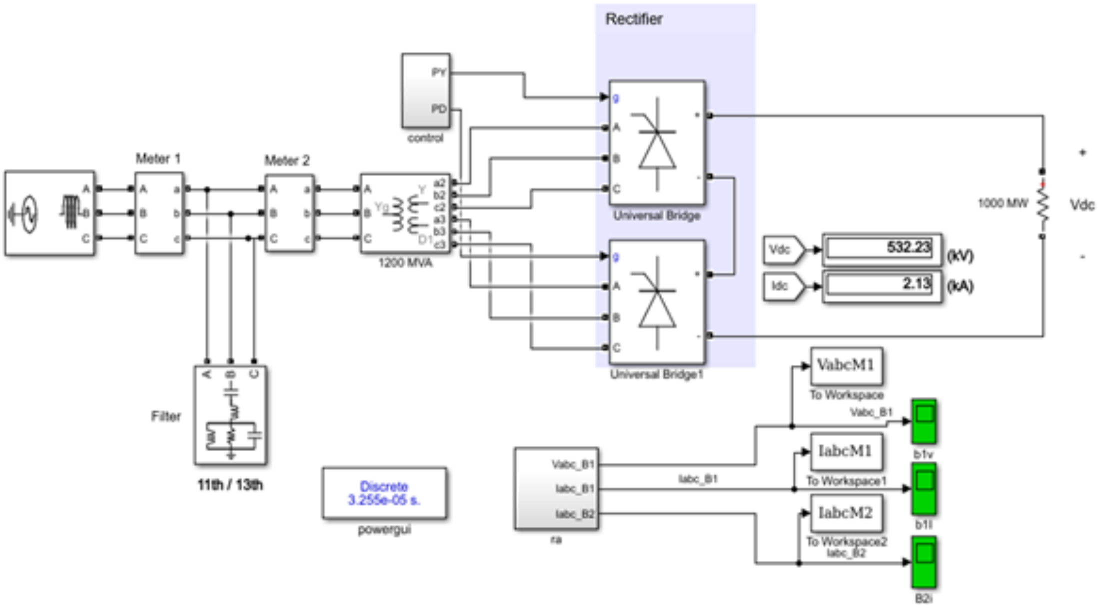

Figure 3. 12-pulse AC-DC converter circuit with filter.

4. Results

This section shows the results of implementing two strategies for the mitigation of harmonic components generated by a three-phase AC-DC rectifier, adapting each of the scenarios described above for a partial cancellation of the harmonics present in the system.

4.1. First scenario (base circuit)

In the first scenarios, the results obtained were alarming, since the threshold established by the IEEE Standard [11] is exceeded, so it is concluded that a system with these conditions does not meet the needs required for proper operation.

Table 1. Harmonic distortion balance (6-pulse converter).

Frequency (Hz)	Description	Phase a (%)	Phase b (%)	Phase c (%)
	THD%	30.42	30.42	30.42
0	DC	0.00	0.00	0.00
180	h3	0.01	0.01	0.01
300	h5	22.63	22.63	22.63
420	h7	11.31	11.31	11.31
540	h9	0.01	0.01	0.01
660	h11	9.04	9.04	9.04
780	h13	6.45	6.45	6.45

Table 1 shows the results obtained after performing the fast Fourier transform in each of the phases of the system, in which the shaded harmonic components indicate the frequencies that significantly help the increase of THD in the studied system.

4.2. Second scenario (12 pulse converter)

In contrast to the results obtained in the first scenario, the 12-pulse converter manages to significantly reduce the harmonic distortions seen in a six-pulse rectifier, obtaining THD values per phase around 15%, due to the structure of this type of converter, in Table 2 it is shown that the 5th and 7th harmonic is reduced to less than 1% of the magnitude of the fundamental frequency by attenuating the total harmonic distortion.

Table 2. Harmonic distortion balance (12-pulse converter).

Frequency (Hz)	Description	Phase a (%)	Phase b (%)	Phase c (%)
	THD%	15.00	15.00	15.00
0	DC	0.00	0.00	0.00
180	h3	0.01	0.01	0.01
300	h5	0.20	0.20	0.20
420	h7	0.16	0.16	0.16
540	h9	0.01	0.01	0.01
660	h11	9.23	9.23	9.23
780	h13	7.59	7.59	7.59

4.3. Third scenario (12-pulse converter with filter)

In this phase the second stage converter is simulated with a filtering stage which seeks to reduce the THD to a lower level of 5%, the designed filter has double tuning frequency which suppresses harmonic No. 11 and No. 13 which in the last measurements they have the highest magnitudes, as shown Table 3.

Table 3. Harmonic distortion balance (12-pulse converter with filter).

Frequency (Hz)	Description	Phase a (%)	Phase b (%)	Phase c (%)
	THD%	2.85	2.85	2.85
0	DC	0.19	0.19	0.19
180	h3	0.06	0.06	0.06
300	h5	0.10	0.10	0.10
420	h7	0.06	0.06	0.06
540	h9	0.00	0.00	0.00
660	h11	2.30	2.30	2.30
780	h13	1.42	1.42	1.42

4.4. Strategy comparison

Table 4 compares the results obtained in this work with the results found in the literature. It is shown that the results obtained in this work exceed those obtained in the other works. The total harmonic distortion voltage (THDv) and total harmonic distortion current (THDi) indicators are used.

Table 4. Comparison of results with related works.

Model	THDi	THDv
12-Pulse converter with filter	2.84	0.38
24-Pulse converter [10]	8.33	1.58
20-Pulse converter [6]	5.50	3.31
12-Pulse converter [10]	9.95	3.03

5. Conclusions

For a three-phase six-pulse converter, the most notable distortions prevail in the fifth and seventh harmonic, reaching levels of 30% of the fundamental signal, which generates a large distortion in the resulting wave, the latter is the one that causes the negative effects already known, in the same way, it is important to note that the harmonic distortion that occurs in the circuit could be reduced by filters, however, a twelve-pulse converter was used to comply with IEEE 519.

The number of pulses of a converter is inversely proportional to the THD levels generated in the network, however, it is proportional to the cost associated with its implementation. Likewise, in the 12-pulse rectifier, the voltage on the DC side will be the sum of the voltage of each six-pulse converter, due to the existing serial connection between them.

The output wave of the twelve-pulse rectifier has less curling than that of a six-pulse rectifier, the above is caused by the electric phase shift in the voltages of the transformers of the twelve-pulse converter, making it possible to make the filtering process of DC output be more efficient.

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