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# Analysis of AC - to - DC Uncontrolled Converters Harmonics for Electric Vehicles Applications

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## ABSTRACT

This paper discusses the harmonic analysis of the AC-to-DC uncontrolled converters commonly used in electric vehicles charging station. The aim of this paper is to model and simulate different rectifier models in addition to explaining the differences in input current harmonics, the total Harmonic Distortion (THD) as well as the power factor (pf). The converter configurations include single-phase bridge, 6-pulse and 12-pulse rectifier circuits. The single phase is normally used for electric scooter charging, while three-phase converters can be used for both electric bus and car charging. The circuit configurations of the rectifiers were modelled and simulated using Matlab R2014a to achieve the objective of the study. The results revealed that the THD levels were extremely high which is unacceptable if the system is connected to the utility grid.

*Keywords:* Harmonic analysis, AC to DC converters, electric vehicles

## INTRODUCTION

Electric vehicles have become part of our lives revolutionising the transport sector. They are environmental friendly as they are not powered by fossil fuel. The main source of energy in an electric vehicle is a battery which is a DC power supply. Thus, to provide sustainability and continuity for the battery, stations are needed to charge the battery. The only fix energy source available is the grid which provides AC, which means the AC will be converted to DC by using a charger. The charger is basically a rectifier which converts AC to DC). However, the problem is when rectifiers are considered a source of

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harmonics. Thus, the first issue appears the harmonics mitigation to the grid.(Liu, Dow, & Liu, 2011; Wanik et al., 2013).

Most of the effects of harmonics are caused by the nature of nonlinear loads which are connected to the system. The total harmonic distortion (THD) shows why there are a lot of standards for acceptable percentages and limitation at the point of connection to the grid (Duffey & Stratford, 1989; Kazem, Albaloshi, Al-jabri, & Al-Saidi, 2005; Mahar & Uqaill, 2011)

Diode rectifiers are commonly utilised for the process of conversion, bridge configuration is one of them but it produces high harmonics and THD. The 6-pulse is widely used because it is cheap and has the simplest structure. A 12-pulse rectifier consists of two sets of 6-pulse rectifier and it is very commonly used for high power grid application.(Venkatesh & Dinesh, 2014)

## Bridge, 6 Pulse and 12 Pulse Uncontrolled Circuits

The bridge is a 1-phase model which utilises 4-diodes combined in a particular way to provide the output voltage (Rashid, 2001; Singh et al., 2004). All the 4-diodes are D1,4 and they connected in two arms; two diodes are ON at each 1/2 period. At first 1/2 cycle of the source, D1 and D2 are ON, while diodes D3 and D4 are OFF as shown in Figure.1.

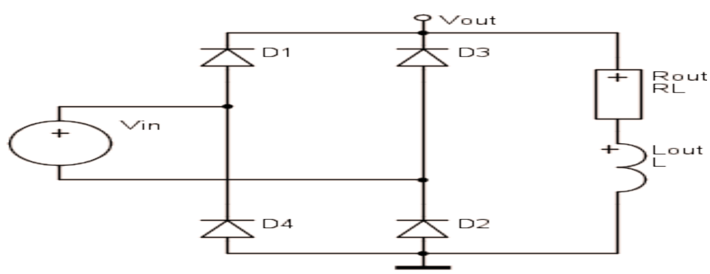
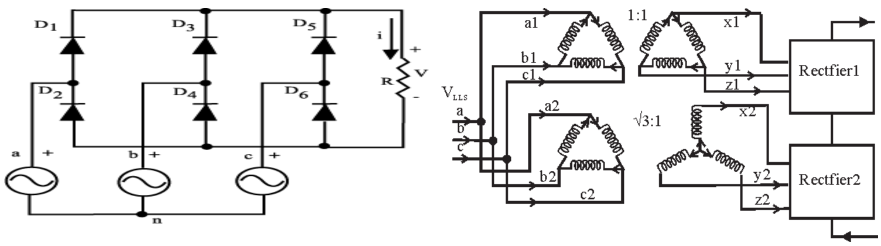



*Figure 1.* Uncontrolled single-phase converter

The three phase 6-pulse converters have 6-diodes and any pair is connected to one arm of 3-phase power supply (see Figure.2a). As a matter of fact, 2- diodes in the model are simultaneously ON, first one is represented by the three diodes (D1, D3 and D5) and the second one (D2, D4 and D6). The two conducting diodes are connected to two arms of 3-phase source in the series to output DC points. The output DC voltage is known as the combination of two arms of 3-phase voltages. However, 12- pulse model is mostly two 6-pulse configurations combined in a series at the output points and organised with a phase shifting in the input source as shown in Figure.2b.

## Harmonics

A harmonic is a periodic element of a complex signal with a frequency that is an integral multiple of the main frequency (Mahar & Uqaili, 2011; Venkatesh & Dinesh, 2014; Rashid, 2001). Any non-pure signal which is neither pure sine nor levelled DC is considered a source




(a) (b)

*Figure 2.* (a) Uncontrolled Six-Pulse Converter; (b) Uncontrolled 12-pulse converter

of harmonics. The term complex signal consists of all the repeating waveforms which are not sinusoidal. The 2nd harmonic has a double frequency of the main frequency; therefore, nth harmonics have frequency equals to (n*f). where (f) is the main source frequency, n =1,2,3,.....,∞

Harmonics are defined as an individual and even components; when a signal has difference between the positive half and the negative half, even components will appear (2nd,4th,..) and perhaps some odd components may appear as well. On the other hand, when the signal has identity between the positive and the negative half, odd components appear (3rd,5th,....).and this signal is free of DC component. Therefore, a distorted signal consists of multi harmonics, dissimilar amplitudes and frequencies with a phase shifting between them. Harmonics can be obtained by using Fourier analysis. Common code for Fourier analysis, periodic function f (t) of any signal alter with cycle of 2π is expressed as

$$f(t) = a_o + \sum_{n=1,2,...}^{\infty}(a_n \cos n\omega t + b_n \sin n\omega t \qquad (1)$$

Where $a_o$ is the DC level of the main signal, ($a_n$ Cos nωt + $b_n$ Sin nωt) is the nth component for the signal. $a_o$, $a_n$ and $b_n$ calculated using the formulas (2-4).

$$a_o = \frac{1}{2\pi}\int_0^{2\pi} v_l \, d\,\omega t \qquad (2)$$

$$a_n = \frac{1}{\pi}\int_0^{2\pi} v_l \cos n\omega t \, d\,\omega t \qquad (3)$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} v_l \sin n\omega t \, d\,\omega t \qquad (4)$$

formula (1) could given in 5 :

$$f(t) = a_o + \sum_{n=1,2,...}^{\infty} c_n \sin(n\omega t + \phi_n) \qquad (5)$$

Where $c_n = \sqrt{a_n^2 + b_n^2}$, $\emptyset_n = \tan^{-1}\frac{a_n}{b_n}$ $c_n \& \emptyset_n$ is amplitude and angle of nth element of the signal.

## THD Calculation

The percentage of distortion in any signal (THD) is defined as Root-Sum-Square (RSS)(Wanik et al., 2013; Rashid, 2001). In order to determine the THD, take the root square of summations of the squares of the first few components of the fundamental. The THD may be calculated as below which can be used for both current and voltage.

$$THD_i = \frac{\sqrt{I_2^2 + I_3^2 + \cdots + I_\infty^2}}{I_1^2} = \frac{\sqrt{\sum_{i=2}^{\infty} I_i^2}}{I_1^2} \qquad (6)$$

Where In is the RMS current

## Converters Simulation

Matlab software is one of the powerful tools to design and model different types of systems, starting from generation, transmission among others. Matlab 2014a release 8.3.0.532 with SimPowerSystems block set was used in this paper. All the models were simulated without using any type of filters.

**Load.** The load in our model was different electric vehicles battery which has the specific details:
V Battery =600 V, I battery =100 A (bus)
V Battery =300 V, I battery =50 A (car)
V Battery =48 V, I battery =25 A (scooter)

**Single Phase rectifier.** The Matlab library contains most of the electrical elements which can be used for all the purposes. One of them is the power electronics library used in our models.

Figure.3 shows the single phase converter with the scooter as a load and capacitor as a smoothing tool.

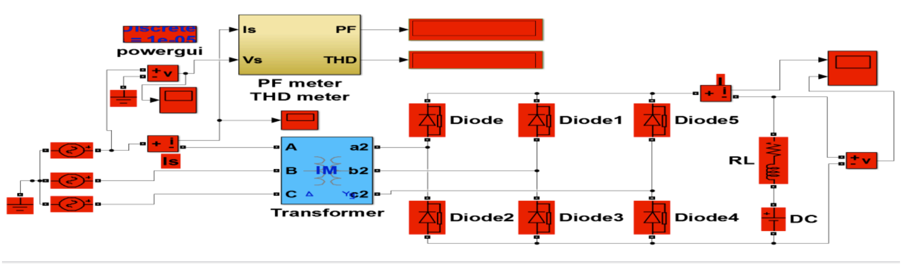



*Figure 3.* Single-phase rectifier

**3-Phase 6-diodes rectifier.** It utilises the same elements as in the single phase full wave rectifier this time to model the three phase converter which can be used for the electric bus or car. This configuration has 6-diodes combine with 3 single phase AC sources shifted by 120 degrees. Figure.4 shows 6-pulse diode rectifier.

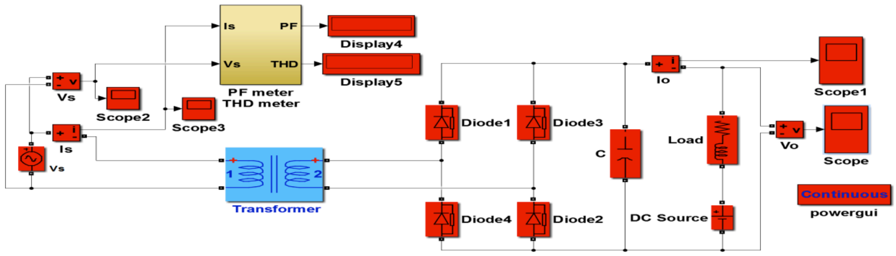



*Figure 4.* Three-phase 6-diodes rectifier

**3-Phase 12-diodes rectifier.** This type of converter is also used for charging cars or buses; it has 12-diode which is normally 2 sets of 6-diode connected either in series or parallel. In this paper, we connected the sets in series. Figure 5 shows the 12-pulse diode rectifier.

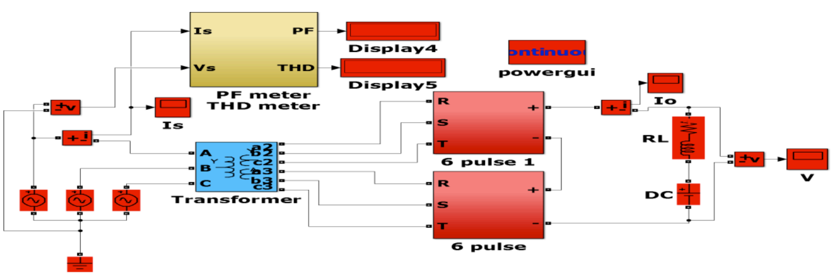



*Figure 5.* Three-phase 12-diodes rectifier

## Simulated Results

All the three types of converters were simulated for the three loads without using any filters. The results showed that increasing the number of pulses leads to improved performance of the system and reduce the THD for the current supply. For the scooter as a load, the results are shown below.  single phase full wave rectifier Figure.6 shows the input current and voltage.

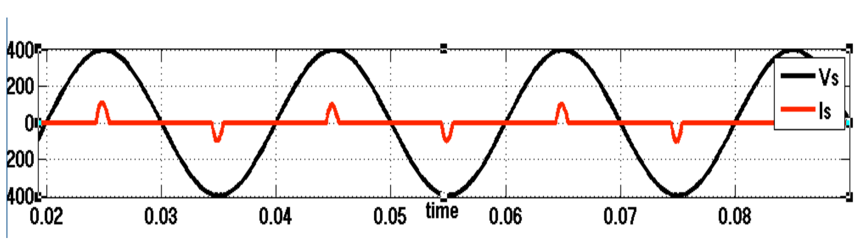



*Figure 6.* Input current and voltage for single phase rectifier with scooter as a load  Fourier analysis is available in Matlab library to analysis the input current, the harmonics order and the THD percentage are displayed in Figure7. which shows that THD=217.21%

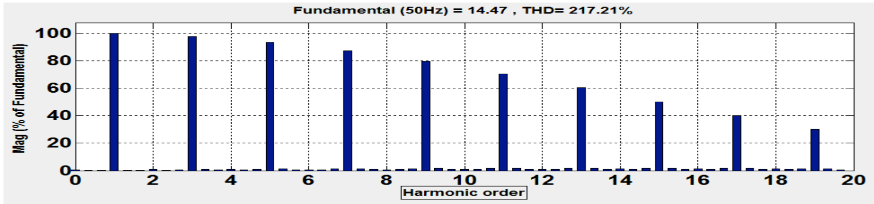



*Figure 7.* FFT for input current with scooter as a load

For three phase 6-diode converter, Figure 8 shows the input current and voltage. The load is electric car.

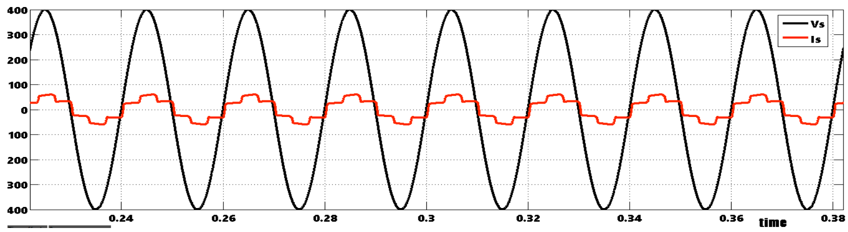



*Figure 8.* Input current and voltage for 3-phase 6-diode rectifier with car as a load

Applying FFT for the input current show that some of the harmonics are cancelled and the THD was reduced to THD=25.97% as shown in Figure.9.

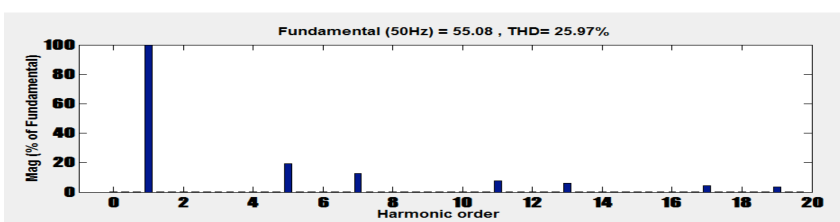



*Figure 9.* FFT for input current with car as a load

For three phase 12-diode converter the input current and voltage are shown in Figure.10 (the load is bus).

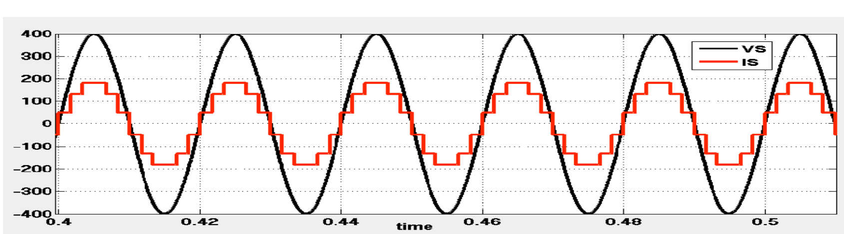



*Figure 10.* Input current and voltage for 3-phase 12-diode rectifier with bus as a load

Using FFT to analyse the input current shows that the THD level is less than in other configurations as seen in Figure11, THD=15.20%.

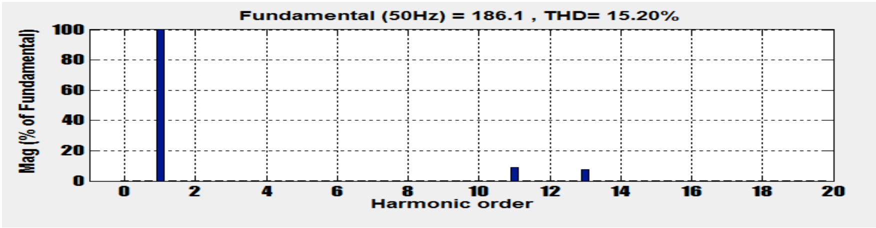



*Figure 11.* FFT for input current with bus as a load

The results can be summarised in Table 1 which shows a comparison between the three models. Table 1

Table 1
*Simulation results of the converters*

| Type of converter | load | Harmonics order | Fundamental | THD % | Pf |
|---|---|---|---|---|---|
| Single phase | scooter | 1,3,5,7,9,11,13,15,17,19 | 12.88 | 217.21 | 0.39 |
| 3-phase 6-diode | car | 1,5,7,11,13,17,19 | 55.28 | 25.97 | 0.68 |
| 3-phase 6-diode | bus | 1,5,7,11,13,17,19 | 181.5 | 24.07 | 0.68 |
| 3-phase 12-diode | car | 1,11,13 | 56.31 | 14.32 | 0.704 |
| 3-phase 12-diode | bus | 1,11,13 | 187.4 | 15.20 | 0.7046 |

Table 1 shows that if the number of pulses increases, the THD of the input current decreases, and the efficiency of the system as well as the power factor improves.

## CONCLUSION

A 12-diode converter shows that the THD level and input current harmonics were lowers than other types of converters. As the number of pulses increased, the DC output quality was better and the input harmonics was reduced. Thus, increasing the number of pulses can be considered harmonics filtering. However, it was still not enough to reduce the THD levels to the standard levels which is less than 5%; thus, requiring some types of filters ( passive filters, active filters, adaptive filters). On the other hand, using converters with pulses higher than 12 such as 18, 24, 26, 48 pulse would give better results, yet, this requires more elements and leads to high complexity circuits which makes the analysis difficult and complicated.

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