Analysis and Modeling of Harmonic Distortions in Power Networks Containing a Powerful Non-Linear Load

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Abstract **-** n recent years with increasing of power electronics applications, the use of non-linear loads is also increasing. These non-linear loads create harmonic currents in power lines and this situation causes some problems such as reactive power load, overheating, low power quality. The objective of this paper is to quantify the impact of harmonics at equipment connected to the network especially at the nodes, and to show the effect of propagation of harmonics in electrical networks, we propose a model of a line transmission with MATLAB / SimPower Systems , and to designate the harmonic distortion must be completed by the spectral distribution to have a clear idea of the pollution. This is why we chose the tool (FFT analysis) Power System that gives the harmonic distortion with spectral analysis**.**

Keywords **-** Harmonics, Power factor, Power Quality, THD, MATLAB, FFT analysis.

I. INTRODUCTION

Harmonics generated by the nonlinear loads is a serious concern to the power system engineers as it adversely affects the power quality of the system. Angelo Baggini [1] explained the effect of current harmonics on the performance different power system equipment such as s capacitors, transformers, motors, energy and demand metering equipment causing additional losses, overheating and overloading and interference with telecommunication lines.

Recently, many researchers have sought to use different methods to reduce harmonics in the input current wave of the rectifier.

Numerous research articles have highlighted the efforts made toward eliminating the harmonics and improving the power factor in the AC system with nonlinear loads [2–3]. In order to improve the power quality in the power system, the main task that has to be faced is to eliminate or reduce the harmonics generated by the use of nonlinear loads. The increasing use of nonlinear loads such as rectifiers, inverters, UPS, mobile battery chargers, and arc lamps, power electronic converters has injected harmonics into the power system.

The various types of controllers are addressed to mitigate the harmonics using Shunt active filter with their relative merits and demerits in [4].

The distorted voltage and current waveforms lead to various power quality issues such as de-rating of equipment, unwanted electrical noise interferences, malfunctioning of the circuit breaker, interference in a communication system, reduction in life span, efficiency and output power of the device. To enhance the performance of the utility system by various harmonic reduction techniques such as capacitor banks, shunt active filters, passive filters and hybrid filters in the power system network is discussed [2–5]. In order to reduce the harmonics, filters are connected in either series or parallel to the load side and/or supply side. Shunt active filter (SAF) is generally used to reduce the harmonics in the power system. The SAF can cancel the load current or source current harmonics by injecting opposite compensating currents to the connected system.

They supply Real and reactive power to the system while being highly effective in attenuating harmonic components. In Typically, Passive filter banks installed in medium-voltage systems are able to provide satisfactory to reduction in currents and voltages distortions after their planning and design the other solution is the application of active filters [6-7].

Harmonic current is isolated by using harmonic filters in order to protect the electrical equipment from getting damaged due to harmonic voltage distortion [8].

They are also be used to improving the electrical power factor. Harmonic distortion is a growing concern for many customers and for the overall power system due to increasing application of power electronics equipment. Harmonic distortion levels can be found throughout the complete harmonic spectrum, with the magnitudes of each individual harmonic component varying inversely with their position in the spectrum.

Furthermore, the phase angle of each component is unique into itself. It is also common to use a single quantity, the total harmonic distortion (THD), as a measure of the magnitude of harmonic distortion. Passive filters exhibit the best relationship cost-benefit among all other mitigation techniques when dealing with low and medium voltage rectifier system [9-10].

In this study the method of passive filter connections is used, which is the most commonly used methods. The filters that have been used in this study are connected in parallel (shunt) with the rectifier. And in this paper is extraction of fundamental and harmonic components in voltage/current signal using FFT in both cases without filtering and with filtering, and we plot the stylized spectrum of distorted signal in MATLAB with power system frequency and classify the subtypes of harmonics and study the different characteristics and calculate total harmonic distortion (THD), that will be useful for solving problems related to power quality.

II. HARMONIC STABILITY CONCEPT AND PHENOMENA

Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency being 50 or 60Hz (50Hz for European power and 60Hz for American power). If the fundamental power frequency is 50 Hz, then the 2nd harmonic is 100 Hz, the 3rd is 150 Hz, etc., Harmonic frequencies from the 3rd to the 25th are the most common range of frequencies measured in electrical distribution systems, [11].

A) Causes and effects of harmonics

Symptoms of harmonic problems include overheated transformers, neutral conductors, and other electrical distribution equipment, as well as the tripping of circuit breakers and loss of synchronization on timing circuits that is dependent upon a clean sine wave trigger at the zero crossover point.

An overheated neutral can lead to heavy damage to attached equipment. Other loads contributing to this problem are variable speed motor drives, lighting ballasts and large legacy UPS systems. Methods used to mitigate this problem have included over-sizing the neutral conductors, installing K-rated transformers, and harmonic filters [12].

B) Types of harmonics

There are two types odd Harmonic and even Harmonic, for odd harmonics distortion is typically dominant in supply voltage and load current. The effect of odd harmonics is an increase or decrease of the amplitude of the signal with 10%. The RMS value increases only very little 0.5%, so that the crest factor increases or decreases by about 10%. Generally a third harmonic component leads to a change in the crest factor. The effect of the distortion is the same for the positive and for the negative half of the sine wave. The positive cycle is the same as the negative cycle of the voltage wave as long as only odd harmonics are presents in the voltage. Even harmonics is normally small. That generates by some large converters, transformer energizing (temporary increase), but modern rule on harmonic distortion state that equipment should not generate any even harmonics. In fact, a measurement of supply voltage shows that the amount of even harmonic is indeed very small. The result of even harmonic distortion is that positive and negative half cycles of the signal are no longer symmetrical. They only occur in the presence of a D.C. component. If there are significant amount of even order harmonics then the signal is not symmetrical with respect to zero axis [3, 4]. The two most commonly used indices for measuring the harmonic content of the waveform are the total harmonic distortion (THD) [11].

C) Harmonic distortion

Harmonics can be understood as different frequency periodic components that are superimposed on the main frequency waveform. In power systems, existing harmonics are mostly odd integer multiple of the power frequency. The 3rd, 5th, 9th, 7th, 11th and 13th orders can be identified as most the common harmonics. In addition to these common harmonics, it is possible to face signal components that are not integer multiples of the fundamental. Such components are called as “inter-harmonics” and they are usually encountered while dealing with non-periodic signals. In recent years a rapid growth in harmonic voltages and currents injected into power systems has been observed due to the increased utilization of non-linear loads. Figure 1 shows Harmonic distortion example.

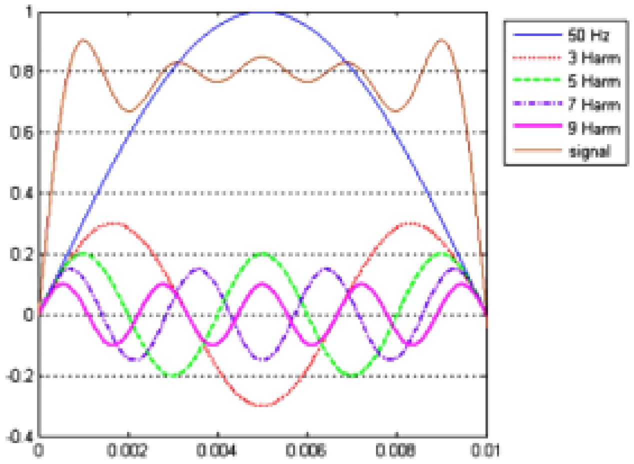

Fig.1. Harmonic distortion

D) Harmonic size

It is one of the sinusoidal components of the variation of the physical quantity having a frequency that is multiple to that of the fundamental component.

E) Harmonic rank

It is the ratio of its frequency f_n to that of the fundamental (usually the industrial frequency, 50 or 60 Hz).

$$n = f_n / f_1 \quad (1)$$

On principle, the fundamental f_1 has the rank one, [13].

F) Fourier series

This means that "every periodic signal of period $T = 1 / f$ can be decomposed into an infinite sum of sine and cosine terms of multiple frequencies of f. Mathematically, this is written

$$s(t) = \frac{a_0}{2} + \sum_0^{\infty}(a_n \cos(n\,\omega t) + b_n \sin(n\omega t)) \quad (2)$$

The value a_0 represents the mean value of s (t).
The coefficients a_n and $b_n$are calculated with the following formulas:

$$a_n = \frac{2}{T}\int_0^T f(t).\cos(n\omega t)\,dt \quad (3)$$

$$b_n = \frac{2}{T}\int_0^T f(t)\sin(n\omega t) \quad (4)$$

Moreover, there are some prerequisites that make it possible not to do unnecessary calculations:

- If the function is even, the coefficients b_n are zero
- if the function is odd, the coefficients a_n are zero
- if the function has symmetry over its two half-periods, the even-numbered terms are zero, [13].

G) Effective value of an alternative quantity

There is an identity between the usual expression of this effective value calculated from the temporal evolution of the alternating quantity (y (t)) and the expression calculated from its harmonic content) :

$$Y_{eff} = \sqrt{\frac{1}{T}\int_0^T Y^2(t)dt} = \sqrt{\sum_{n=1}^{n=\infty} y_n^2} \quad (5)$$

H) Distortion rate

The distortion rate is a parameter which defines the deformation of the alternative quantity

$$THD = 100\frac{\sqrt{\sum_{n=2}^{n=\infty}(Y_n)^2}}{Y_1} \quad (6)$$

There is also another definition that replaces the fundamental Y_1 by the total effective value Y_{eff}. Some measuring devices use it.

- **Individual rate**

It gives a measure of the importance of each harmonic in relation to the fundamental.
The individual rate is the ratio of the effective value of the amplitude of the harmonic of rank n to that of the fundamental.

- **Overall distortion or simply 'distortion'**

It gives a measure of the thermal influence of the set of harmonics; it is the ratio of the effective value of the harmonics to that of the effective value.
Either of the fundamental alone where THD> 0 can be very large

$$THD = 100\frac{\sqrt{\sum_{n=2}^{n=\infty}(Y_n)^2}}{Y_1} \quad (7)$$

Let (more rarely) the measured distorted quantity, where $0 < THD < 1$:

$$THD = \frac{\sqrt{\sum_{n=2}^{n=\infty}(Y_n)^2}}{\sqrt{\sum_{n=1}^{n=\infty}(Y_n)^2}} \quad (8)$$

Unless otherwise indicated, we shall use the definition in IEC 61000-2-2, which corresponds to the ratio between harmonic load and undeformed current at industrial frequency.

The harmonic voltages and currents superimposed on the fundamental wave combine their effects on the devices and equipment used [13].

III. DISCRETE FOURIER TRANSFORM

After digitization, the formula of Fourier becomes :

$$G(k) = \frac{1}{N}\sum_{n=0}^{N=1} g(n)e^{-j\frac{2\pi kn}{N}} \quad (9)$$

This formula is adapted to numerical calculations k refers to f_k and n refers to t_n, [14].

The calculation of a DFT requires a large amount of operations and becomes very long if the number of samples is high; but the same can be calculated by the fast Fourier transform.

Once the Fourier series decomposition of a signal is done, we plot the spectrum representing the amplitudes x_i as a function of the frequency, [14] and this will be the object of study of this article.

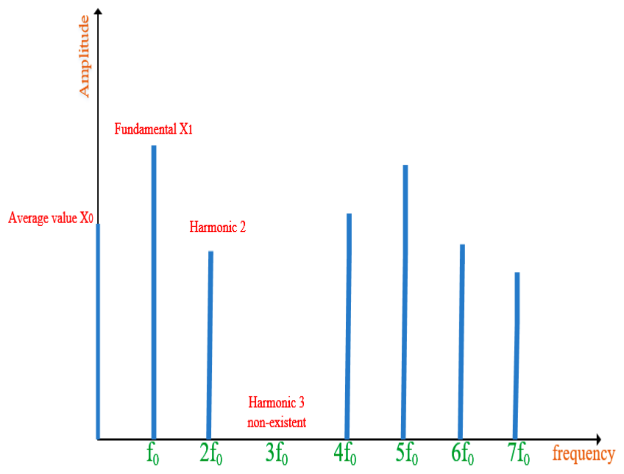

Fig.2. Frequency spectrum of a periodic signal.

IV. PASSIVE FILTER

The passive filter consists of elements like inductor, capacitor and resistor for their filtration purpose. Now this makes the passive filter configuration simple and easy to implement. The passive filter is connected with the electrical power distribution system and is series tuned and shunt tuned to present low impedance (Z) to particular harmonics so that these harmonics distortion are diverted from their normal flow path through the filter or is tuned to present high impedance to particular harmonics to stop them from affecting the circuit. The tuning depends on the configuration of the filter designed. The passive filter is a very good choice for constant loads and is a cost effective solution to harmonic reduction and power factor improvement. All these advantages can be lost if the input filter is not properly designed. An oversized input filter unnecessarily adds cost and volume to the design and compromises system performance Proposed Filter Connections This project explains how to design the optimal input filter for a two pulse diode rectifier application using optimization. For a two pulse diode rectifier circuit with low power rating, using a passive filter is best suited. In most of the cases a passive filter involves an RLC combination tuned (shunt and series) to serve the purpose. The proposed RLC filter approach to reduce line current and voltage harmonics generated by two diode rectifier. The simple passive-filter solution is the R-L-C passive filter equivalent circuit. The transfer functions of the filter, [12]:

V. SIMULATION AND RESULTS

As shown in figure 3 schema bloc of power network in the Matlab/power system software, the model of the electrical network is taken as a test network consisting of an alternator as an energy source, it is modulated from "3-phase" programmable voltage and three nodes where for each of them the influence of the presence of harmonics on electrical quantities is evaluated, with and without a filter. And since our load is non-linear, we chose a universal 2-block AC-DC-AC PWM Converter (with Total Harmonic distortion = 47%) which generate the harmonics by the bridge of the rectifier of the variator and which are responsible for the pollution of the electrical network and to reduce the harmonic we choose a two passive filters one shunt and the other in series.

The passive filters are used to mitigate power quality problems in ac-dc converter with R-C load. Moreover, apart from mitigating the current harmonics, the passive filters also provide reactive power compensation, thereby, further improving the system performance. Voltage and current source type of harmonic producing loads, generally, passive shunt filters and passive series filters are recommended. These filter apart from mitigating the current harmonics, also provide limited reactive power compensation and dc bus voltage regulation. The performance of these Passive filters depends heavily depends on the source impedance present in the system or device, as these filter act as sinks for the harmonic currents. On the other hand, for voltage source type harmonic producing loads, the use of the series passive filters is recommended.

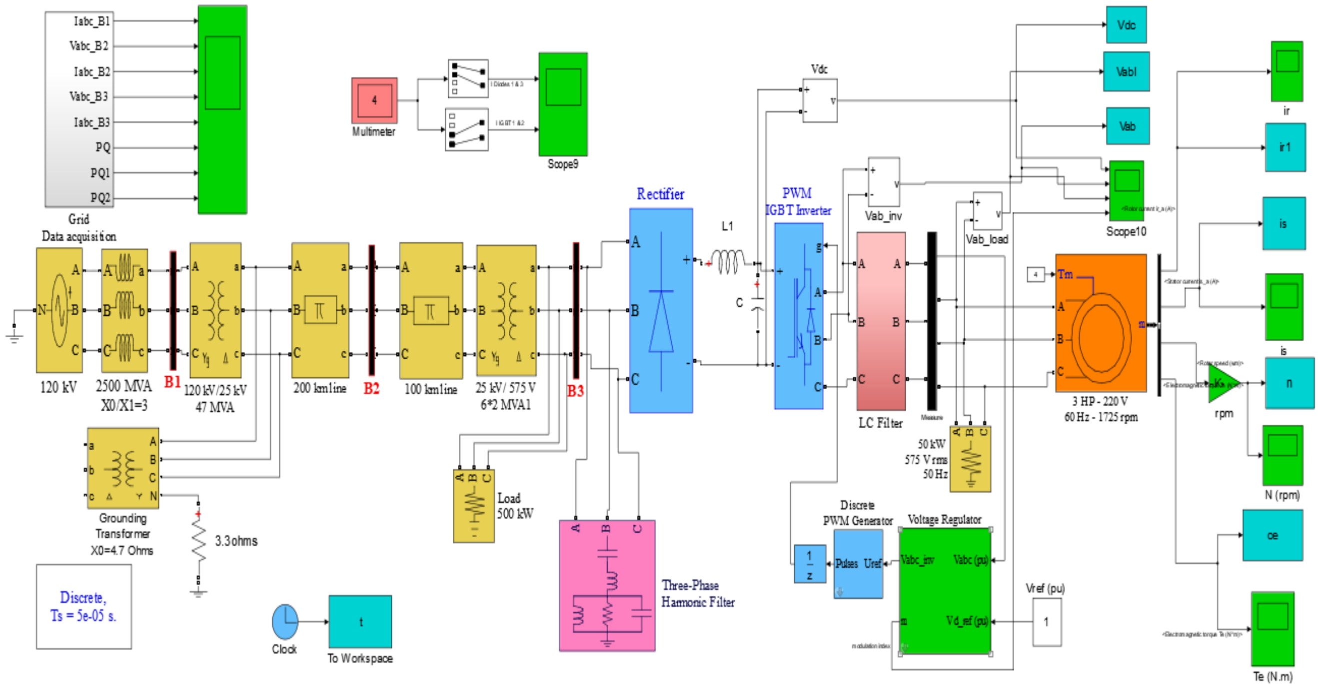

Fig. 3. Model of a transmission line.

Start the simulation. After a transient period of approximately 50 ms, the system reaches a steady state. The harmonics generated by the inverter around multiples of 2 kHz are filtered by the LC filter.

Parameters of line:

$R_1 = 0.1153\ \Omega/\text{km}$; $R_0 = 0.413\ \Omega/\text{km}$;

L_1 =1.05. e^{-3}H/km ; $L_0 = 3.32. e^{-3}$ H/km ;

$C_1 = 11.33. e^{-9}$F/km ; $C_0 = 5.01. e^{-9}$ F/km ;

In the next figure, evaluate impact harmonic resulting from the presence of non-linear load (speed control of asynchronous motor) on speed motor with filter and without a filter.

To find the spectrum of a periodic signal and the rank of its harmonics, the Fourier series decomposition is used to evaluate the distortion rate of the current, on a three nods (575v, 25kv, 120kv) of transmission line with a length of 300km (without and with compensation) By following these steps, once simulation is completed, open the Powerguis and select 'FFT Analysis' to display the 0 - 1000Hz frequency spectrum of signals saved in the 'psbbridges_str' structure. The FFT will be performed on a 2-cycle window starting at t=0.1-2/50 (last 2 cycles of recording). Select input labeled ' Vab Load'. Click on Display and observe the frequency spectrum of last 2 cycles the resultants shows in following figures (5 à10):

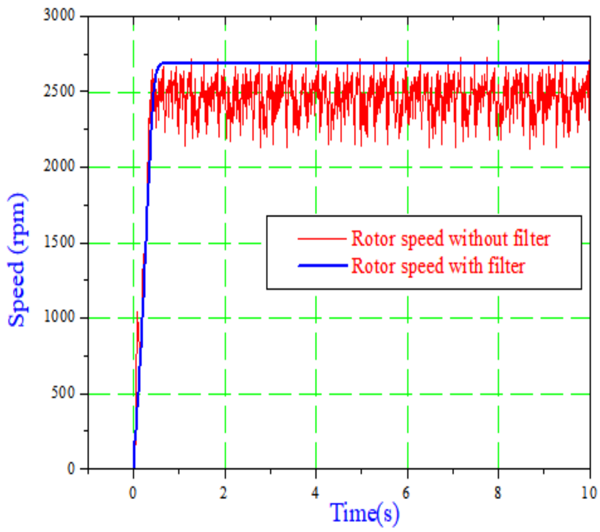

Fig.4. Speed motor with filter and without a filter.

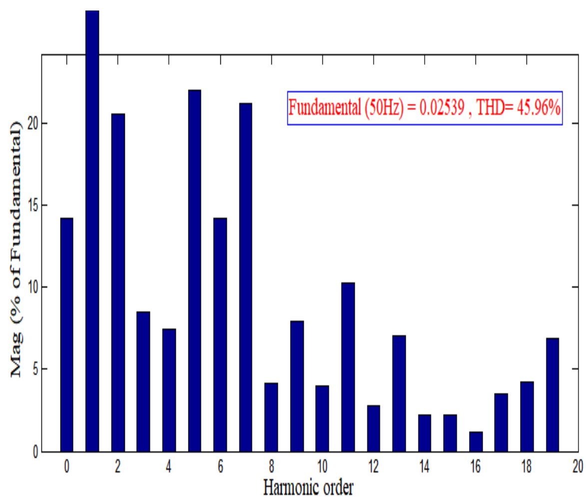

Fig.5. Frequency spectrum of current in the busbar B3 Without filter.

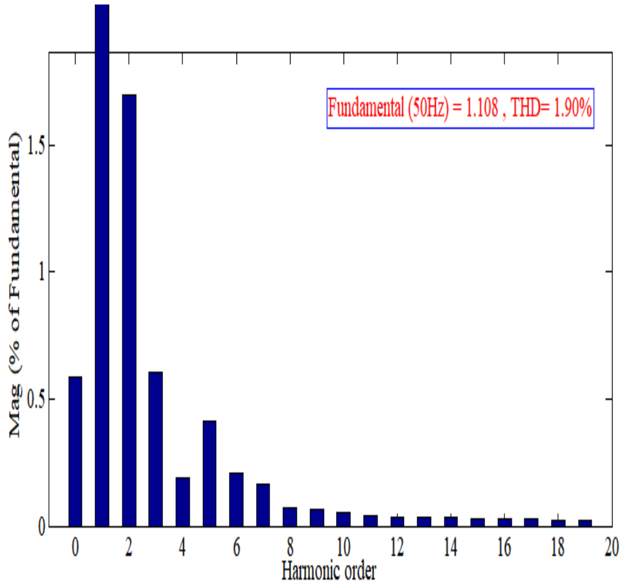

Fig.6. Frequency spectrum of current in the busbar B3 With filter.

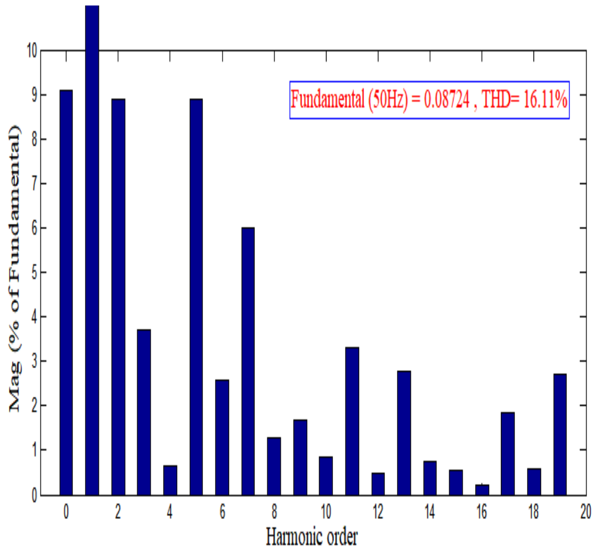

Fig. 7. Frequency spectrum of current in the busbar B2 Without filter.

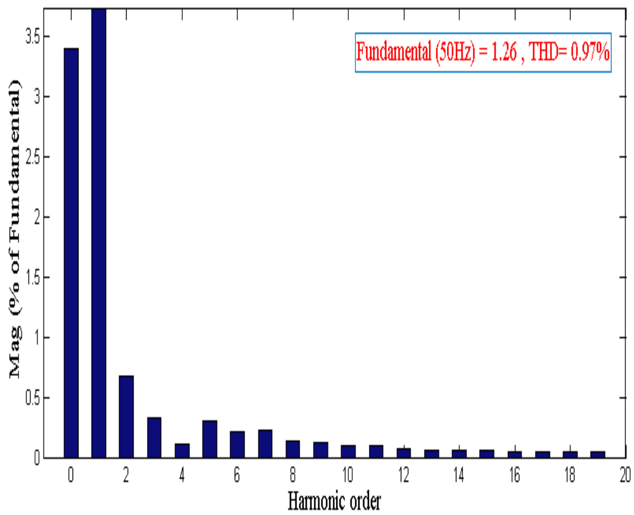

Fig. 8. Frequency spectrum of current in the busbar B2 With filter.

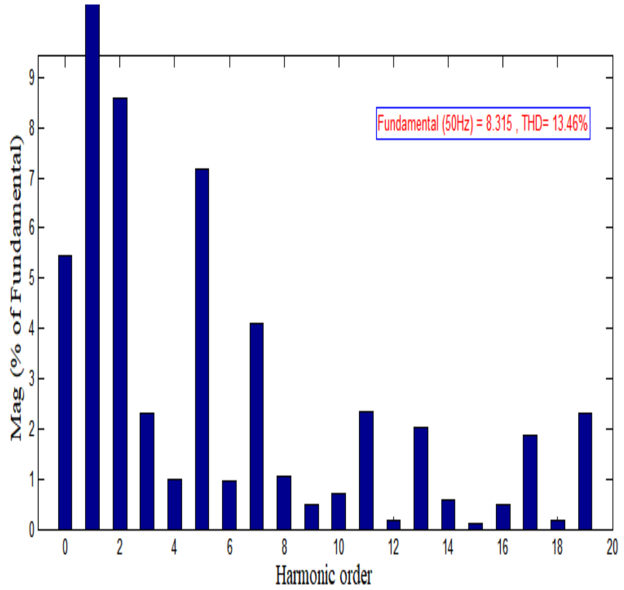

Fig.9. Frequency spectrum of current in the busbar B1 without filter

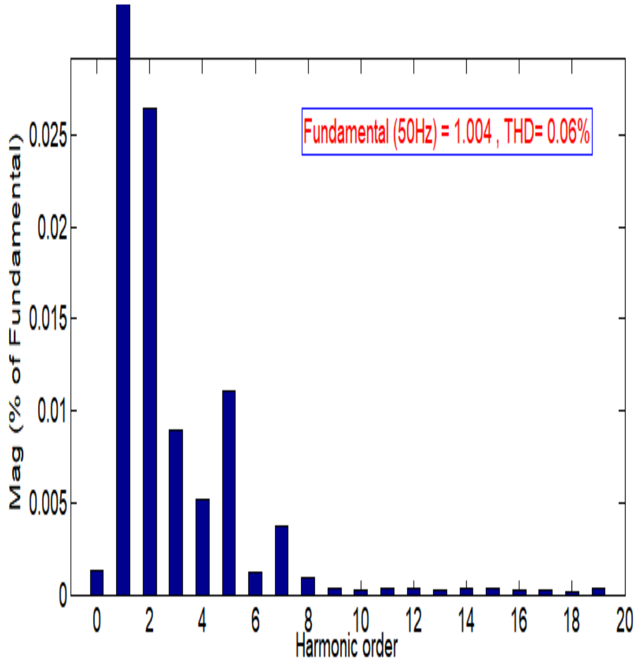

Fig.10. Frequency spectrum of current in the busbar B1 with filter.

VI. INTERPRETATION OF RESULTS

The results of the simulations indicate that the harmonic filters reduce the THD of the current injected into the system from 45.96% to 1.9% , the influence of the presence of harmonics in the presence of the non-linear load (speed control) is overshadowed by the first node considering the deformation of the waveform of the current and the voltage and a fluctuation in the reactive energy of the system.

The waveform of the voltage is less distorted than that of the current since the non-linear loads absorb a current with distortion in the presence of components at frequencies other than the fundamental frequency.

And for the asynchronous machine in the first "without-filtering" test, the transient time greater than the asynchronous machine in the second test "with filtering" and according to the figures of the peaks and oscillations without exceeding.

All the simulation results show that the use of the passive filter makes it possible to considerably reduce the harmonic.

VII. CONCLUSION

The influence of the harmonics on the nodes of the electrical network and their impact on the performance of the asynchronous machine was evaluated. Deformation of the current and voltage at the non-linear load exceeded on the busbar at the source has been observed and the performance of the asynchronous motor is decreased despite its robustness. This implies that the quality of electrical energy is not only related to energy distributors (power supply systems), but also to consumers, because a user's equipment can cause disruptions to the network likely to interfere with other users. So the distributor and the user are both concerned with the quality of electricity, we checked it since the simulation results.

Thanks to FFT analysis, we obtained the spectral analyzes of the currents and voltages, as well as those of the 5, 7, 11, 13 harmonics generated by the variable speed drive. We also get how to reduce them using a harmonic compensator.

With the THD application, we noticed a higher harmonic presence at the node closest to the non-linear load (B3) compared to the other nodes. However, there is a propagation of the harmonics in the nodes (B2.B1), but with less THD and less influence.

VIII. REFERENCES

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