FILTERING OF HARMONICS IN DC TRACTION SUBSTATION SYSTEM

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Abstract: *The railways are the most important and modern means of transportation are used to transport a large number of people, and also used in the industrial field to transport heavy weight and raw materials for very long distances. Direct current (DC) electrified railway systems show many power quality problems such as harmonic, reactive power, unbalanced and low power factor. Our study concentrated on the propagation of currents harmonics in the electric network and their filtering solutions. In this article we made a model in Matlab/Simulink of a real DC traction substation which is located in the mineral line Tebessa - Annaba (in east of Algeria), this line transport raw materials such as iron and phosphate. We present in this work to mitigate harmonic currents the passive filtering, using filters (tuned at frequencies 11 and 13) at two different locations before and after the transformer which freedies the DC traction substation. The results of simulations with the proposed solution give the best results with minimum values of total harmonic distortion (THD) in both cases.*

Keywords *–Electrification, DC Traction Substation, Filtering Harmonics, Power Quality, Passive filter, Railway System.*

1. Introduction

Electricity has become the primary source of traction power in modern railways .While the diesel or coal driven trains are still heavily used in some countries , they are often limited to long distance commutation and/or freight transportation [1].

The electric traction system is the most efficient traction system. It offers several benefits over other systems, including quick start and stop, very efficient, pollution free, easy to handle and easy speed control [2]. The DC electric traction system plays again an important role for domain of transportation because of high efficiency, heavy ridership and fast transportation of series DC motor (high initial torque) , and we note that DC train consumes less energy compared to alternating current (AC) unit for operating same service conditions [2-3].

However, the DC electrified railways cause a lot of problems for the power quality such as injecting harmonics (high THD); reactive power , and low power factor issue [4-5]. In this paper we concentrated on filtering of currents harmonics generated by the DC electric traction units in a railway system by using passive filter which installed on different locations of transformer feeding (before , after).

These solutions are cheap, economy and work in the middle and high voltage, eliminate negative sequence current, and also participate in the compensation of the reactive power deficit thus improving the power factor of the power networks [5, 6].

2. Description of DC traction substation

With the development of electrified railway, electric locomotive was applied in railway transportation more and more widely [4]. And they can be harmed security on power system network, production and manufacture badly and more then electrified railway security and reliability in the railway transportation [6-7].

The electrical system studied is DC traction station that exists in the mineral line between the two cities Tebessa and Annaba (eastern Algeria).

The schematic diagram of the system studied is shown in Figure 1.

This series connection of two 6-pulse converter bridges requires two three-phase systems feed by a three winding transformers with star/star/triangle connections (Y/Y/Δ) which are spaced from one another by 30 electrical degrees, that is to say form a 12-pulse rectifier. This grouping of rectifiers has the advantage of eliminating the harmonics (5th and 7th) on the AC side [7-8].

The positive output of the group rectifier (3KV DC) is transmitted along the track via overhead contact (catenary) , and feeds an electric locomotive (3600 horsepower), while the negative output will be connected to the rail (Figure 1). This locomotive consists of six series DC traction motors, each of which is powered by a 750 V voltage through a chopper [8].
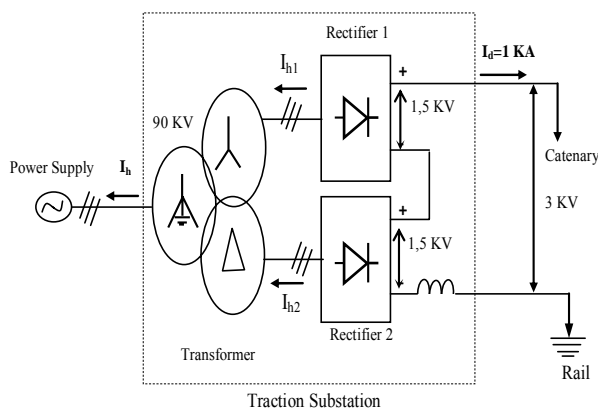

Fig.1. DC traction substation supply

3. Harmonic filtering

We used in this article passive filters which are a classic methods for power quality improvement , consist of series LC tuned for removing a specific harmonic or blocking a bandwidth of severe harmonics of nonlinear loads current [9].

For mitigating the harmonic distortion passive filtering is the simplest conventional solution. The most commonly used passive filter is the single tuned filter. This filter is simple and least expensive as compared with other means for mitigating the harmonic problems [10]. These filters have low impedances for the tuned frequencies such as 11th and 13th (used in our application).

Low cost is a great benefit of these filters. These filters are always connected in parallel across the network [6-10].

3.1. Principle of passive filtering

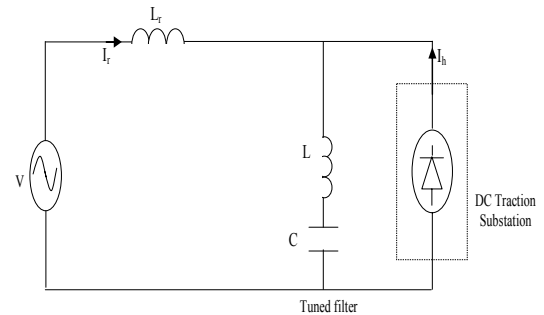The single tuned filter connected to the network is represented in Figure 2.

Fig. 2. Single phase equivalent circuit diagram of a filter connected in parallel on the network

With:
L_r : The inductance of the network
V : Voltage of the line.
I_r : Current of line
I_h : Harmonics currents equivalent to the « DC traction substation ».
L & C: Parameters of passive filter
Impedance of filter branch is given by

$$Z = j\left(L\omega - \frac{1}{C\omega}\right) \tag{1}$$

ω : angular frequency

Resonant filter is given by the equation (2):

$$L\omega_r = \frac{1}{C\omega_r} \; ; \text{ and } \quad f_r = \frac{1}{2\pi\sqrt{LC}} \tag{2}$$

The capacitive or inductive reactance which corresponds to the frequency is:

Hence: $\omega_r^2.L.C = 1$

In harmonic regime:

$$X_{Lh} = hX_L \; ; \text{ and } \quad X_{Ch} = \frac{X_C}{h} \tag{3}$$

In the case of resonance: $X_{Lh} = X_{Ch}$

$$X_r = L.\omega_r = \frac{1}{C\omega_r} \tag{4}$$

Therefore:

$$hX_L = \frac{1}{C\omega_r} \tag{5}$$

$$hX_L = \frac{X_C}{h} \tag{6}$$

Either: $h^2 = \dfrac{X_C}{X_L}$ (7)

Hence: $h = \sqrt{\dfrac{X_C}{X_L}}$

(8)

But we can express in terms of reactive power "*Q*" and short-circuit power "S_{cc}". As follows:

$h = \sqrt{\dfrac{S_{cc}}{Q}}$ (9)

With:

h: order harmonic resonance producing parallel
Anti-resonance is given by the following formula:

$\omega_{ar} = 2\pi f_{ar} = \dfrac{1}{\sqrt{(L_r + L)C}}$ (10)

3.2. Use of multiple filters

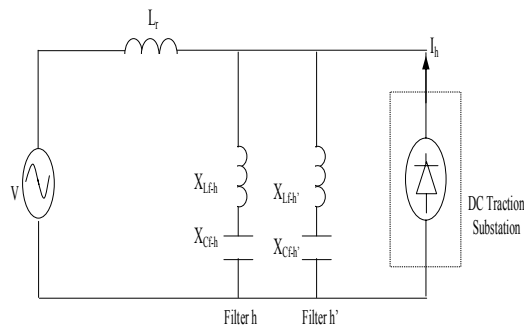In our work we use two tuned filters to both harmonics h=11 and h'=13

Fig. 3. Equivalent circuit diagram of a tow tuned filters connected

This method requires several conditions to achieve [7]:

$h^2 = \dfrac{X_{Cf-h}}{X_{Lf-h}}$ (11)

$h^{2'} = \dfrac{X_{Cf-h'}}{X_{Lf-h'}}$ (12)

$\dfrac{V^2}{X_{Cf-h} - X_{Lf-h}} + \dfrac{V^2}{X_{Cf-h'} - X_{Lf-h'}} = Q$ (13)

$Z_{f-h}' = \dfrac{h'}{h}.Z_{f-h}$ (14)

After simplification we find the generalized formulas for the use of multiple filters at the same place [7].

$X_{Lf-h} = \dfrac{(h+h').V^2}{(h^2-1).h'Q}$ (15)

$X_{Cf-h} = \dfrac{h^2(h+h').V^2}{(h^2-1).h^2Q}$ (1

$X_{Lf-h'} = \dfrac{(h+h').V^2}{(h^{2'}-1).hQ}$ (17)

$X_{Cf-h'} = \dfrac{h^{2'}(h+h').V^2}{(h^{2'}-1).hQ}$ (18)

With :

h & h': Order harmonic of filter 11and filter 13.
Q : Reactive power at the filtering place
V : Voltage at the site of filtage
X_{Lf-h} and X_{Cf-h} : Parameters of the filter 11
$X_{Lf-h'}$ and $X_{Cf-h'}$: Parameters of the filter 13

4. Simulation results
4.1. Operation without filtering

We used Power System Toolbox in MATLAB /Simulink ; by affecting the true values (see Annex 1 & 2) for our DC traction substation studied.

In the following figures we present the differents waveforms of the voltages and currents during normal operation of DC traction substation.
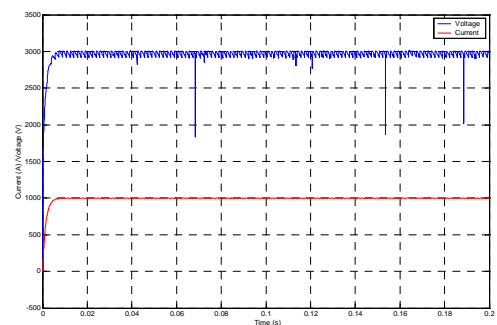

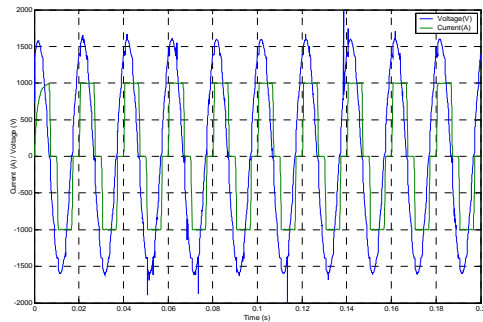Fig. 4. Waveform of the Voltage & Current at the output of group rectifier

Fig. 5. Waveform of the voltage /current absorbed of rectifier (Y/Y)
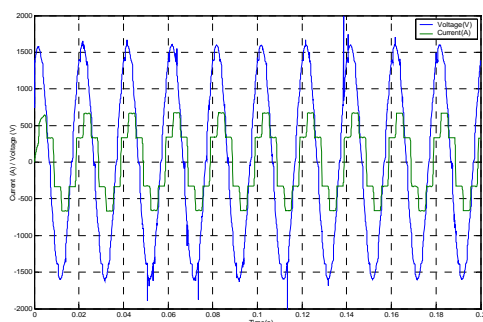

Fig. 6. Waveform of the voltage /current absorbed of rectifier (Y/Δ)
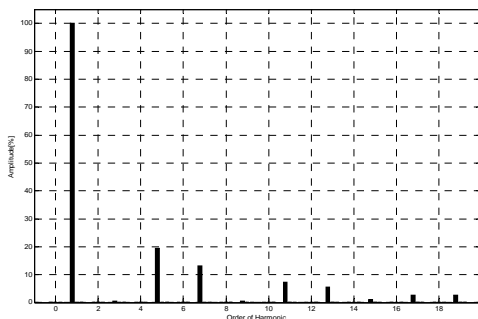

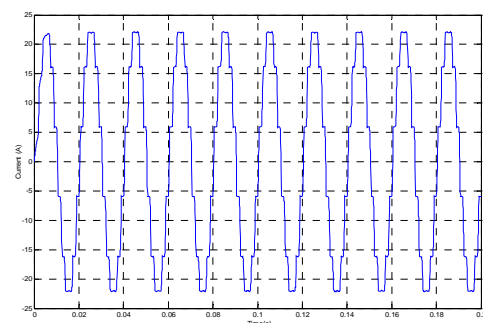Fig. 7. Harmonic Spectrum of current harmonic absorbed by one rectifier

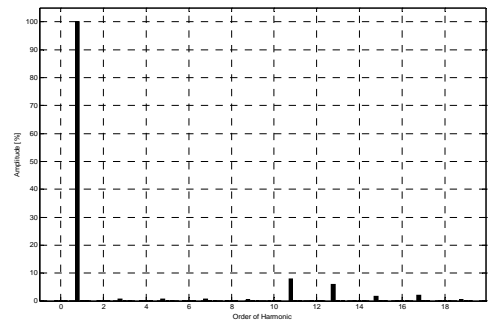Fig. 8. Waveform of the current injected in electric network

 Fig. 9. Harmonic Spectrum of current harmonic injected

In figure 7, we see that the current harmonics that exist are of the form $6k \pm 1$ (with k integer) , so we can see the existence of 5, 7, 11,13, ..., since the load of pollution is a three-phase rectifier and also marks a high value of **THD = 26.31%.**

From the figure 9 we see the elimination of harmonic of the 5th and 7th order and it returns to the advantage is the use of transformers with three connections Y / Y / Δ (formation of a 12 pulse rectifier), the remaining harmonics are the form $12k \pm 1$ (with integer k) ie, 11,13, ..., the value of **THD = 10.38%** is still higher than the standard, it is for this reason we think of the passive filtering solution with implementations of tuned filters in 11th and 13th before and after the power transformer.

4.2. Operation with filtering

4.2.1. Filtering before transformer (Case 1)

Since the harmonic characteristics that have large amplitudes are 11th and 13th; so the idea is to install two tuned filters corresponding to these harmonics as shown in the following figure 10.
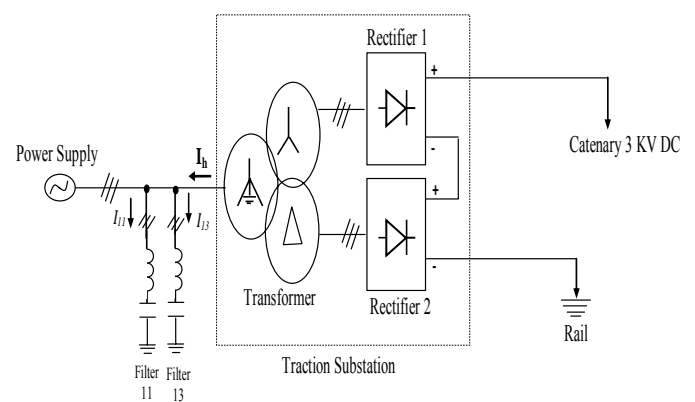

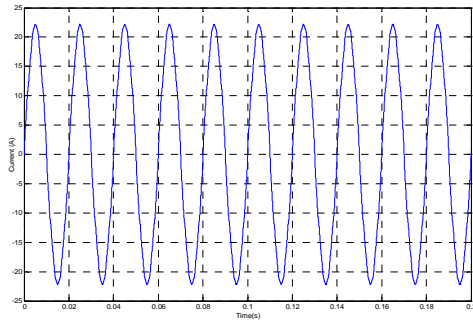Fig. 10. Systems studied with passive filtering (case 1)

Fig. 11. Waveform of the current injected (I_h) in electric network with passive filter (case 1)

Fig. 12. Harmonic Spectrum of current harmonic injected with filtering (case 1)

4.2.2. Filtering after transformer (Case 2)

It is known that 5th and 7th harmonics are theoretically removed before transformer (do not propagate through the electric network); so the idea will be oriented towards eliminating harmonic 11th and 13th with the use of passive filters tuned to these frequencies to just before the three-phase rectifiers as shown in the following figure 13.

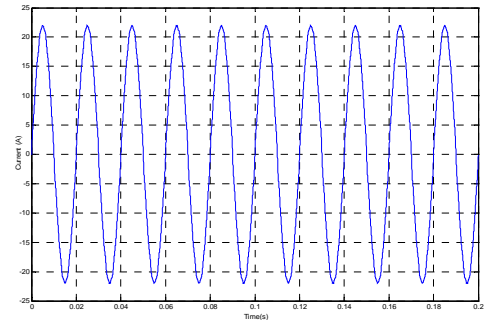Fig. 13. Systems studied with passive filtering (case 2)

Fig. 14. Waveform of the current injected (I_h) in electric network with passive filter (case 2)

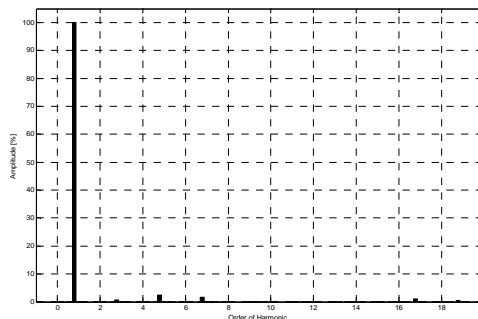Fig. 15. Harmonic Spectrum of current harmonic injected with filtering (case 2)
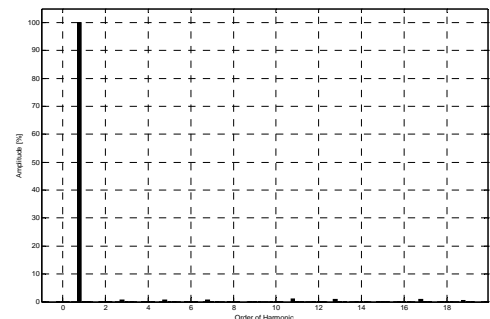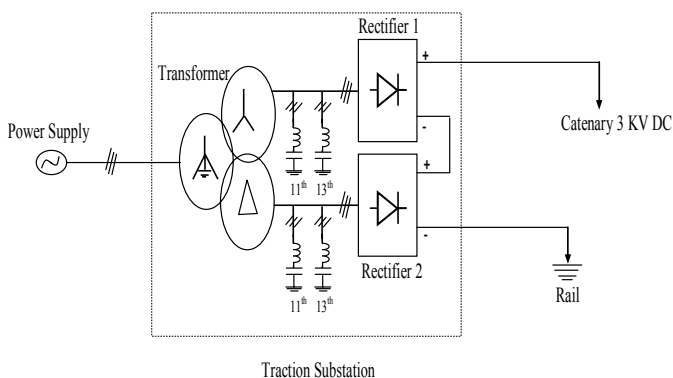
Table 1: Simulation Results

	Without Filtering	With Filtering	
		Case 1	Case 2
THD (%)	10.38	3.24	1.98
h_5 [%]	0.80	2.48	0.72
h_7 [%]	0.68	1.65	0.62
h_{11} [%]	7.88	0.06	1.03
h_{13} [%]	6.00	0.01	0.83

5. Conclusion

Harmonic disturbances cause damage to power systems and can sometimes be dangerous. This result in overloads, reduced service life and, in some circumstances, can lead to premature failure of electrical and electronic equipment. . In this paper we have used the simplest and most efficient method of attenuating harmonic currents as passive filtering and we have chosen to filter the harmonics 11 and 13 with the use of tuned filters because it is known that the harmonics of Current which propagate in the electrical network, they are with these frequencies.

To achieve this solution in the best way we chose two locations for the installation of these filters (before, and after the transformer that supplies the traction station).

Finally, the simulation results obtained give a minimum value of the current THD injected into the network in the case of filtering after the transformer (medium voltage) and the filtering before the transformer (high voltage).

Annex 1: Characteristic of DC Traction Substation

Coupling transformer	Yn-Dy
Number of tapping points of the tension	0.5 (+ or - 4 to + or - 8% A)
Nominal voltage network side	90 kV
Effective cell side load voltage	1.236 kV
Short circuit voltage	6.7% V
Current cell side	817 A (for the delta winding)
Current cell side	844.4 A (for winding star)
Supports loss (power at rated voltage)	24 kw
Total loss (power at rated voltage)	31.7 kilowatts
Dynamic short-circuit current	0.85 kA
Thermal short circuit current	0.33 kA

Annex 2: Characteristic of the Rectifier Group

Number of diode in series with the bridge arm.	1
Number of parallel diode bridge arms	4 + 1 = 5
Total number of rectifier diodes	2x30 = 60
Input Rated current (AC side).	577 A
Nominal output current (continuous rating)	1000 A
Actual DC voltage (at the output of the rectifier group)	3310 V
Nominal voltage charge (at the exit of the group)	3240 V
Current DC front (DC side)	16.7 kA
Losses block transformer - rectifier (charging)	38.24 kw
Rated inductance	0.2 mH

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