Simulation Results on the Currents Harmonics Mitigation on the Railway Station Line Feed using a Data Acquisition System

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Abstract: - With the progress of power electronic devices in electric railway, harmonics in power systems become increasingly of concern. This paper presents a case study on harmonics in a traction power supply system. The study was based on measurements realized in an electrical drive station using a data acquisition system and a computer. It was analyzed the main power quality indicators: the power factor, the reactive power factor, the deforming power factor and the total harmonic distortion of the current and voltage. The paper present also the simulation results of process of electric drive vehicles especially in railway using different passive LC filters using PSCAD-EMTDC simulation program.

Key-Words: - harmonics filtering, railway, power quality, PSCAD EMTDC simulation program

1 Introduction

Nowadays the electric power is used in many real applications. Thus, it must taking account of the power quality with protection of environment. The exigencies that must by observed for the power distribution systems pertain to the power supplying continuity and power quality, and lead to a detailed analysis of the electric power parameters.

The quality of electric power – a requirement of the power supply – must be analyzed in correlation with the distortions of the consumer's receivers, which are introduced in the electric supplying network. If the power supplying parameters are not within the standard limits, the life span of the electrical equipments decreases. On the other hand the equipment has to be over dimensioned, in order to cope with these situations. The quality of the electric power, an important component of the electro-energetic system, is a concern of the producer and also of the consumer. The concern of the electric power producer is the distribution and transportation electric network, which must work within certain parameters. On the other hand the consumer is interested in an appropriate electric power quality, but, in the same time, he is involved in this quality preservation. On the output generators, electric voltage is practically sinusoidal, but, at the consumer, it is more or less disturbed. For study the possibility to improve the power quality it was use the simulation program PSCAD EMTDC. PSCAD (Power System Computer Aided Design) is a multi-purpose graphical user interface capable of supporting a variety of power system simulation programs. This release supports only EMTDC (Electro-Magnetic Transients in DC Systems).

2 The main power quality indicators

Spectral analysis of current and voltage wave disclose multiple frequencies of fundamental of 50 Hz named harmonics. Frequencies domains which correspond to these harmonics are in general between 100 Hz and 2000 Hz irrespective harmonics of k = 2 and k = 50 rank. Actually international standards specify that non-sinusoidal regimes analysis will be made using the first 50 harmonics, and for this reason the programs which we will be use will be construct upon this analyze. It is possible to exists in electrical voltage "inter-harmonics", these been components of his frequency are suitable between the harmonics.

The criteria of quantitative analysis of power quality are [1], [3], [4], and [5]:

Apparent power absorbed by a charge in no sinusoidal regime can be defined in the same way like in sinusoidal regime as product between effective values of voltage and currents

$$S = U \cdot I \,. \tag{1}$$

Computing of rms values of current and voltage is made according to relations

$$U = \sqrt{U_0^2 + \sum_{k=1}^{\infty} U_k^2}\ , \qquad (2)$$

$$I = \sqrt{I_0^2 + \sum_{k=1}^{\infty} I_k^2}\ . \qquad (3)$$

Active power absorbed by a dipole supplied with electrical energy such as voltage and current are no sinusoidal is mean over a period of instantaneous absorbed power

$$P = \frac{1}{T}\int_0^T p \cdot dt = \frac{1}{T}\int_0^T u \cdot i \cdot dt\ . \qquad (4)$$

It can be demonstrate [4], [5] that active power is equal to the sum between product of constant terms (continuous current power) and the sum of active harmonic powers corresponding to relation

$$P = U_0 \cdot I_0 + \sum_{k=1}^{\infty} U_k \cdot I_k \cdot \cos\varphi_k\ . \qquad (5)$$

Reactive power absorbed by a dipole in no sinusoidal regime is equal with the sum of reactive powers corresponding to harmonics

$$Q = \sum_{k=1}^{\infty} U_k \cdot I_k \cdot \sin\varphi_k \qquad (6)$$

Deformed power, specify the no sinusoidal regime give by relation:

$$D^2 = S^2 - P^2 - Q^2 \qquad (7)$$

and has the expression

$$D = \sqrt{\sum_{j>}^{\infty}\sum_{k=1}^{\infty}\left[U_j^2 \cdot I_k^2 + U_k^2 \cdot I_j^2 - 2U_j U_k I_j I_k \cdot \cos(\varphi_j - \varphi_k)\right]} \qquad (8)$$

The power factor

$$K_P = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2 + D^2}} \qquad (9)$$

The reactive power factor

$$\rho = \frac{Q}{P} = tg\varphi \qquad (10)$$

The deforming power factor

$$\sigma = \frac{D}{\sqrt{P^2 + Q^2}} = tg\xi \qquad (11)$$

where P is active power, S is apparent power Q is reactive power and D is deforming power.
The total harmonic distortion for current,

$$THDI = \sqrt{\sum_{k=2}^{40}\left(\frac{I_k}{I_1}\right)^2} \cdot 100\,[\%], \qquad (12)$$

respectively for voltage,

$$THDU = \sqrt{\sum_{k=2}^{40}\left(\frac{U_k}{U_1}\right)^2} \cdot 100\,[\%] \qquad (13)$$

The pondered partial total harmonic distortion for current,

$$THDI_P = \sqrt{\sum_{k=2}^{40} k \cdot \left(\frac{I_k}{I_1}\right)^2} \cdot 100\,[\%], \qquad (14)$$

respectively for voltage,

$$THDU_P = \sqrt{\sum_{k=2}^{40} k \cdot \left(\frac{U_k}{U_1}\right)^2} \cdot 100\,[\%] \qquad (15)$$

where U_1, I_1 are the rms values for voltage and current on the fundamental and U_k, I_k the effective values for voltage and current on the k^{th} harmonic order.

3 Results obtained by measurement in electrical station

3.1 The principle scheme of the feed system in the power supply station

The tendency of combining the industrial advantages of the contact line's alimentation to a high voltage (16-25 kV) with the workable connection of the electric railway to the electrical networks and systems of general utilizations took to the appearance and development of the 50 Hz alternative mono phased current system. The nominal voltage of the contact line was established at 25 kV and the walking in blank voltage at 27.5 kV.

The main advantages of the 50 Hz mono phased current system are:

- because of the big voltage used at the contact line, the distance between the traction substations is bigger (50-80 km), sometimes being able to reach even 100 km, the contact line has a smaller section (150-200 mm2) and an easy construction, the copper consumption being much smaller than at the continuous current system ;
- the traction substations are extremely simple, comparative to the other systems' substations; their cost is very frugal and they need skimpier expenses at maintenance and exploitation;
- the 50 Hz mono phased current system can easily be considered one of the electrical systems and networks of general utilizations;
- the traction current has no corrosive action at the underground installations and sewages it meets.

A disadvantage of the 50 Hz mono phased current system is the fact that it inductively influences in a bigger way than the other systems the electric lines at the telecommunications located along the railway.

But because the modern tendency is to cabling the telecommunications lines apart from electrification, and, in the latest years, there has been gone from cabling with classic circuits to optical fiber, this disadvantage loses importance. The incontrovertible advantages of the 50 Hz mono phased current system could be improved only after the building of some solid electrical steam-engines and with appropriate parameters, like electrical steam-engines equipped with rectifiers circuits.
The principle scheme of the 50 Hz alternative mono phased current system is indicated in figure 1.

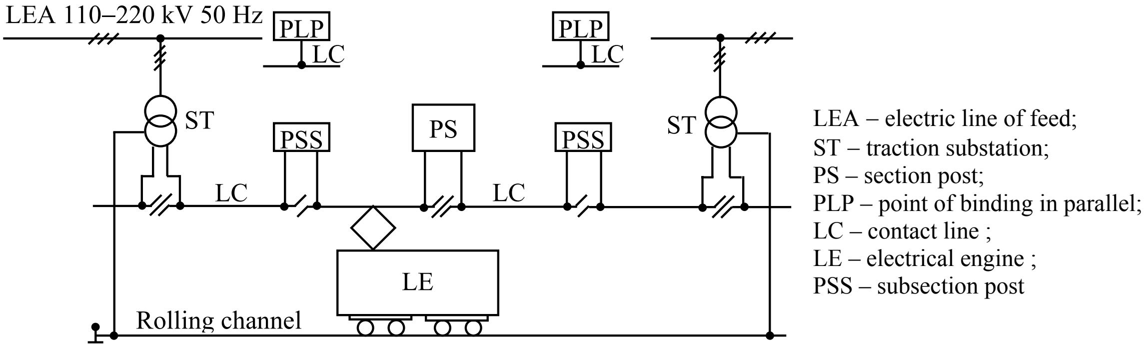


Figure 1. The principle scheme of the 50 Hz alternative mono phased current system.

block, means that measurement errors depend especial on errors introduced by transformers, errors introduced by adapting block been smaller.
For the nonsinusoidal operating identify we are performed some measurement on the railway electrical station in Romania, and we are determine the distortions level for the current and voltage. The measure data are store in a PC, and there are ulterior processes.
The data were input to a computer in order to be processed at a later stage. The modern methods of measuring electric magnitudes use numeric systems

3.2 The measuring of the three phased electrical items on LEA 110-220 KV

In scope of measurement of currents and voltages on LEA 110-220 KV it will be use three current transformers CITO 1000A / 70A and a voltage three phased transformer CITO 220KV /1000V, like in figure 2. The secondary transformers will be connected to high currents and voltages adaptation based on systems of data acquisition and the method we introduced in this paper uses such a system. We used a computer with an ADA 3100 acquisition board [9] to which we connected an adapting block for the high currents and voltages. The role of this block is to achieve the compatibility of the magnitudes to be measured with the measuring range of the data system, as well as to lead to a

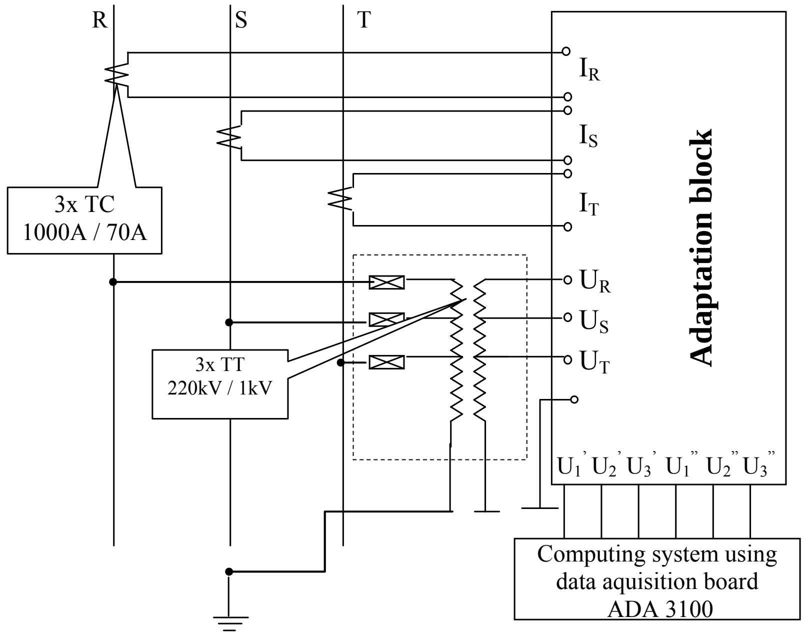
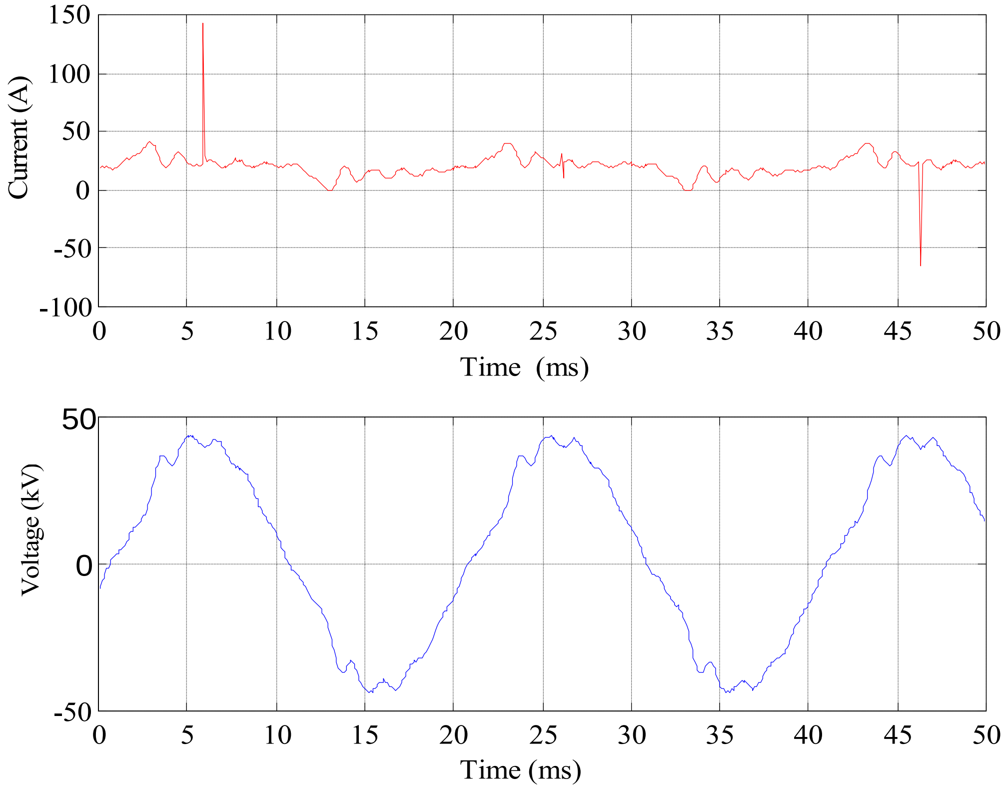


Figure 2. The measurement scheme of voltages and currents on LEA 110-220 KV.

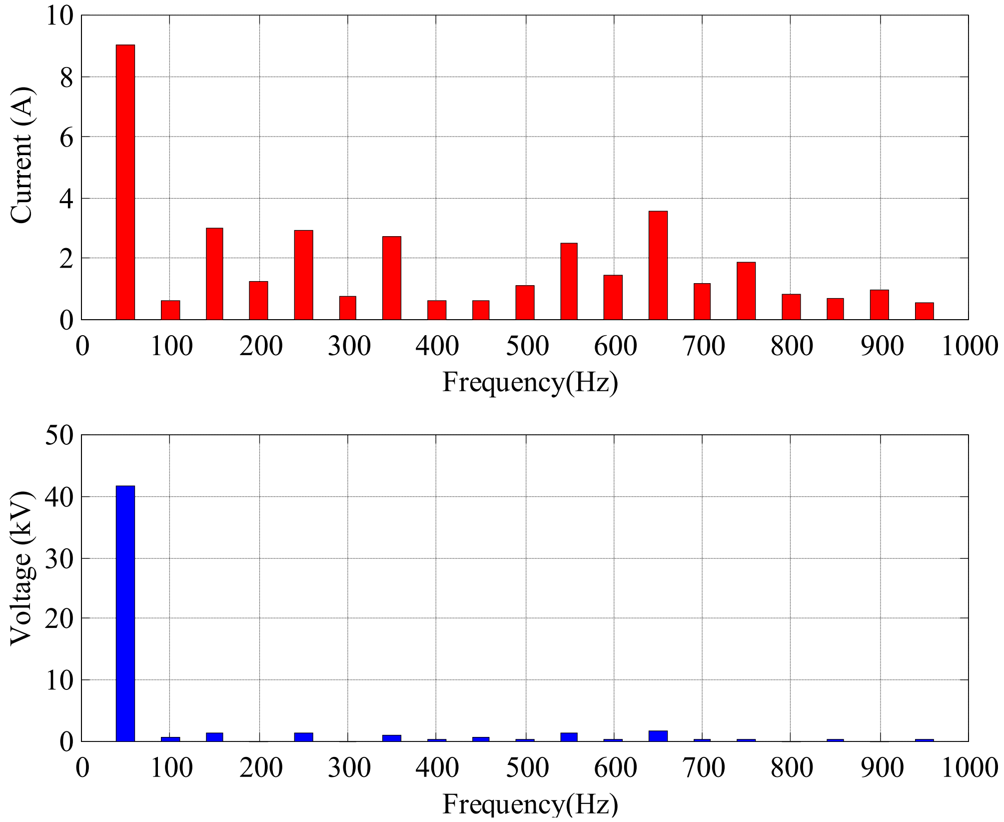
galvanic isolation between the force circuit and the data acquisition system.
The adapting block allows the simultaneous acquisition of three currents and three voltages. In order to obtain an analysis of the variation of electrical magnitudes along an hour, the data acquisition has been carried out along this hour. This process shows a set of specific characteristics, depend on both the nature of the electric magnitudes to be measured and on the technical characteristics of the data acquisition system in use and the computer on which the programs run.
Taking into account both the characteristics we have shown and the recommendations concerning data acquisition in the systems of measuring currents and voltages on medium and high voltage lines given in [4], [5] the 2-channel data acquisition has been done as follows:
- during 250 ms we sampled data simultaneously on 2 channels, the acquisition frequency being 5 KHz. In this way was sampled the signals along 12.5 time periods. This thing allows that in case of a different frequency value from 50 Hz, the sampled data containing a 12 full period of signals.
- the 250 ms acquisition process was resumed at an interval of 9.75 seconds, interval along which we saved in the memory the data previously acquired. Thus, it results that along the entire duration of the charge we sampled data in time windows of 250 ms each, the interval between two windows of consecutive data being 10 seconds.
From the set of data acquisition we select some windows, which we considered representatives, and we analyze these windows. So, in figure 3 a) are represented the variation of the current and voltage on the low voltage feeding line in case of no distorted load (no train is passing, or the train is far away from the measure point). In figure 4 a) and 5 a) are show the current and voltage waveforms on the low voltage feeding line if a train is passing. One can notice their strong distortion. For the data window from figure 4 a) is found a significant value of the distorted power that confirm the presence of the currents harmonics. In figure 5 a) is present also a data window with a significant distorted current on the feeding line. The spectral characteristics are obtained by data acquisition processing, using the Fourier transform. Because the acquisition frequency was 5 KHz, the spectral analyzed frequency band are 0 – 2,5 KHz, which, divide by 1250 samples from data window leads to 2 Hz frequency step. Because, like is present in the reference literature [5], the analyze of the first 40 harmonics values, the power, power factors and distortions coefficients determination was made based on the 40 harmonics values, but for a good clarity the graphics was represent by 1 kHz, according with the first 20 harmonics values.
The spectral characteristics for the current and voltage are present also in figures 3 b), 4 b) and 5 b) for the analyzed data windows. By analyzing both, the variation of the current and voltage and the spectral characteristics especially in case of presence of the load (fig 4 b) and 5 b)) one can observe that the higher deformation is on the current. However, the voltage is also deformed, but it preserves an approaching sinusoidal shape.
One can also observe, on the spectral characteristic for the current and voltage that the odd order harmonics are higher comparative with the non-odd order harmonics. It can be observed that the 13^{th} – order harmonic is the biggest, and after that the values are decreasing strongly. In case of absence of the load (or in case of the far away load) the current distortions are much lower.
Regarding the values of the active, reactive and distortion power, the values of the power factor and the reactive factor are present in table 1, for all three data windows.
We also gave in table 1, the values for the distortion coefficients. It can be observed from these data the presence of the reactive power, therefore reactive power compensation is necessary. The distortion of the current and voltage are also obvious by analyzing the value of the distortion power that is very significant.

4. Simulation results

In this section will be present the filters effects for the 3, 5, 7, 9, 11, 13, 15, 17 and 19 harmonics. For this analyze we use the acquisition dates and introduced them to the input of filters. This result was obtained by using the simulation program PSCAD-EMTDC. For this aims it was present the current and voltage variation before and after filtering. The most frequently used solution (for the technical-economical reasons) is harmonics filters, which are, in fact, serial resonant LC circuits. In this paper the simplest type of such a filter was analyze. This type of filter is made by a single serial inductivity with a capacitor, named first order passed band filter (figure 6).
For each harmonic current it is use such a circuit. The components for each circuit are dimensioned in such way that for the resonance frequency, which are equal with the harmonic frequency, result null impedance:



a)



b)

Figure 3 a) Variation of the current and voltage on the low voltage feeding line in case of no distorted load (the train is far away)
b) The current and voltage harmonics

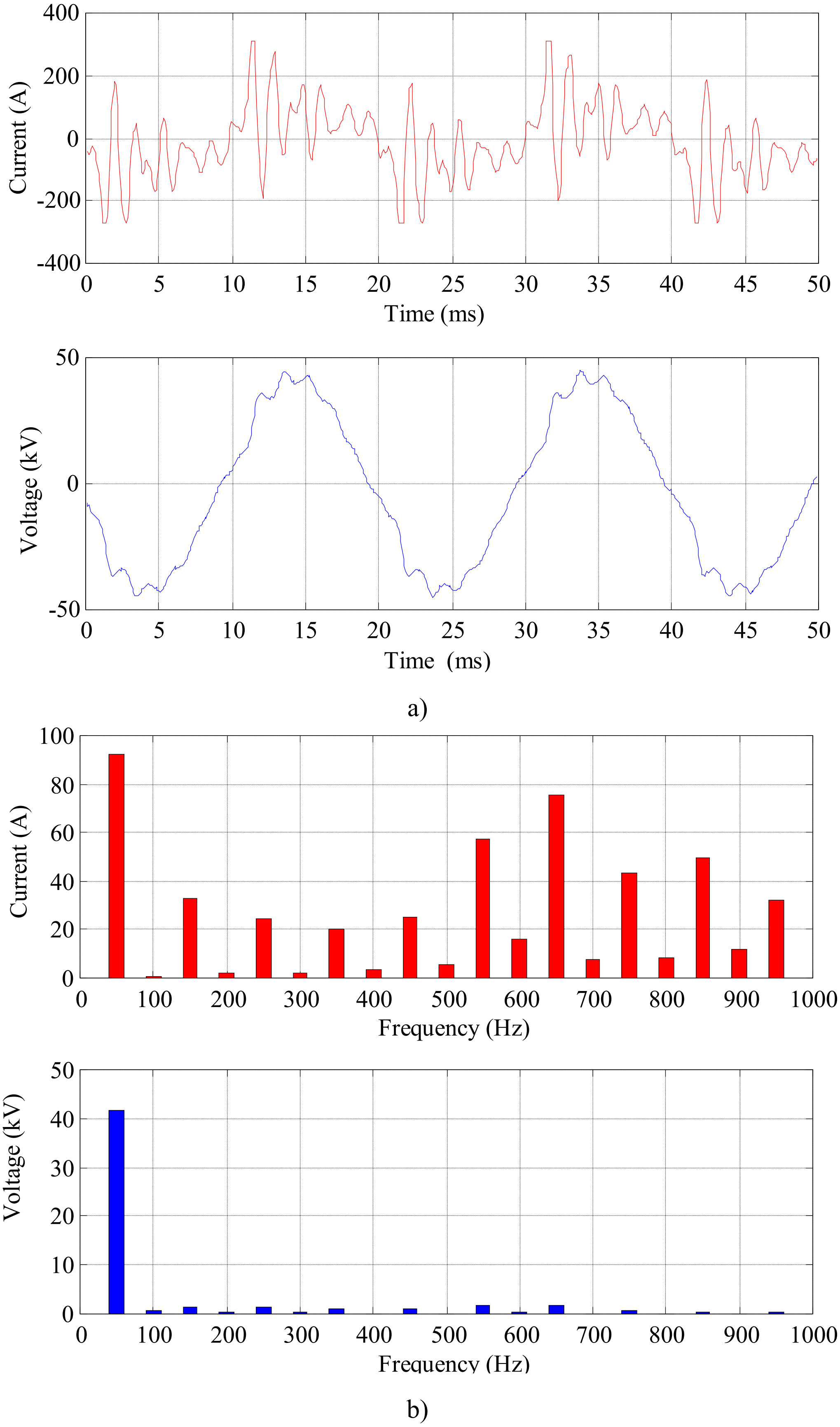
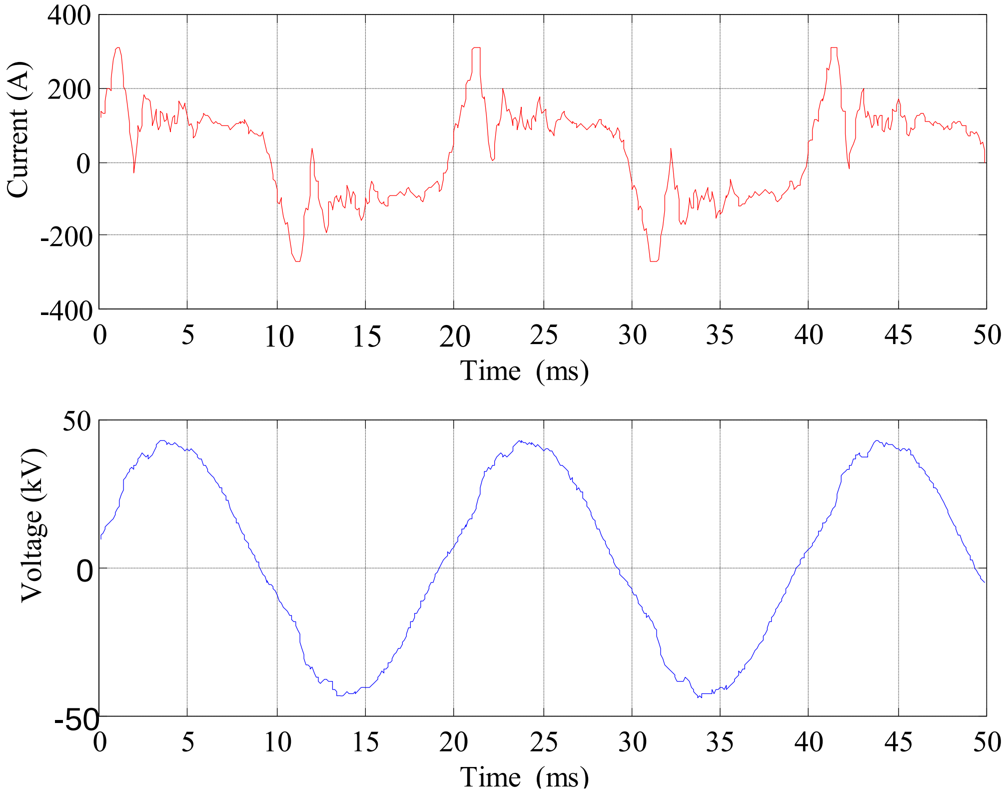
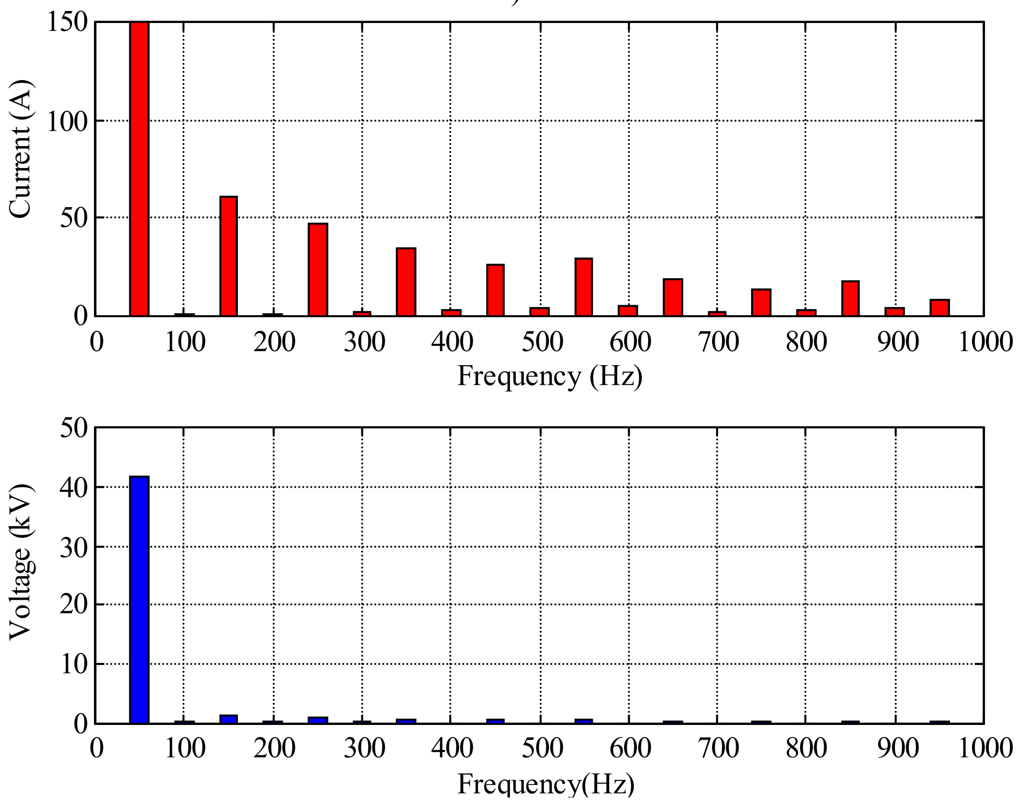


Figure 4 a) Variation of the current and voltage on the low voltage feeding line if the train is passing nearly of the measure point (the station)
b) The current and voltage harmonics



a)



b)

Figure 5 a) Variation of the current and voltage on the low voltage feeding line if the train is passing between two station b) The current and voltage harmonics

Table 1

	The train is far away of the measure point (power supplying station)	The train is passing	
		Nearly of measure point	Between two power supplying stations
The apparent power [MVA]	0.32	3.43	3.76
The active power [MW]	0.165	1.77	3.03
The reactive power [MVAR]	0.081	0.188	0.337
The distortion power [MVAD]	0.263	2.92	2.208
The power factor	0.514	0.518	0.8
The reactive factor	0.493	0.105	0.11
The distortion factor	1.427	1.638	0.724
THDI [%]	104.12	146.47	66.06
THDPI [%]	448.69	549.22	184
THDU [%]	7.86	8.705	5.66
THDPU [%]	24.42	27.53	15.89

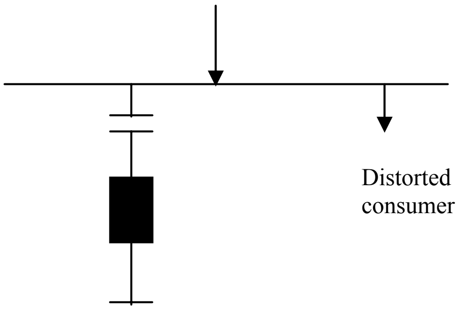


Figure 6. The electrical scheme for a first order pass-band filter.

$$Z_k = k\omega_1 L_k - \frac{1}{k\omega_1 C_k} \quad (16)$$

where Z_k are resonant circuit equivalent impedance for the k-order harmonic (equivalent resistances for the impedance, capacitors and electric cables are neglected) and ω_1 is fundamental current pulsation:

$$\omega_k = k\omega_1 = \frac{1}{\sqrt{L_k C_k}} \quad (17)$$

It can be observed that for smallest values for the pulsation vis a vis resonant pulsation $\omega<\omega_k$, $Z_k<0$, therefore the character is capacitive, and for greatest values for the pulsation vis a vis resonant pulsation the character is inductive.

Usually, the absorbing filters are installed for the harmonics with the highest amplitudes. Establishing of filters' inductivity and capacity values is made by applying of some algorithms that could be differentiated first depending on the filters' role from the viewpoint of reactive power compensation on the fundamental. All the resonant circuits will have capacitive character on the fundamental's frequency, so they will produce, no matter what, a capacitive transversal compensation of the network. Even though this rare solution, it could be taken into account in boundary situations when the distorted regime in current is very pronounced. Even the reactive power compensation is not aimed either, the filter will flow in the network reactive power on fundamental. Therefore, the filter's dimensioning criteria, more specifically of the capacity, is to minimize the installed capacitive reactive power (which, beside a minimum cost of the battery, leads to a minimum influence on the active power circulation in the network). This reactive power will have two components corresponding to the two above mentioned currents, the current corresponding to the fundamental and the current corresponding to harmonic k on which the resonance is taking place:

$$Q_c = Q_{c1} + Q_{ck} = U_c^2 \cdot \omega_1 \cdot C + \frac{I_k^2}{k \cdot \omega_1 \cdot C} \quad (18)$$

where:

Q_{c1} is reactive power supplied by the filter's capacitor on fundamental;

Q_{ck} is reactive power supplied by the filter's capacitor on k harmonic;

U_c is voltage at the capacitor's terminals;

I_k is harmonic current that follows to be filtered.

Considering the partial derivate depending on capacity of the installed capacitive reactive power equation and canceling it, we obtain the equation of the filter's capacitor capacity:

$$C = \sqrt{\frac{1}{k}} \cdot \frac{I_k\left(k^2 - 1\right)}{U_1 \cdot \omega_1 \cdot k^2} \quad (19)$$

The L filter's inductivity is determined from the resonance condition of the filter's LC serial circuit:

$$L = \frac{1}{\omega_k^2 \cdot C} = \frac{1}{k^2 \cdot \omega_1^2 \cdot C} \quad (20)$$

By introducing of such resonant filters on the odd harmonic frequencies, we can see the influence on each filter in part, as well as the effect of more filters connected in parallel. Is aimed also, beside the amplitude value, also the phase difference introduced by each harmonic against the fundamental. The PSCAD EMTDC simulation scheme is show in figure 7.

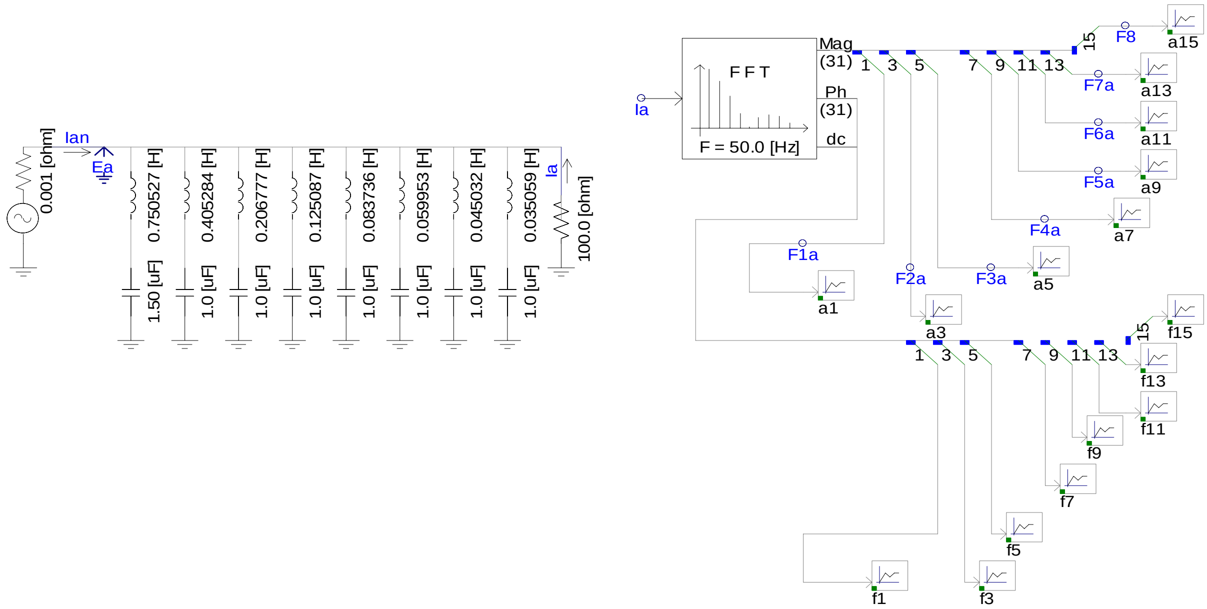


Figure 7. The PSCAD EMTDC simulation scheme.

The analysis is made for each filter in part, the results being listed in table 2, as well as for an increasing number of filters, depending on the harmonic's order, of which results are in table 3. The waveforms and instrumentation corresponding to the harmonics and phase-differences are show, on a graphic corresponding to a single filter (fig 8) and on a graphic corresponding to more filters (fig 9).

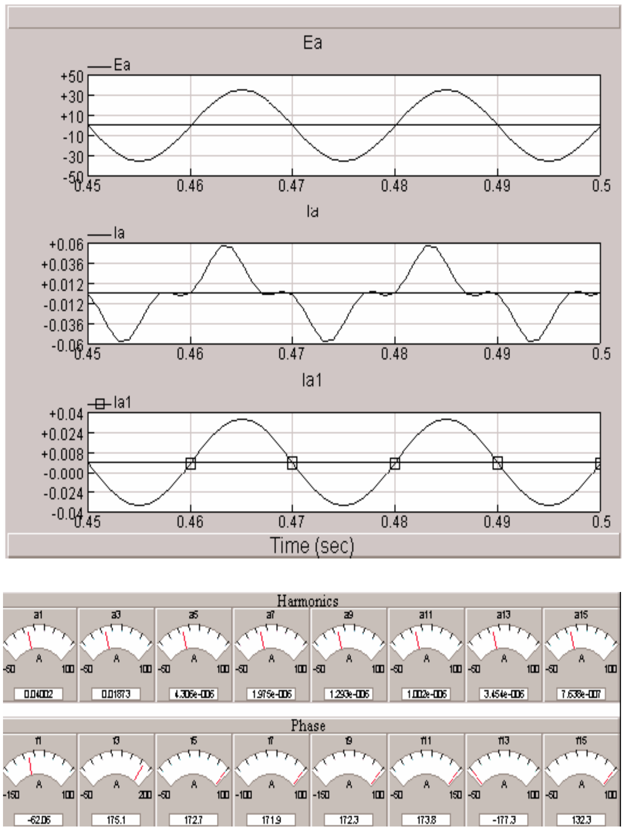


Figure 8 The waveforms, the harmonics amplitudes and phases for a single filter

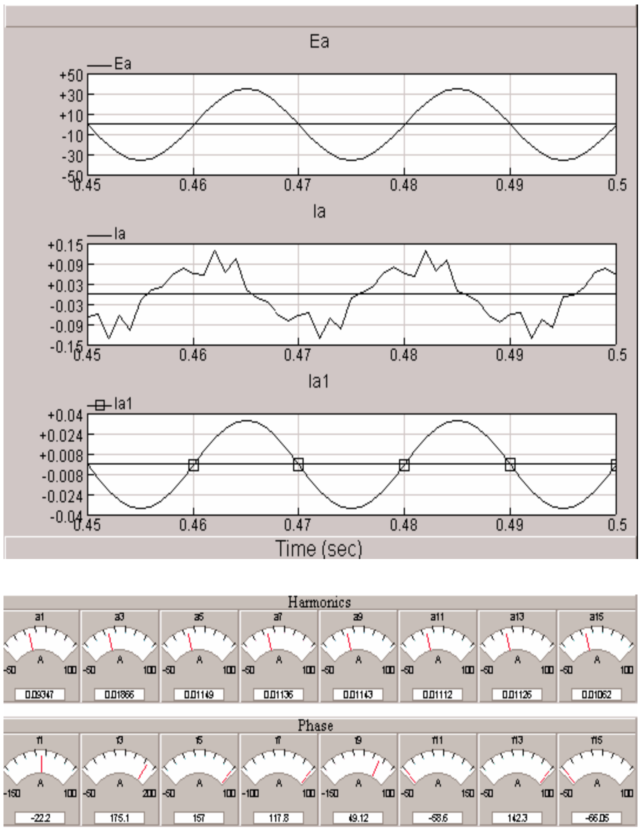


Figure 9 The waveforms, the harmonics amplitudes and phases for multiples filters

5. Conclusions

From the obtained data analysis, we can find the effect of each filter, both as harmonic's value and phase-difference on each frequency. From table 3 results that for a greater number of filters the effects are smaller and smaller, reason for which is not used a quite great number of passive filters for harmonics compensation. To attenuate the superior rank harmonics, which have more reduced values, usually are used power active filters, the general compensation being made by combining the two types of filters, passive and active. The number of passive filters utilized is determined depending on the consumer power, on its characteristics, on the electric power's quality requirements, as well as on the system's economical efficiency.

Table 2

	amplitude	phase
3	18.73	171.1
5	11.56	157.4
7	11.32	118.1
9	11.19	48.54
11	11.15	-59.98
13	11.13	144.6
15	10.78	-64.92

Table 3

Ampl [A]	Numbers of filters						
	1	2	3	4	5	6	7
a3	18.73	18.72	18.72	18.77	18.73	18.78	18.66
a5		11.56	11.55	11.58	11.57	11.58	11.49
a7			11.34	11.31	11.36	11.32	11.36
a9				11.18	11.28	11.22	11.43
a11					11.09	11.29	11.12
a13						10.99	11.26
a15							11.62
Phase							
f3	170.1	175.1	175.2	175.2	175.1	175.3	175.1
f5		157.4	157.5	157.7	157.4	157.6	157
f7			118.2	118.6	118.4	118.6	117.8
f9				48.82	49.6	49.02	49.12
f11					-59.8	-59.8	-58.6
f13						144.6	142.3
f15							-66.1

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