Power factor correction, controlling voltage distortion

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Abstract: *This paper presents, an approach for determining optimal sizes of single-tuned passive harmonic filters among existent capacitor busses in a power system. The proposed method uses Edsa Harmonics Analysis and the obtained results are presented in detail.*

Keywords: *power factor correction, passive harmonic filters, harmonic distortion.*

I. INTRODUCTION

The Power Quality has concerned the experts from power engineering area as far back as first years of using the energy, in a large amount of applications, the alternating current; during the last decade, we can observe several ascertainments to the involvement for this domain, owing to development based on power electronics.

At this moment we cannot talk about a united standardization of electrical energy quality on an international level and sometimes on national one. It does not exist and international quality standard for electrical energy but a lot of problems regarding this subject are shown on International Electrotechnical Commission papers (IEC).

IEC on 38th publication recommends in normal conditions of supply, that the voltage into delivery point has to be similar with nominal voltage, just with 10% difference. In almost all the countries, the directives system of electrical energy quality is composed by several quantitative characteristics of slow or rapid variations of effective voltage value, the shape or symmetry as well as characteristics of slow or rapid frequency variations. [1]

As it can be seen in Figure 1 there are presented the main causes of an improper electrical energy quality. In this paper we will analyze the behavior of an electrical installation in non-sinusoidal regime.

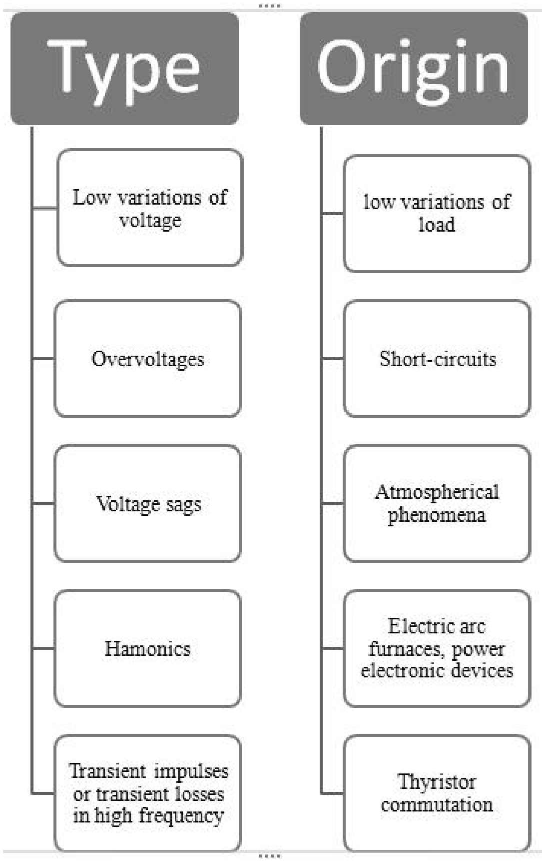

Figure 1 Causes of an improper electrical energy quality.

II. HARMONIC POLLUTION

The problem considering harmonic pollution represents a main aspect into relation between energy provider and consumer, the enactment of efficient measures to ensure the power electrical quality in attendance of perturbation sources it is a main concerning for the experts from this area. [2]

Industrial developing, the great utilization of modern technology, electric traction, and utilization of take-up converters, all these lead to an important augmentation of disturbance source number, entail an intensively pollution in power grids. More that 60% from electrical power, in developed countries is transferred by static power converters.

Therefore, besides the known advantage, these brings also disadvantages related of current and voltage alternative shape of feeding installation due tantamount to presence out of the fundamental harmonic and of superior order harmonics from the network. [3]

Curvilinear charges distort networks current even if supply voltage is sinusoidal. Electrical installation of such as loads can be presented like as linear load corresponding to current fundamental harmonics and array current sources of superior order. The last ones call forth on one side additional loss by Joule effect, on the other side bring to incorrect operation of protections and by the reason of drops in voltage on short-circuit impedances distort the condenser voltage and pollute the area with electromagnetic emissions of high frequency.

Parameter	Definition	Relations
Deforming residue	- waveform obtained from an original one, after suppressing the fundamental (sinusoidal) waveform	$A_d = \sqrt{\sum_{n=2}^{\infty} A_n^2}$
Harmonic level	- ratio between effective value of the considered harmonic and the effective value of the fundamental.	$^*\gamma_u = \frac{U_n}{U_1} \cdot 100, (\%)$
Total harmonic distortion	- ratio between deforming residue and effective value of fundamental waveform.	$^*\delta_u = \frac{U_d}{U_1} \cdot 100 = \frac{\sqrt{\sum_{n=2}^{40} U_n^2}}{U_1} \cdot 100,$

Table 1 **Parameters for non sinusoidal regime**

Therefore there exist two main problems, on one side the power $U_{ef(1)} \cdot I_{ef(h)}$ it is taxed on the same price as reactive power, on other hand beyond a several level of harmonics the power operators have the right to interrupt the consumers from the supply. It is necessary to develop solutions for current and voltage harmonics compensation. These kind of solutions are represented by active and passive filters. [1], [4]

Directives to appreciate non-sinusoidal form of the voltage or current one are presented in Table 1.

III. HARMONIC FILTRATION

One of the main targets is the attenuation of the harmonics, with a certain set of solutions that can be classified as follow: *technical solutions* and *operational solutions.* In Figure 2 it is presented a diagram which contains general methodology for harmonics elimination. The paper bellow deals exclusive the first category of methods, which consist of remission of harmonics with filters. Harmonics filters are representative for industry. There exist two types of filters: *passive*, constituted on passive elements: resistors, coils and capacitors, well as active filters constituted on current and voltage controlled sources.

Passive filters, are also of two types (series and parallel). Concerning the importance of the last ones, these will be the topic of the paper as follows. In *Annex 1* it can be followed a synthesis of the principle types on filters.

IV. SIMULATION RESULTS

In this section a polutted power grid is simulated on EDSA T2K, filters design is made using Edsa. [4]

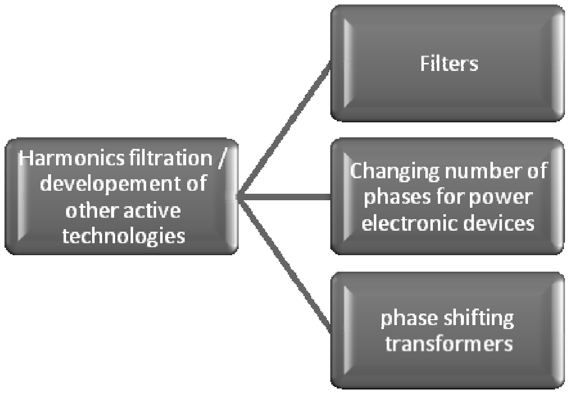

Figure 2. Methodology for harmonics attenuation

Harmonic Analysis module. Figure 3. illustrates only the bus with problems, regarding the presence of a great amount of harmonics.

4.1. Algorithm

The first step is to run advanced power flow and short-circuit module to obtain working conditions of the whole installation.

The next step is power factor correction and the installation of capacitor banks. The total demanded reactive power of the simulated installation is equal to *4.2 MVAr* , *1.8 MVAr* on low voltage buses, and *2.4 MVAr* on medium voltage buses. At the end of this operation, power factor calculated on high voltage bus has the neutral value, *0.92.*

Interaction between capacitor banks and the inductances in the circuit, can result in a resonance at a certain harmonic. As a result, the

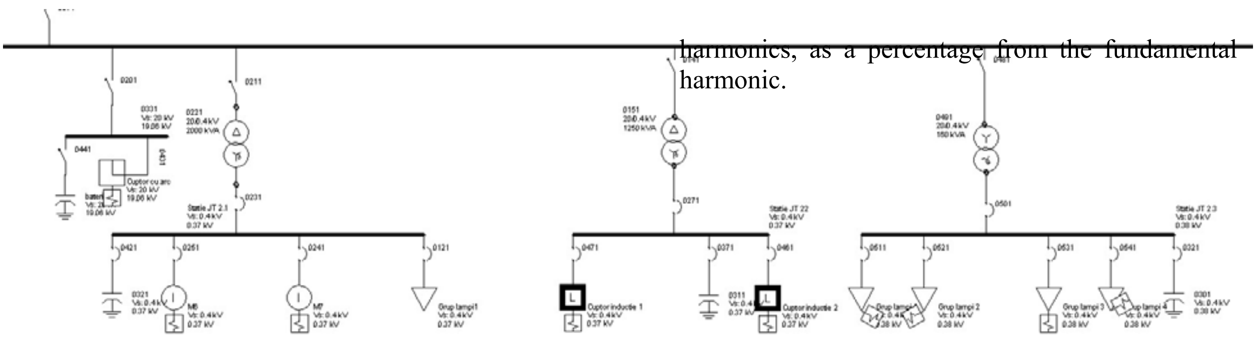

Figure 3. The bus with harmonic problems

equivalent impedance has a low magnitude, and the current can be increased very much, at that harmonic order.

In this way, the following step in our analysis is to run frequency scan, for the network.

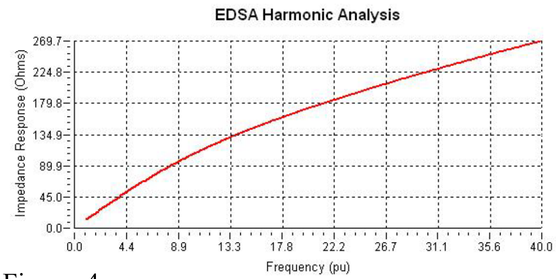

Figure 4.a

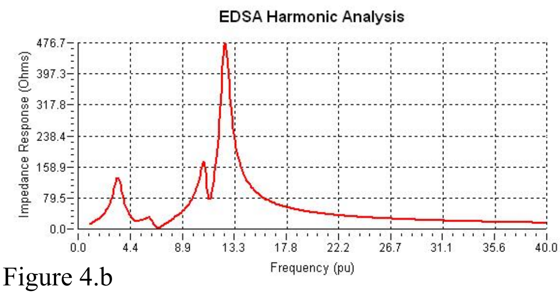

Figure 4.b

Figure 4.a shows the impedance response when the *4.2 MVAr* capacitor banks are „Off-line”, and 4.b illustrate the response with capacitor banks „On-line”. Using these picture, its no hard for us to conclude, that in the presence of capacitor banks for power factor correction, parallel network resonace will take place around the frequency equal with 550Hz (11th order). As it has been presented before the resonance between capacitive and inductive devices will expose capacitor banks to harsh conditions like overvoltages, or even their destruction.

To evaluate the harmonic distortion of the power sistem, first we have to know exactly the distortion. As soon as we know that, it can be proceeded to filters calculation. In our analysis we consider that only the second medium voltage bus, is supplying deforming users (EAF, VDF, etc). Table 2 express them, with the most important harmonics, as a percentage from the fundamental harmonic.

Knowing the harmonics level from network, next step is filters calculation, in that way that we get an appropriate value for THD. Rolling up *view curves* module, will get a graphical current/voltage THD studies in certain points in considered installation, and then with *THD Text Result*, will obtain a database with THD values in desired points. Table 3 show these values, where LV represent the low voltage bus (1,2,3), and EAF (Electric Arc Furnace).

Also we have to mention, that for all medium voltage users (electric arc furnace) the filters will be mounted on medium voltage bus, and for *0.4KV* consumers we will migrate to a filter disposure at low voltage distribution station.

For a better understanding of filters necessity in figures 5.a and 5.b will be presented the current waveforms without filters for harmonic reduction, on the deforming receiver’s line, in the most negative case (when reactive power compensation capacitor banks are on-line).

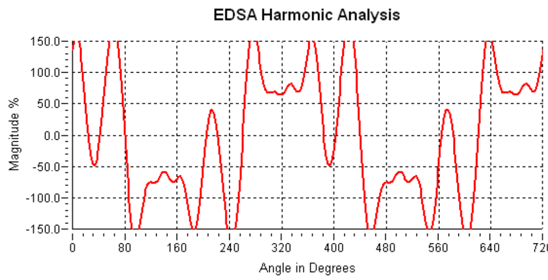

Figure 5.a

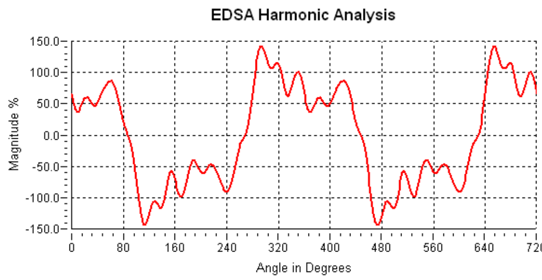

Figure 5.b

Consumers	No.	Apparent power [MVA]	Harmonics [%]					
			3	5	7	9	11	13
Electric arc furnace	1	1	29	7.9	3.1	2	-	-
Variable drive freuency	2	0.6	-	28.8	8.8	-	6.7	3.8
Fluorescent lighting	5	0.03	18	5	2	1.2	-	-
Average commercial load	2	0.5	3.5	8.8	5.9	-	2.5	1.9

Measure point	**VTHD*[%]***		**ITHD*[%]***	
	BC On-line	BC Off-line	BC On-line	**BC Off-line**
LV21	15.09	14.69	30.04	**30.02**
LV22	25.49	7.53	92.25	**23.18**
LV22	8.31	7.55	115.5	**11.7**
EAF	**2.72**	**7.21**	**87.98**	**16.25**

Table 2 Deforming consumers

Table 3 Voltage & Current THD / Text results

User	R	X_C	X_L	Tuned frequency
EAF	0.11	2.9	3.7	150
LV21	0	0.103	0.006	250
LV22	0	0.153	0.008	250
LV23	0.003	0.588	0.111	150

Table 4. Filters parameters

After the *Automatic Filter Sizing* module will be executed for a good configuration will calculate the parameters of filters. These filters will be mounted in the circuit with the purpose of correction the voltage, implicit the current waveforms will result close to sinusoidal waveform. That will result in a value for THD, accepted by actual directives which control this (IEEE 519). [5]

To obtain a waveform, like that one from Figure 6, that means a value for THD, less than 8 percents, we have to build the filters with parameters from Table 4, where LV represent the low voltage bus(1,2,3), and EAF (Electric Arc Furnace).

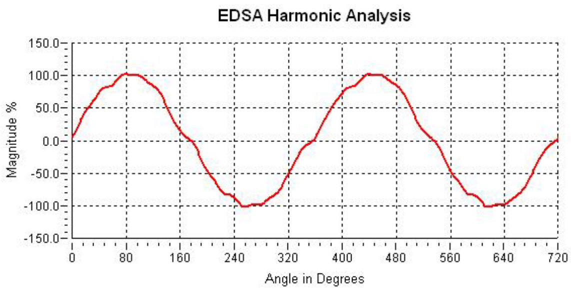

Figure 6. Current waveform with filters

V. CONCLUSIONS

Power factor correction became a very sensitive problem in networks with great content of harmonics. Due to the merits of single tuned filters, we analyze and propose an algorithm to calculate them and give an appropriate solution for a polluted power grid.

After a short discussion on harmonics the paper presents an application using a very modern soft EDSA T2K. Lastly the proposed filter design method is used for harmonic elimination and reactive power compensation.

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[5] M.A. Zamani, M. Mohseni, Damped-Type Double Tuned Filters Design for HVDC Systems, 9th International Conference.Electrical Power Quality and Utilisation. Barcelona, 9-11 October 2007.

Annex 1.

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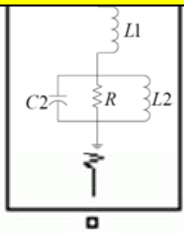
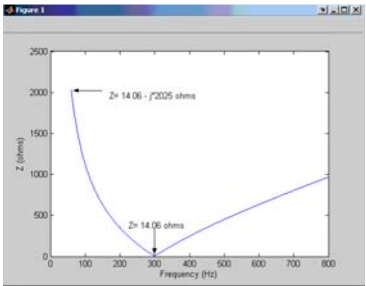
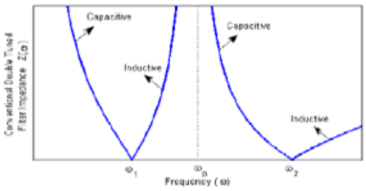
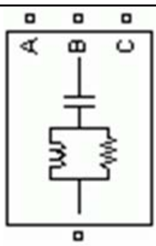
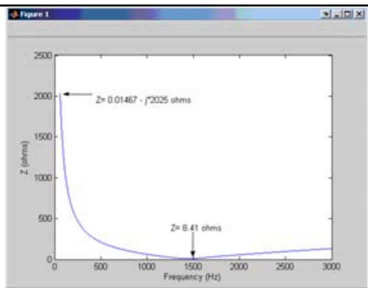
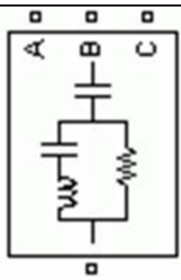
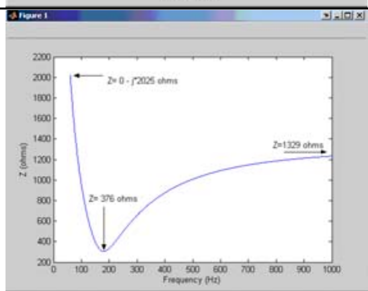
<table>
<tr><th>Filter Type</th><th>Filter block</th><th>Impedance vs. frequency curves</th><th>Description</th></tr>
<tr><td>Single tuned-filter</td><td>
</td><td>
</td><td>- tuned harmonic order $n = \frac{f_n}{f_1}$
- quality factor $Q = \frac{n \cdot X_L}{R} = \frac{X_C}{n \cdot R}$
- reactive power at f_1, $Q_C = \frac{V^2}{X_C} \cdot \frac{n^2}{n^2 - 1}$
- active power at f_1, (losses) $P \cong \frac{Q_C}{Q} \cdot \frac{n}{n^2 - 1}$
V – nominal line-line voltage
X_L, X_C – reactances at fundamental frequency</td></tr>
<tr><td>Convetional double tuned filter</td><td></td><td>
</td><td rowspan="2">The double-tuned filter performs the same function as two single-tuned filters although it has certain advantages: its losses are much lower and the impedance magnitude at the frequency of the parallel resonance that arise between the two tuning frequencies is lower.
If f_1 and f_2 are the two tuning frequencies, both the series circuit and the parallel circuit are tuned to approximately the mean geometric frequency $f_m = \sqrt{f_1 \cdot f_2}$. To prevent network resonance to take place, and to avoid exposing network elements to harsh condition, damping resistors are added the conventional double-tuned filter in a different configurations.</td></tr>
<tr><td>Damped type double-tuned filter</td><td></td><td></td></tr>
<tr><td>High-pass filter</td><td>
</td><td>
</td><td>The high-pass filter is a single-tuned filter where the L and R elements are connected in parallel instead of series. This connection results in a wide-band filter having an impedance at high frequencies limited by the resistence R. The quality factor of the high-pass filter is $Q = \frac{R}{L \times 2 \cdot \pi \cdot f_n}$</td></tr>
<tr><td>C-type high-pass filter</td><td>
</td><td>
</td><td>The C-type high-pass filter is the variation of the high-pass filter, where the inductance L is replaced with a series LC circuit tuned at fundamental frequency. The quality factor of the C-type filter is still given by the ratio $Q = \frac{R}{L \times 2 \cdot \pi \cdot f_n}$</td></tr>
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