Improvement of Power System Distribution Quality Due to Using Dc-Converter Loads and Electric Arc Furnaces

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Abstract: A Power quality improvement approach is introduced using passive tuned filters. This approach is applied to improve the power quality of the two different non-linear loads, witch are connected to the real power system distribution. The considered non-linear loads are the DC converter loads and the electric arc furnace loads (EAF). The DC converter loads are used for feeding the under ground metro in Cairo, while the EAF loads are used in steel industries in Arco-Steel Factory located in Sadat City, Egypt.
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Keyword: Improvement, Power System Distribution Quality, Using Dc-Converter Loads, Electric Arc Furnaces.

1. Introduction

A power quality is an issue that becoming increasingly important to electricity consumers at all levels of usage. Due to the increasing of using loads witch has non-linear characteristics, such as DC converters, PCs, electric arc furnaces, arc welders, etc. It is found that these loads may cause disturbances in the power systems distribution. These disturbances in are distortion in voltage and current waveforms due to generated harmonics, voltage fluctuations and flickers, over or under voltage and unbalance of voltage and current phases.

According to these disturbances, the power quality expression has appeared to determine the best service conditions. When the consumer is fed by specified values of sinusoidal waves of voltages and currents and these voltages and currents are balance (equal in magnitude and 120° apart), it is said that "Good Power Quality".

Due to the difficulty of achieving the best service conditions (that is pure waves and fixed voltage) at each consumer terminals, the power quality international standards such as the IEC 61000 and IEEE 519-92 standards have appeared to give the acceptable disturbances levels of each electrical variable.

However, the power quality is mainly related to the voltage and current and can be judged by the following factors:

1_ the harmonic content.
2_ the system frequency.
3_ the degree of voltage stability.
4_ balancing and symmetry of three- phase system voltage values.

When the above values are within limits of the international standards, the objective of power quality is realized. [1]

2. Literature review:

For the DC converter loads, two passive single tuned filters witch in 11th and 13th harmonic order frequencies are designed and used for improvement of the power quality problem. Considering each of the total harmonic distortion THD of voltage and current, the filter quality factor, the effect of one filter outage, the effect of filter detuning and the effect of manufacturing tolerance of filter capacitance and inductance.

The filter parameters R, L and C are determined for each of the two filters. Furthermore, a non-linear optimization technique is used to obtain the optimal values of these parameters. Also, the cost of the two filters and their active power losses are considered in the two filters design. [2]

It is found from the power quality measurements for the electric arc furnaces load EAF, the THD is greatly exceeds the IEEE 519-92 standards limits and the current waveform is distorted.

So, we have deigned two passive tuned filters witch in 2nd and 3rd harmonic order frequencies to improve the power system quality for this distribution system. [3]

3. Experimental test:

Power system harmonics are defined as sinusoidal voltages and current at certain frequencies that are integer multiple of the main fundamental frequency. They constitute the major distorting components of the load main voltages and current waveform. When the harmonic current passing through the impedance of the network , other voltage harmonic will appear. In this study, we have discussed two major sources of harmonics witch are the DC converter loads and the electric arc furnaces loads.

3.1 The dc-converter loads:

It is considered that the DC-converter feeds underground metro substation, and the type of this DC-converter is a 12-pulse converter as shown in Fig.(1). Due to the harmonic current generated from the connected DC-converter, it is found that the harmonic voltage is generated at the point of common coupling PCC.

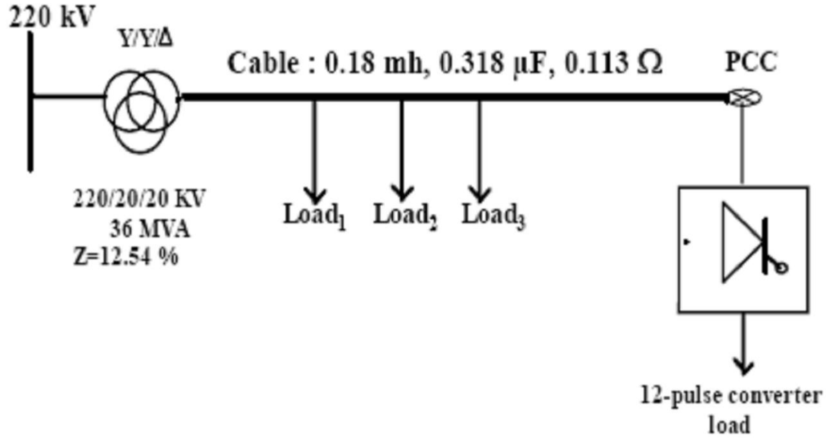

Fig.(1): connection diagram of the considered distribution system for DC-Converter loads.

It is of importance to note that the DC-converter loading conditions are dependent upon the number of traveling trains and the number of passengers in the trains as given in table(1).

Table (1): Harmonic content of voltage and current waves at the PCC.

Loading conditions	Harmonic order	Voltage (V)	Current (A)
Full load	1^{st}	$11547\angle -13$	$392\angle -20$
	11^{th}	$1466\angle -31$	$61\angle -284$
	13^{th}	$1658\angle -119$	$57.4\angle -7.3$
Light load	1^{st}	$11547\angle -10$	$130\angle 6.5$
	11^{th}	$560\angle 47.3$	$23\angle -203$
	13^{th}	$673\angle -26$	$22\angle -6.5$

For each of the DC-converter two loading conditions, the total harmonic distortion THD values for the voltage and current waves at the PCC are measured and they are given in table (2) .From that table, it is clear that the THD values for both the voltage and the current waves exceed the IEEE 519-92 Standards limits, witch are 5% and 8% for voltage and current , respectively.[2,5]

Table (2): The total harmonic distortion values for different loading condition at the PCC.

Loading conditions	Light load	Full load
THD of voltage (%)	8.09	21.59
THD of current (%)	24.44	21.5

Figs. 2-a through 2-d show the waveforms and harmonic analysis for the current and voltage at the PCC.

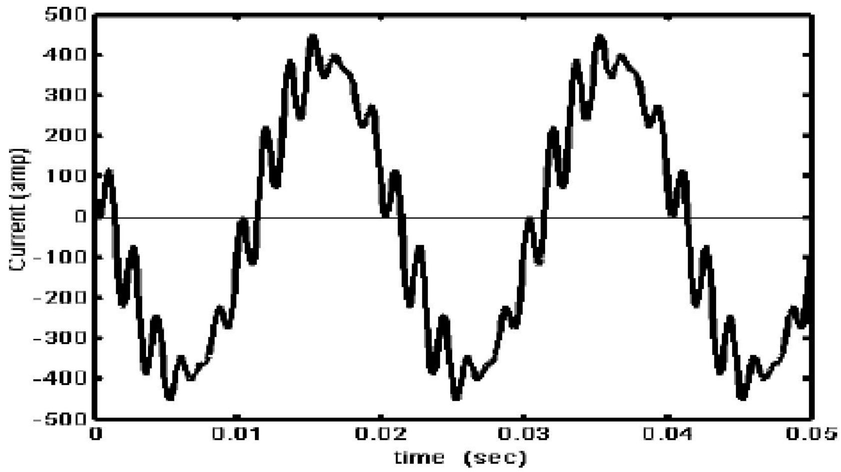

Fig.(2-a): The current waveform at the PCC for the full load condition.

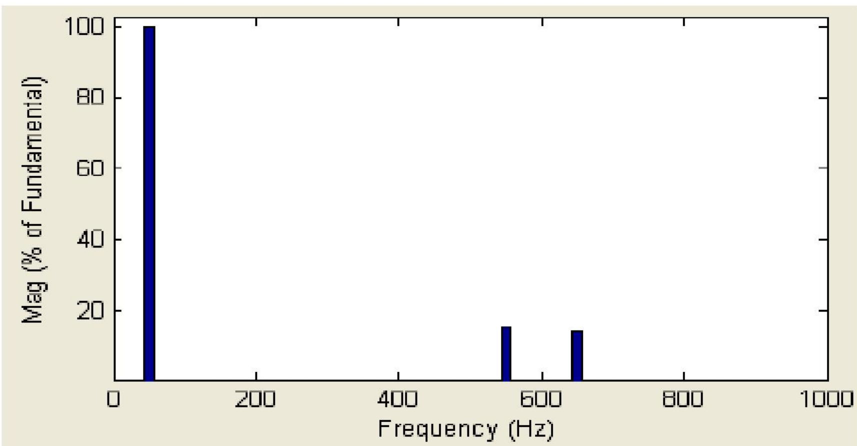

Fig.(2-b): The harmonic analysis of the current at the PCC for the full load condition.

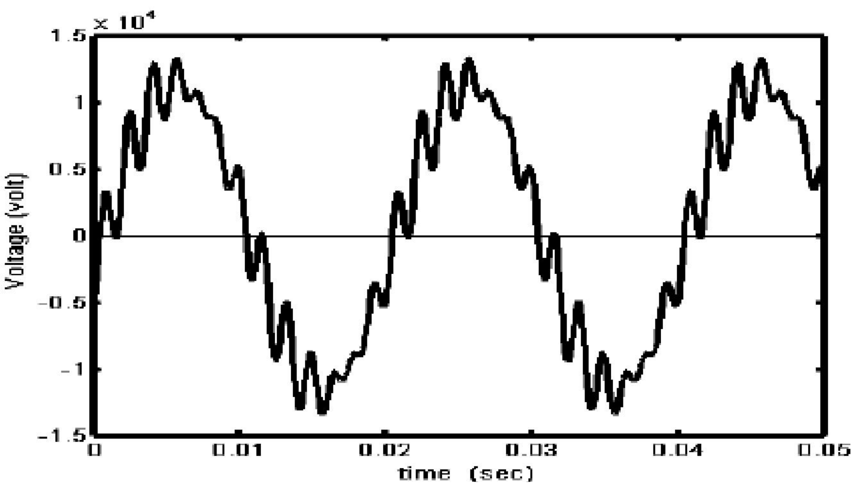

Fig.(2-b): The voltage waveform at the PCC for the full load condition.

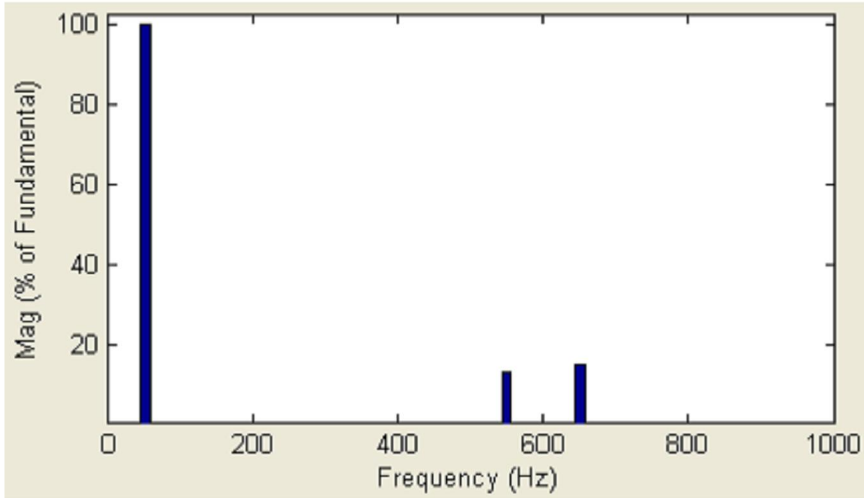

Fig.(2-d): The harmonic analysis of the voltage at the PCC for the full load condition.

3_2 The electric arc furnaces loads:

Electric arc furnaces EAF are widely used nowadays in steel industries. EAF can be either alternating current AC or direct current DC. EAF is a good choice for steel industries due to their productivity, flexibility and some advanced applications.

However, EAF are large highly non-linear and time-varying loads. They introduce some power quality problems to their nearby power system.

The EAF have strong and stochastically fluctuating reactive power consumption witch, unless remedied, will lead to voltage fluctuations and flickers. Furthermore, the electric arc furnaces loads suffer from continual three-phase unbalancing due to unequal are resistances and unequal inductances of the flexible conductors feeding the electrodes, especially during the melting periods. So that , the EAF are considered as strong sources of harmonics as well as phase unbalance, needing to be dealt with safe-guarding of the power quality in the proper power system distribution. It is considered a real distribution system shown in figure (3).

It consists of an 80MVA, 220 kV/22.5 KV/ 22.5KV, Y/Y/Δ, main transformer witch feeds two electric arc furnaces of a steel factory through a 0.5km long cable. The factory is in Sadat City-Egypt, and it is known as Arab Company for Special Steel (ARCO-STEEL). [4, 9]

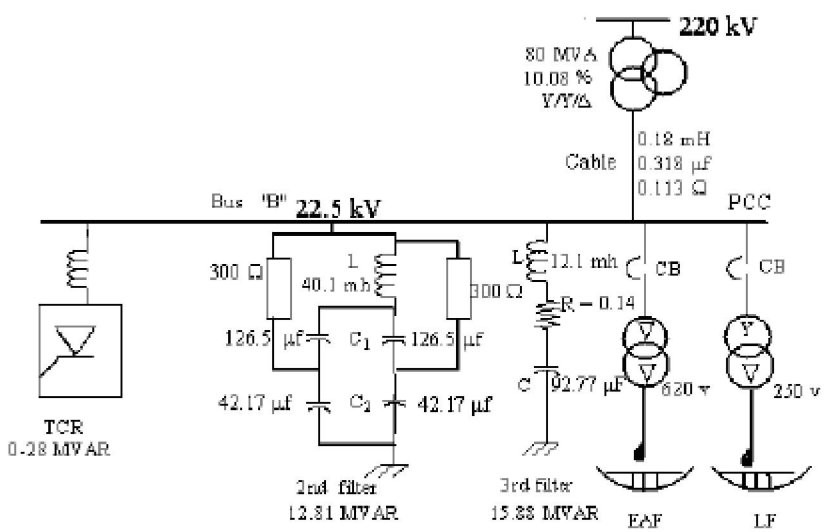

Fig.(3):The single line diagram for the considered real distribution system.

For the considered distribution system, the power quality measurements have been carried out for both the transformer low and high voltage sides during 8 days. Isolating the two connected filters, the measured values of the individual harmonic orders for the voltage and the current at the 22.5 KV bus (at the PCC) are given in table (3) & (4).

Table (3): The voltage individual harmonic values at the PCC without the two filters.

Odd Harmonic	Max. value % of Fund.	IEEE-519-992 Max. limit	Even Harmonic	Max. value % of Fund.	IEEE-519-992 Max. limit
3	1.37	3.0	2	1.15	1.5
5	1.73		4	0.5	
7	1.29		6	0.43	
9	0.37		8	0.31	
11	0.66		10	0.3	
13	0.54		12	0.31	
15	0.34		14	0.21	
17	0.5		16	0.2	
19	0.41		18	0.19	
21	0.28		20	0.17	
23	0.27		22	0.19	
25	0.35		24	0.18	

Table (4): The current individual harmonic values at the PCC without the two filters.

Odd Harmonic	Max. value % of Fund.	IEEE-519-1992 Max. limit	Even Harmonic	Max. Value % of Fund.	IEEE-519-1992 Max. limit
3	58.19	12	2	38.19	3
5	135.52	12	4	12.34	3
7	54.85	12	6	5.56	3
9	4.4	12	8	2.75	3
11	3.32	5.5	10	2.5	3
13	11.36	5.5	12	2.23	1.375
15	1.97	5.5	14	1.91	1.375
17	8.87	5	16	1.4	1.375
19	5.25	5	18	1.24	1.25
21	1.87	5	20	1.28	1.25
23	2.46	2	22	1.45	1.25
25	3.92	2	24	1.41	0.5

Also, the measured values of the THD for the phase voltage and current are given in table (5) & (6). Fig.4 shows the current waveform at the PCC without the two filters.

Table (5): The voltage THD at the PCC.

Phase	Max. THD %	Min. THD %	IEEE-519 Max. permitted THD %
R	3.7	0.8	5.0
S	3.9	0.8	5.0
T	4.0	0.7	5.0

Table (6): The current THD at the PCC.

Phase	Max. THD %	Min. THD %	IEEE-519 Max. Permitted THD %
R	130	1.2	5.0
S	127	1.4.	5.0
T	120	1.4	5.0

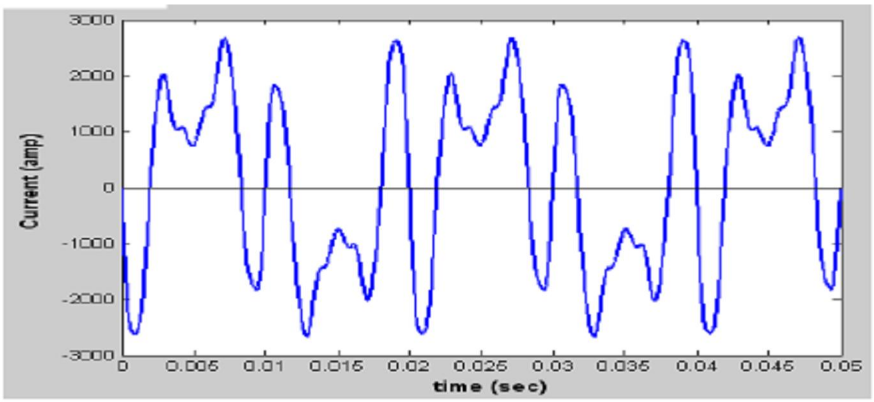

Fig.(4): The current waveform at the PCC without the two proposed filters.

4_Results and Discussion:

We will discus in this section the optimum design for the considered filters for both the DC-converter loads the electric arc furnaces, and make some power quality studies for these filters.

4-1 Optimum design of the two filters parameters R,L and C witch used for the dc-converter loads:

It is found that from power quality studies, the choosing capacitances for each of the proposed two filters should be less than105µF.Thais essentially means that minimum filters are chosen, and they can satisfy the following conditions:

1_The peak and RMS voltages across each of filter capacitor terminals.

2_The THDi and THDv values at the PCC don't exceed the IEEE-Std. 519-92 limits.

3_The parallel resonance can not occur near any of the two filters tuned frequencies.

4_ Least constant values of the two filters active power loss.

For the considered capacitances values for each of the proposed two filters, the corresponding Rand L parameters values are computed by using equations (1) and (2) and the obtained results are given in table (7).

$$L = \frac{1}{\omega_h^2 C} \quad \text{Eq.(1)}$$

$$R = \frac{\omega_h L}{Q} \quad \text{Eq.(2)}$$

Where,

$\omega_h = 2\pi \times 50 \times h, \qquad h = 11 \text{ and } 13$

Q is the filter quality factor and it is taken to be equal 100, witch is the nominal value for the air-cored coil of the filter.[5, 10]

Table(7):Parameters pf the proposed two filters.

11th harmonic filter parameters			13th harmonic filter parameters		
R (Ω)	L (mH)	C (µF)	R (Ω)	L (mH)	C(µF)
0.289	8.37	10	0.244	6	10

Considering the two filters parameters values as given in table 6, the corresponding values of the capacitor voltages Vpeak and V RMS, the total harmonic distortion of currents and voltages and the total active power loss are given in table (8).

Table (8): Results of the power quality studies for the considered distribution system with the proposed two filters

THD_i %	THD_v %	V_{RMS11} P.U	V_{p11} P.U	V_{RMS13} P.U.	V_{p13} P.U.	P_{loss} kW
0.45	0.12	1.01	1.09	1.003	1.07	3.2

Now, by using Matlab-Simulink for the two proposed filters in the considered distribution system, the current waveform at the PCC is obtained as shown in Fig. (5).A comparison of the two current waveforms before and after the two proposed filters connection, as shown in figures (2) & (5).That means a nearly sinusoidal current waveform is obtained and the considered distribution system power quality problems can be improved by using these two proposed tuned filters.

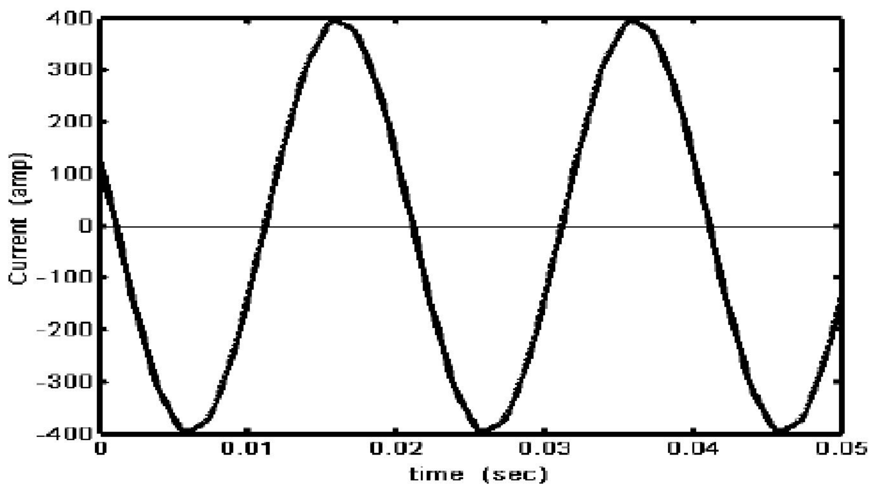

Fig.(5): The current waveform at the PCC after connecting the two proposed filters.

4-1-1 The power quality studies for the dc-converter loads considering to capacitance and inductance manufacturing tolerance of the two proposed filters:

Noting that the typical tolerance values are 10% and 5% for capacitance and inductance, respectively. Then, the power quality studies are repeated for the distribution system with the two proposed filters. These obtained results of THDi, THDv, Veak, VRMS and the two filters power losses are given in table (9).

Table (9): Results of power quality studies when manufacturing tolerance is considered.

THD_i %	THD_v %	V_{RMS11} P.U.	V_{p11} P.U.	V_{RMS13} P.U.	V_{p13} P.U.	P_{loss} kW
6.8	2.9	1.007	1.164	1.004	1.05	8.07

Comparing the results given in table (8) and table (9), it can be deduced that the manufacturing tolerance values of THDi,THDv and Ploss will be increased .However, the THDi and THDv values don't exceed the IEEE-Std. 519-92 limits. Figure (6) shows variations of the system impedance Zsystem with the frequency when the manufacturing tolerance is either neglected or considered. It can be shown that, referring to Fig.(6), a parallel resonance is occurred near the frequency for witch the 11^{th} filter is tuned. [6, 7].

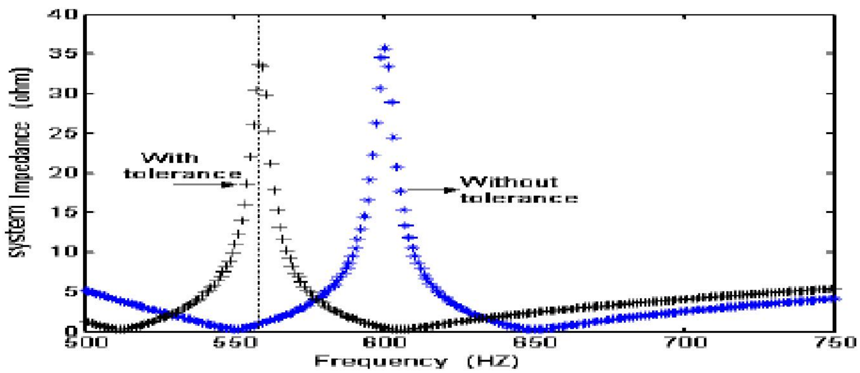

Fig.(6): Variation of the system equivalent impedance with the frequency considering the two filters manufacturing tolerance.

4-2 The distribution system performance for the electric arc furnace with the proposed tuned filters:

From figure (3) witch has been shown in the previous, it is clear that there are two tuned filters witch are used for the electric arc furnace distribution system to improve the power quality, and these two tuned filters are designed and connected to the power system distribution by Arco-Steel Factory, Sadat City, Egypt.

Then, we will study the power quality by another view that will suggest keeping the 2nd tuned filter without change and designing new two single-tuned filters at the 3rd and 5th harmonic frequencies, knowing that the 5th harmonic tuned filter is additional filter.

In this solution, the 2nd tuned filter still without any change in its parameters illustrated in Fig.(3).The existed capacitor bank (92.77μF) that in the previous 3rd tuned filter will be equally partitioned between the new 3rd tuned filter and the additional 5th tuned filter, as the current waveform contains high values of these harmonic frequencies. Then, the 3rd and the 5th filter capacitances will be 46.5μF.Using equation (1) and (2), the new 3rd and 5th tuned filters parameters R and L are computed and given in table (10).

Figure (7) shows the system equivalent impedance Zsystem at different values of frequencies. Referring to this figure, it is clear that the series resonance occurs at frequencies 100Hz, 150Hz and 250 Hz, respectively. Also, the parallel resonance can be occurred when the system frequencies are equal to 118 Hz and 190 Hz, witch don't occur at the harmonic currents produced by the electric arc furnace load.[9,10].

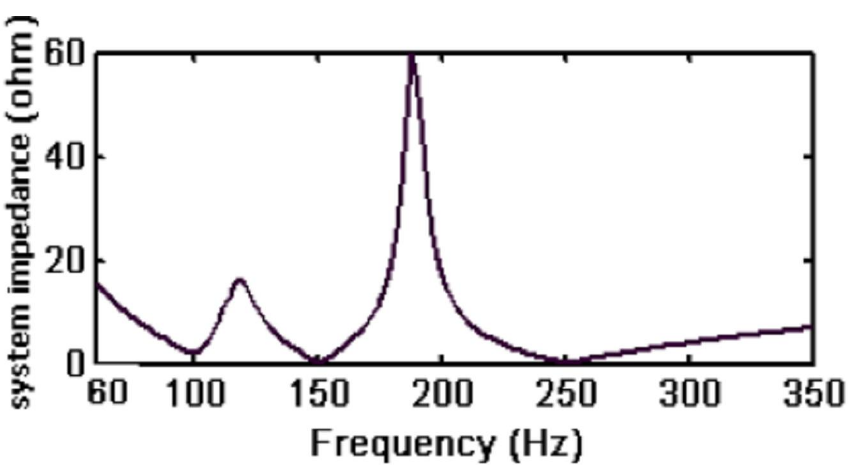

Fig.(7): Variation of the system equivalent impedance with frequencies after connecting the proposed three filters.

Also, the current waveform and its harmonic analysis after connecting the proposed three filters at the PCC are obtained as shown in Fig.(8-a) & (8-b).It can be observed that the current waveform is nearly sinusoidal.

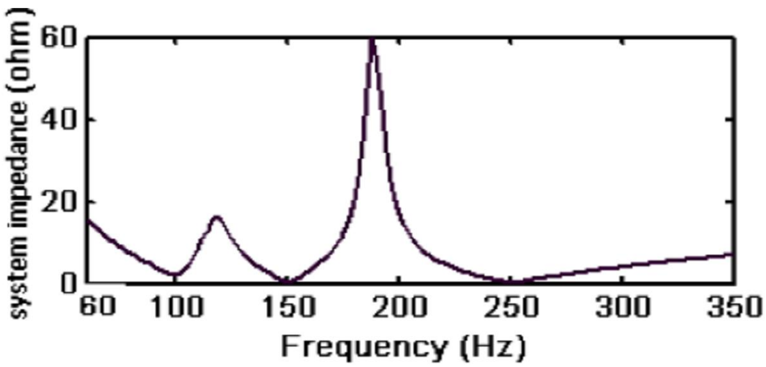

Fig.(8-a): The current waveform at the PCC after connecting the proposed three filters.

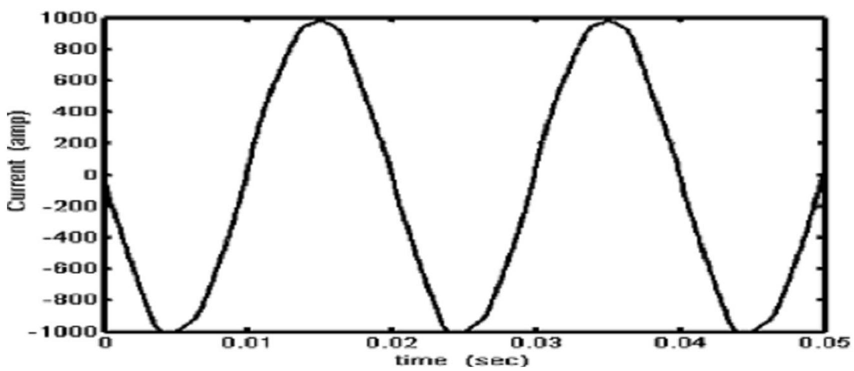

Fig.(8-b): The current harmonic analysis at the PCC after connecting the proposed three filters.

4-2-1 Manufacturing tolerance of the three filters capacitance and inductance for the electric arc furnace loads:

The typical values of the manufacturing tolerance are 5% and 3% for the capacitance and inductance, respectively. Considering the manufacturing tolerance, the system equivalent impedance versus frequencies can be obtained as shown in Fig.(9).Referring to this figure, it is clear that the series resonance occurs at frequencies 96 Hz, 144 Hz and 245 Hz. Also, the parallel resonance occurred when the system frequencies are equal to 114 Hz and 182 Hz. However, the parallel resonance don't occur at any of the EAF generated harmonics.[8,11]

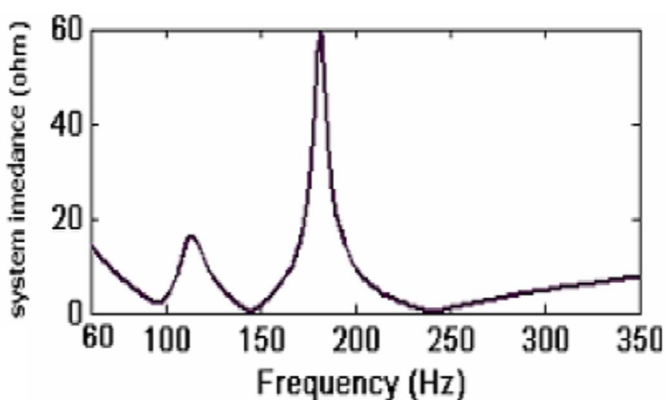

Fig.(9): Variation of the system equivalent impedance with frequencies with after connecting the proposed three filters considering the manufacturing tolerance.

5 _ Summary and Conclusion:

The power quality problems due to either a DC-converter loads or an electric arc furnace loads EAF were improved. From power quality studies for DC-converter loads, we can conclude the following:

_An occurrence of the parallel near one of the two proposed filters tuned frequencies can be avoided by choosing equal capacitance values for each of the filters capacitors.

_choosing smaller capacitance values for each of the two filters capacitors can lead to a sharp increase in the THDi , THDv and active power losses values.

_Considering the manufacturing tolerance of capacitance and inductance, a parallel resonance can occur near the frequency at witch one of the two filters is tuned.

_Values of the THDi and THDv at the PCC can exceed the IEEE-Std. 519-92 limits after one filter outage.

_ A shunt connected capacitor may be used for improving the power quality problems resulted from one filter outage.

_ Choosing the optimal values for the filters R,L and C constant can lead to decrease in the two filters cost and their active power losses.

From power quality studies for the electric arc furnace loads, we can conclude the following:

_Values of the THDi and THDv after one filter outage can exceed the IEEE-Std.519-92 limits.

_ An outage of one of the connected filters doesn't lead to a parallel resonance at the EAF generated harmonic frequencies.

_ Considering the filter capacitance and inductance manufacturing tolerance, can lead to change in the filter tuning frequency in addition to a small increase for the system impedance values.

_For more improving the power quality problems due to the connected electric arc furnace load, a new designed 5^{th} tuned filter should be connected in addition to the 2^{nd} and the 3^{rd} harmonic tuned filters.

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