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POWER QUALITY IMPROVEMENT FOR ARC FURNACE AND CONVERTER FED UNDER-GROUND METRO LOADS

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ABSTRACT

In the paper, a power quality improvement approach using passive tuned filters is introduced. This approach is applied to improve the power quality of two different field nonlinear-loads, which are connected to two real separate distributors. The considered loads are a converter and an electric arc furnace (EAF). The converter is used for feeding the Under Ground Metro in Cairo, while the EAF is used in the Arco-Steel factory located in the Sadat City.

Two passive single-tuned filters are designed and used for improvement of the converter power quality problem. Considering each of the following: total harmonic distortion (THD) of voltage and current, preventing an occurrence of the parallel resonance, the effect of a filter outage, the effect of filter detuning, and the manufacturing tolerance of capacitors and reactors, the parameters R, L, and C are determined for each of the two filters. Furthermore, a nonlinear optimization technique is used to obtain the optimal values of the two filters parameters, considering the two filters cost and their active power losses in addition to the THD of voltage and current.

Despite there exist two passive filters connected in shunt with the considered EAF, it is found, from the power quality measurements, that the THD is greatly exceed the IEEE-519 standard limits, and the current wave is distorted. For improving the resulted power quality problem (that is, reducing the current THD value), it is proposed a third passive single-tuned filter to be designed and connected with the existed two filters. Using the MATLAB-Simulink, the EAF with the three filters are simulated, and it is used to obtain the new filter parameters.

تم في هذا البحث تحسين مشاكل نوعية القدرة الناتجة من أحمال المبدلات و أفران القوس الكهربي. تم الأخذ في الاعتبار كل من حمل المبدل المستخدم لتغذية مترو أنفاق القاهرة و حمل الفرن الكهربي بالشركة العربية للصلب المخصوص بمدينة السادات.

لتحسين مشكلة نوعية القدرة الناتجة من حمل المبدل تم تصميم واستخدام مرشحين سلبيين مع الأخذ في الاعتبار كل من معامل تشوه الموجه للجهد و التيار، عدم حدوث تردد رنين التوازي، سماحية الصناعة للمكثفات والمحاثات، إضافة إلى خروج أحد المرشحات المستخدمة فقد تم تحديد قيم المقاومة و السعة و المحاثة المطلوبة لكل مرشح. إضافة إلى ذلك فقد تم استخدام أسلوب أمثل للحصول على القيم المثلى لثوابت المرشحين وذلك في حالة الأخذ في الاعتبار تكلفة المرشحين ومعامل تشوه موجه الجهد و التيار، إضافة إلى المفاقيد الفعالة في المرشحين.

على الرغم من وجود مرشحين متصلين بالتوازي مع فرن القوس الكهربي بشركة الصلب فقد تبين من قياسات نوعية القدرة التي أجريت عند أطراف الموزع المتصل بهذه الشركة، أن موجة التيار مشوهة، إضافة إلي ذلك فإن قيمة معامل تشوه الموجه الكلي (THD) للتيار تزيد عن الحدود المسموح بها عالميا. لتحسين مشكلة نوعية القدرة في هذه الحالة فقد تم تصميم مرشح جديد بحيث يتم إضافته إلي المرشحات الموجودة. تم استخدام محاكي الماتلاب لتمثيل الموزع و الثلاثة مرشحات، بالاستعانة بهذا التمثيل تم الحصول على قيم ثوابت المرشح الجديد.

Keywords: Power quality problem, Passive tuned filter, Converter loads, Electric Arc Furnace loads (EAF).

1. INTRODUCTION

Due to the technical and economical impact of power quality on distribution system, improvement of the power quality has become a research topic for the past 20 year [1].

The proliferation of power electronic devices and non-linear loads in power systems leads to increasing concern about the distortion of the voltage and current waveforms in distribution networks due to harmonic pollution [2].

Harmonics have been shown to have deleterious effects on equipments including transformers, rotating machines, fuses, switchgear, capacitor banks and protective relays [3]. However, the degree of problems caused by harmonics is dependant on both level of harmonic distortion and the characteristic of the power system [4].

Electric power converters and electric arc furnaces (EAF) are the major sources of harmonics. While power converters produce only odd harmonics, it is found that "EAFs" produce odd and even harmonics.

One way to reduce the effects of harmonics is by preventing the harmonic currents from penetrating into a distribution system. This can be achieved by using R-L-C tuned (series or shunt) filters, or active filters. However, it is found that the shunt filters are more suitable to use since they can be designed for whatever rating is needed, they are less expensive, and they can also provide reactive power at the fundamental frequency.

The quality factor of a filter, which is denoted by Q, determines the sharpness of the filter tuning. In this respect filters may be either of a high or a low Q value, the former is sharply tuned to one of the lower harmonic frequencies (e.g. the 2nd and 3rd frequencies) and the typical value of Q is between 30 and 60 (for single tuned filter) [5,6]. The filter of low Q value, typically in the region of 0.5–5, has low impedance over a wide range of higher frequencies [7].

In Ref. [3], the authors discussed the design of each of single tuned filters, high pass filters, and minimum filters. Note that, minimum filters are designed when the reactive compensation is not a requirement. It was found that to determine the worst possible harmonic condition, the variations in the load and source impedance should be considered.

The authors of Ref. [4], discussed the side effects of applying filters in a distribution system. It was concluded that the parallel resonance frequency decreased as the filter size (that is, the reactive power supplied by a filter at fundamental frequency) increased.

In Ref. [8], two single-tuned filters were used for improving the power quality problem resulted from a converter load. Both of the conventional linear programming (LP) and the modern fuzzy linear programming (FLP) techniques were used to obtain the optimal values of the filters parameters considering either the THD, or the filters cost.

The authors of Ref. [9], presented the solution procedures required for applying multiple active power filters to reduce the harmonic voltages and total harmonic distortions in distributor systems. A real distribution system was used as an illustrative example.

Based on minimizing the network apparent power, two single-tuned filters were designed, in Ref [10], for improving the power quality resulted from a converter load.

Three harmonic filters with a thyristor controlled reactor (TCR) were used in Ref. [11], to mitigate the power quality problems resulted from an electric arc furnace load. The TCR was used for the voltage stabilization.

In this paper, two different types of nonlinear loads, the first is the converter load, while the second is an EAF are considered. For the first considered load, the power quality problem is improved by using a 11th and 13th single-tuned passive filters, which are connected in shunt with the converter. Considering the converter full-load condition, values of the parameters R, L and C for the needed two filters are obtained considering the following: the THD for the voltage and current at the point of common coupling (PCC), the peak and RMS voltages across the filter capacitor, the manufacturing tolerance of capacitors and reactors, the filter detuning and an outage of one filter.

Considering the two proposed filters cost and their active power losses in addition to the THD of voltage and current, a nonlinear optimization technique is used to determine the optimal values of the filter R, L, and C parameters.

The power quality problem resulted from the EAF load is improved by using a new designed passive filter, which is added to the existed two filters. With the aid of the Simulink in MATLAB package, the parameters R, L and C needed for the new filter are obtained.

2. IMPROVEMENT OF THE POWER QUALITY PROBLEM CONSIDERING THE CONVERTER LOAD

2.1. The Considered Distribution System

It is considered a real distributor (an underground cable) which is fed from the Ramsis Underground Metro substation, and it is delivering the power to a number of loads, one of them is a 12-pulse converter, as shown in Fig. 1 [10].

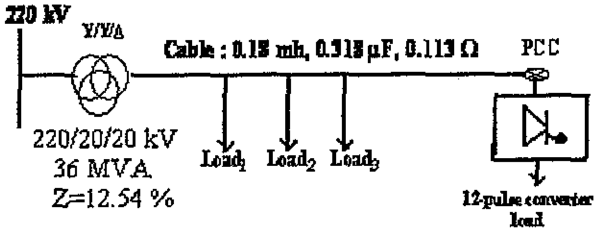

Fig. 1. The considered distribution system

Due to the current harmonics generated from the connected converter, it is found that voltage and current harmonics are generated at the (PCC), as given in Table 1. Note that the converter loading conditions are dependent upon number of the traveled trains and number of passengers in a train.

Table 1 The measured harmonics voltage and current at the PCC.

Loading conditions	Harmonic order	Voltage (V)	Current (A)
Full load	1st 11th 13th	11547∠-13 1466∠-31 1658∠-119	392∠-20 61∠-284 57.4∠-7.3

For the full load condition, Figs. 2-a through 2-c show the current waveform and its harmonic analysis in addition to the voltage waveform at the PCC. It is clear from these figures that the current and voltage waveforms are highly distorted.

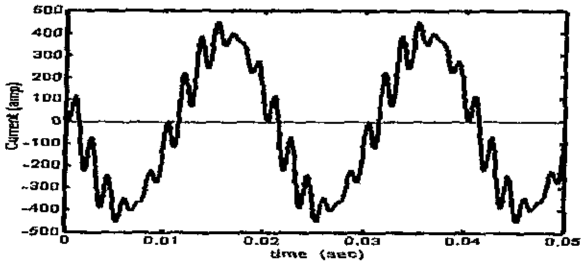

Fig. 2-a The current waveform at the PCC.

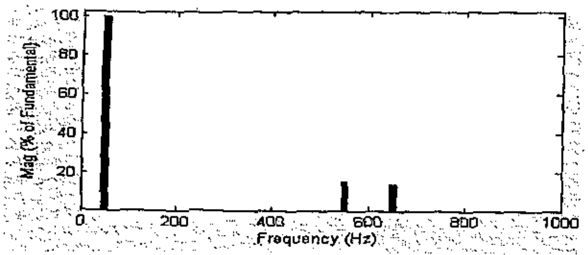

Fig. 2-b The harmonic analysis of the current at the PCC.

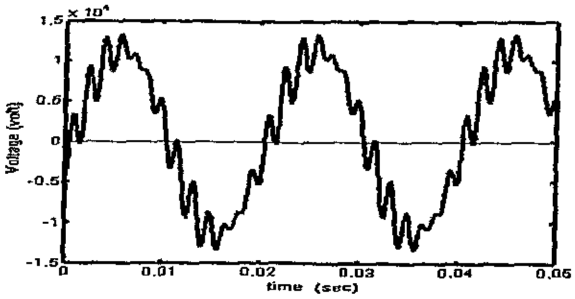

Fig. 2-c The voltage waveform at the PCC.

The measured THD values for the voltage and current at the PCC are given in Table 2, and it is clear that these values exceed the Standard IEEE-519 limits, which are 5 % and 8 % for the voltage and current, respectively [5].

Table 2 The THD of the voltage and current at the PCC.

THD of voltage (%)	21.59
THD of current (%)	21.37

Now, in order to improve the considered distributor power quality problem, (that is, to decrease the THD values to their IEEE-519 Std. limits), a two passive 11th and 13th tuned filters are designed and to be connected in shunt at the PCC.

2.2. DESIGN OF THE TWO PROPOSED FILTERS

As a first step for designing the two proposed filters, it should determine the largest capacitance value that can be connected, in shunt, at the PCC such that the voltage regulation does not exceed the 5 % value. This case study represents the converter when it operates at no load while the two filters are connected.

Taking the base voltage and power to be 20 kV and 36 MVA, respectively, the distributor equivalent circuit for the fundamental frequency is shown in Fig. 3. Note that, the distributor loads other than the converter load are, for simplicity, neglected.

Assuming different values for the connected capacitance "C", the voltage at the PCC is computed and given as shown in Fig. 4, from which it is clear that the capacitance value should be less than 105 μF.

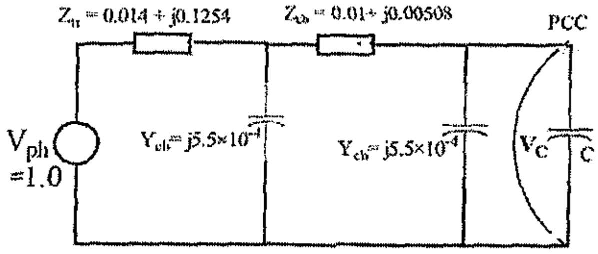

Fig. 3 The distributor equivalent circuit for the fundamental frequency (all values in P.U.)

Z_{tr} is the transformer impedance,

Z_{cb} and Y_{cb} are series impedance and shunt admittance of the distributor cable,

C is the connected capacitance.

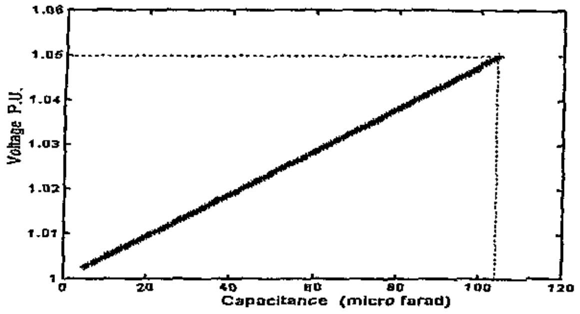

Fig. 4 The computed voltage at the PCC for different capacitance values.

2.2.a. Partitioning the capacitance C between the two proposed filers:

In order to partition the capacitance C between the two filters, it is necessary to carry out the computation for obtaining each of the following [13]:

1- The peak and RMS voltage across the filter capacitor terminals.
2- The parallel resonant frequency for the distributor and the connected two proposed filters.
3- The total harmonic distortion (THD) values for the current and voltage at the PCC.
4- The *total active* power losses in the two filters.

Choosing a filter capacitance value, its corresponding R and L parameters are computed as [3],

$$L = 1 / \omega_h^2 C \qquad (1)$$

$$R = \omega_h L / Q \qquad (2)$$

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

where Q is the filter quality factor, and it is taken to be equal 100, which is the nominal value for the air-cored coil of filters.

2.2.a.1. *Determination of the peak and rms voltages across each filter capacitor:*

Assuming the capacitance C to be partitioned between the two filters, the voltages V_{peak} and V_{RMS} are computed as,

$$V_{peak} = V_1 + V_h \qquad (3)$$

$$V_{RMS} = \sqrt{(V_1)^2 + (V_h)^2} \qquad (4)$$

where V_1 and V_h are the fundamental and harmonic frequency voltages across the capacitor terminals, respectively, and they are computed as follows,

$$V_1 = I_1 X_C \qquad (5)$$

$$V_h = I_h (X_C / h) \qquad (6)$$

where I_1 is the filter fundamental frequency current, and I_h is the filter harmonic current at its tuned frequency. Xc is the filter capacitor reactance at the fundamental frequency, and h is the harmonic order.

Noting that the converter full load fundamental current is equal to 392 A, the voltages V_{peak} and V_{RMS} for each filter capacitor are computed and shown in Figs. 4-a and 4-b, respectively.

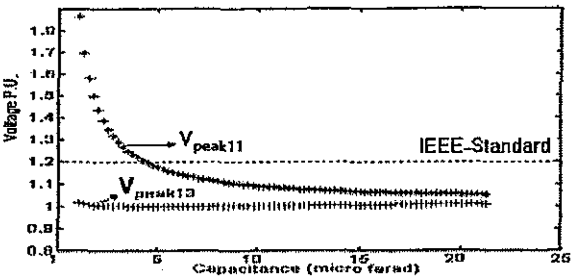

Fig. 4-a The peak voltages across the 11th and 13th filters capacitors for different capacitance values.

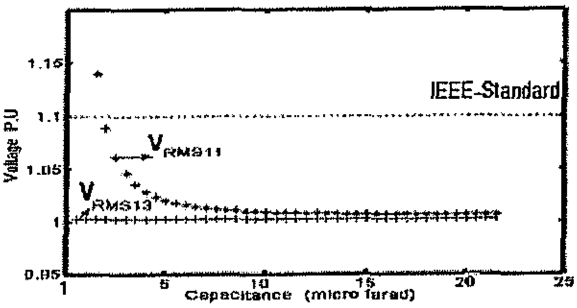

Fig. 4-b The RMS voltages across the 11th and 13th filters capacitors for different capacitance values.

Noting that, according to the IEEE-Std. 18-2002, none of the following limitations can be exceeded [12]:

1. *120 % of a capacitor rated peak voltage.*
2. 110 % of a capacitor rated RMS voltage.

The capacitance for each filters capacitor can be chosen, referring to Figs. 4-a and b, to be equal, or greater than, 5.0 μF.

2.2.a.2. *Determination of the considered distributor parallel resonance frequency:*

It is found, in practice, that a parallel resonance may occur as a *result of the connection* of harmonic tuned filters with a distribution system.

Now, dividing the chosen total capacitance C =20 μF, between the two filters, and using the distributor equivalent circuit, shown in Fig. 5-a, it is computed the distributor equivalent impedance "Z_{dis}" for different frequency values. Note that, Z_{F11} and Z_{F13} are the 11th and 13th filters impedances, respectively.

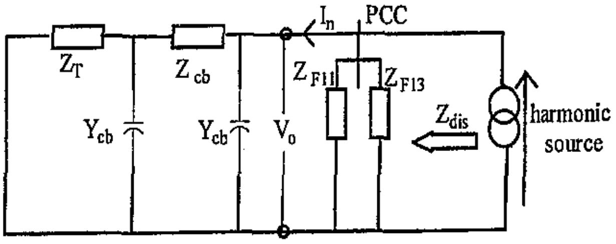

Fig. 5-a The distributor equivalent circuit considering a harmonic source.

Figs. 5-b and 5-c show values of the impedance "Z_{dis}" for unequal and equal division of the total capacitance, respectively, between the two filters. From these figures it can be seen that the parallel resonance (that is, the larger values of Z_{dis}) can not occur near one of the two filters tuning frequencies (that is, 550 Hz and 650 Hz) when the chosen total capacitance is divided equally between the two filters.

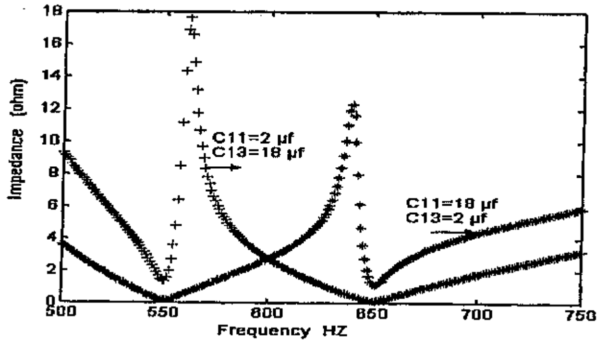

Fig. 5-b Variation of the system equivalent impedance versus frequency for unequal division of the total capacitance.

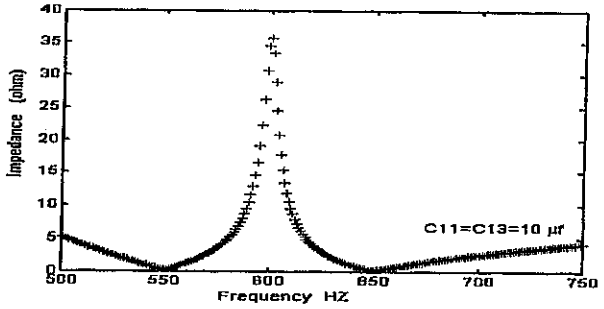

Fig. 5-c Variation of the system equivalent impedance versus frequency for equal division of the total capacitance.

2.2.a.3. ***Effect of the filters selected capacitances on the voltage and current total harmonic distortion (THD):***

The THD of current and voltage are computed from the following two Eqns. [5],

$$THD_I = \sqrt{\sum_{n=2}^{N} I_n^2 \Big/ I_1} \qquad (7)$$

$$THD_V = \sqrt{\sum_{n=2}^{N} V_n^2 \Big/ V_1} \qquad (8)$$

where I_1 and V_1 are the magnitudes of the current and voltage, respectively, at the fundamental frequency. I_n and V_n are the magnitudes of the current and voltage, respectively, for harmonic "n".

Now, assuming different values for the two filters capacitances, and using Eqns. 1 and 2, the filters parameters R and L are obtained. Next, referring to Fig. 3 and 5-a, the fundamental current and voltage and the penetrating currents I_{11} and I_{13}, in addition to the voltages V_{11} and V_{13} at the PCC are computed.

Figs. 6-a and 6-b, show the THD_V and THD_i computed values for different capacitance values.

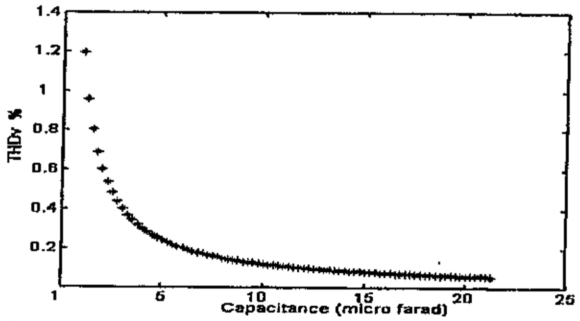

Fig. 6-a The voltage THD values versus the selected capacitances of the two filters.

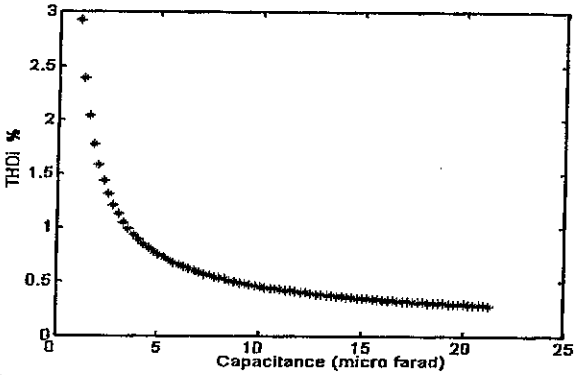

Fig. 6-b The current THD values versus the selected capacitances of the two filters.

2.2.a.4. ***Determination of the active power losses for the two proposed filters:***

For a single-tuned filter, the active power loss is given as [3],

$$P_{loss} = (I^2_1 + I^2_n)\ R_f \qquad (9)$$

where R_f is the filter resistance.

Selecting different values for the two filters capacitances and using Eqn. (9), the power loss for each filter in addition to the total power losses are computed and shown in Fig. 7.

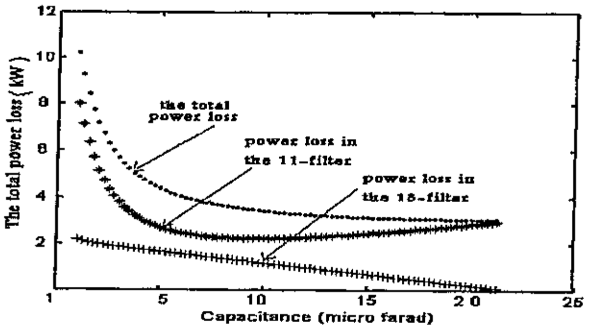

Fig. 7 The active power losses for different values of the filters capacitances.

Now, from the last section computations, the capacitance C = 10 µF, may be chosen for each of the two proposed filters. Hence, using Eqns. (1), and (2), the corresponding values of each proposed filter parameters R and L are computed and given in Table 3.

Table 3 Parameters of the proposed two tuned filters.

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

For the two designed filters, values of the voltages V_{peak}, V_{RMS}, the THD_i and THD_V, in addition to the total active power loss (P_{loss}) are computed and given in Table 4. From this table, it is clear that values of the THD_i and THD_v are greatly decreased compared with those before connecting the designed two filters. This essentially implies that the considered distributor power quality problem has been improved.

Table 4 Values of V_{peak}, V_{RMS}, THD, and P_{loss} for the designed two filters.

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

Fig. 8 shows the current waveform at the PCC after connecting the designed two filters.

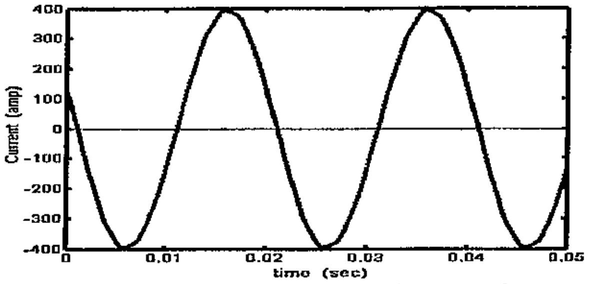

Fig. 8 The Current waveform at the PCC after connecting the two designed filters.

2.2.b. The distributor power quality studies considering the manufacturing tolerance, the detuning effect and a one filter outage:

For the considered distributor with the connected two designed filters, the power quality studies are carried out, in this section, considering each of the following:

1- Manufacturing tolerance of a filter capacitance and inductance.
2- The filter detuning.
3- An outage of one filter, due to maintenance.

2.2.b.1. *The power quality studies considering the manufacturing tolerance:*

Considering the standard manufacturing tolerance values, which are 10 % and 5% for the filter capacitance and inductance, respectively [14, 15], it is carried out the computations of the voltages V_{peak}, V_{RMS}, the THD_i and THD_V, in addition to the filters losses. The obtained results are given in Table 5. It is noticed that larger values of THD_i and P_{loss} are obtained when the tolerance is taken into consideration.

Table 5 Values of V_{peak}, V_{RMS}, THD, and P_{loss} considering the manufacturing tolerance.

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

Now, considering the manufacturing tolerance, the impedance Z_{dis} is computed, referring to Fig. 5-a, for different frequency values, as shown in Fig. 9, which it can be shown that a parallel resonance is occurred near the 11th harmonic frequency.

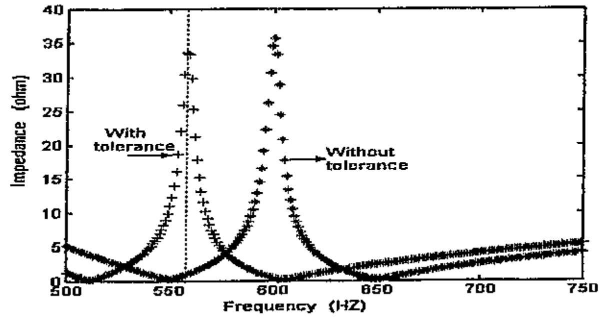

Fig. 9 Variation of the system equivalent impedance when the manufacturing tolerance is considered.

2.2.b.2. *The power quality studies considering the detuning effect:*

The two most common mechanisms that may result in a filter detuning are:

1- The power system frequency may change, thus causing the harmonic frequency to change proportionally.
2- The capacitance may be changed due to the aging effect and the temperature variations.

Now, taking the system frequency variation to be ±2 %, it is found, referring to Fig. 10, that values of the distributor impedance Z_{dis} will increase with very small values when the system frequency variations are taken into consideration.

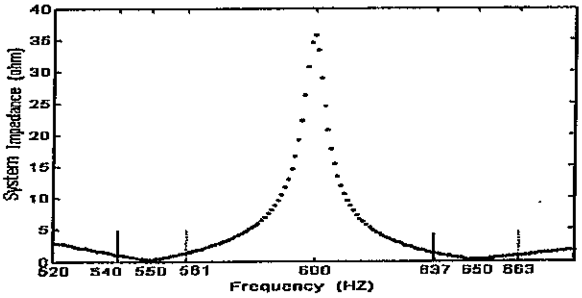

Fig. 10 The distributor equivalent impedance considering variation of the system frequency.

Considering the effect of aging and temperature variation, the filter capacitance, may be changed by about 3 % [6]. It is found, referring to Fig. 11, that values of the tuned frequencies for the two proposed filters decreases when the effect of aging and temperature variation is considered.

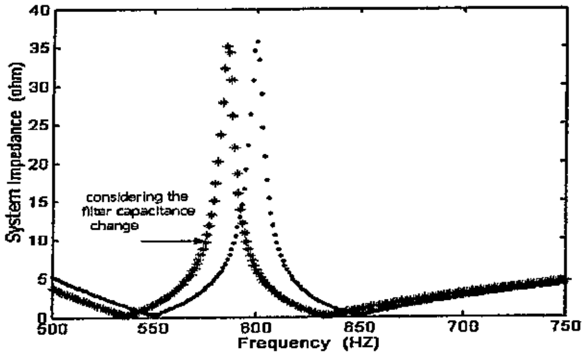

Fig. 11 Variations of the system impedance considering the aging and temperature effect.

2.2.b.3. *The power quality studies considering a one filter outage:*

Assuming that either the 11th, or 13th, filter is switched off, due to regular maintenance, the power quality computations are carried out. It is found that the THD_i value increases to 4.95 %, when the 13th filter is switched off. When the 11th filter is switched off, it is found that the THD_i value is greatly exceeds the IEEE- Std. limits and the resulted current waveform is distorted, as shown in Fig. 12.

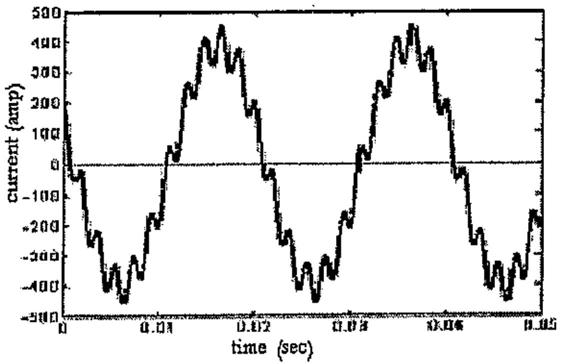

Fig. 12 The current waveform at the PCC when the 11th filter is switched off.

In order to improve the power quality resulted from the 11th filter outage, it is proposed that a shunt capacitor bank to be connected at the PCC. Using the MATLAB-Simulink, the distributor with the 13th tuned filter and the proposed capacitor is simulated, as shown in Fig. 13. Then it is found that the THD_i value can be less than the IEEE-Std. 519-92 limit, when the connected capacitor capacitance equals 20μF.

It is of importance to note that the needed capacitance is equal to 200 % the removed filter capacitance.

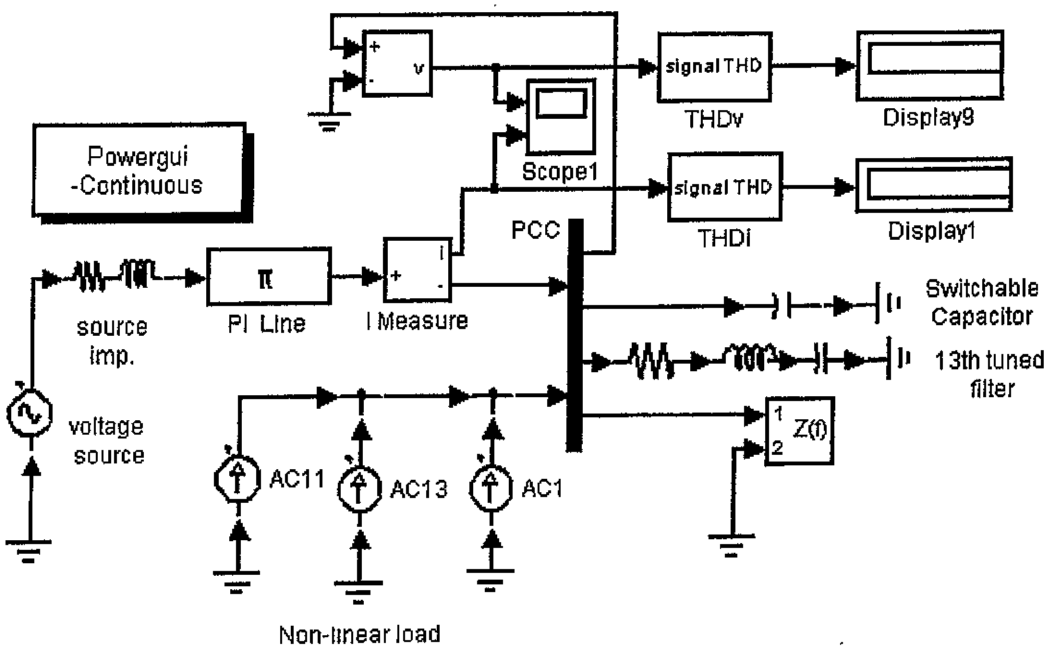

Fig. 13 The MATLAB-Simulink model of the considered distributor system.

2.3. Determination of the Optimal Parameters for the Proposed Two Filters:

It is considered, in this section, the distributor with the connected two proposed filters, for which the optimal parameters are determined. The objective (nonlinear) function J is chosen to be a function of the filters total capacitance $C_t = C_{11}+C_{13}$, and it is taken in the form,

$$J(C_t)=\alpha_1 THDi+\alpha_2 THD_v+\alpha_3 C_t+\alpha_4 P_{loss}+\alpha_5 AQ_{Ct} \quad (10)$$

The constraints are given as,

$5\ \mu F \leq C_{11} \leq 50\ \mu F$

$5\ \mu F \leq C_{13} \leq 50 \mu F$

Note that, the weights α_i, i =1, 2..., 5 are chosen so that each of the five terms make an approximately equal contribution to the objective function.

In Eqn. (10), values of THD_i and THD_V are computed by using Eqns. (7) and (8), and P_{loss} is sum of the two filters active power losses P_{L11} and P_{L13}, which can be computed by using Eqn. (9). Also, A is the capacitor cost, which is equal to 170×10^3 LE / MVAr. The total reactive power $Q_{Ct} = Q_{C11} + Q_{C13}$, where the capacitor reactive power Q_C, is computed as,

$$Q_{Ci} = \left(I_{1i}^2 / \omega_o C_i\right)+\left(I_{hi}^2 / \omega_o h C_i\right), i = 11,13 \quad (11)$$

Note that to avoid any near parallel resonance condition on the combined distributor and filters configuration, the capacitances $C_{11} = C_{13}$ should be chosen (see sec. II-2.a-2)

Now, using the MATLAB Optimization Toolbox routine minimax for minimizing the objective function with respect to the capacitance C_t over the specified harmonic frequencies, that is , 550 Hz and 650 Hz, it is found that the optimal solution is when C_t = 15.5 μF. Next, using Eqns. (1) and (2), the optimal values of the filters parameters L and R are computed and given in Table 6.

Table 6 The optimal values of the filters Parameters.

11th –filter parameters			13th –filter parameters		
R (Ω)	L (mH)	C (μF)	R (Ω)	L (mH)	C(μF)
0.3734	10.8	7.75	0.316	7.7	7.75

Then the values of THD_i, THD_V, and P_{loss} are computed and given in Table 7.

Table 7 The obtained results considering the filters optimal parameters.

THD_i %	THD_V %	P_{loss} (kW)	AQ_{Ct} (LE)
0.54	0.15	3.02	9.758×10^3

Note that, referring to the proposed filters parameters as given in Table 3, it is found that the filters cost equal 12.36 10^3 LE.

It is clear, from Tables 4 and 7, that the total active power loss for the two filters and the filters cost are decreased when the optimal R, L and C parameters values are chosen for the proposed two filters.

3. IMPROVEMENT OF THE POWER QUALITY CONSIDERING THE ARC FURNACE LOAD:

It is considered, in this section, a real distributor which feeds, through a 0.4 km cable, the two arc furnaces of the Arab Company for Special Steel Factory, located in Sadat City. Fig. 14, shows the single line diagram of the considered distributor.

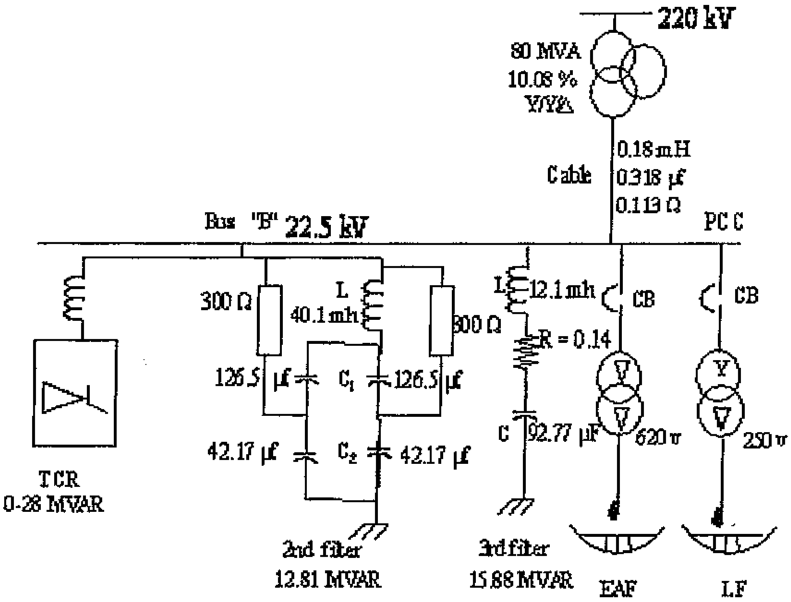

Fig. 14 Single line diagram for the considered real distribution system.

Despite the connected two filters, it is found, from the power quality measurements on the 22.5 kV bus, that the current waveform is distorted (see Figs. 15-a, and b), and the current THD value exceeds the IEEE-Std. 519-1992, limit. This essentially means that for the considered distribution system, there is a power quality problem which should be improved.

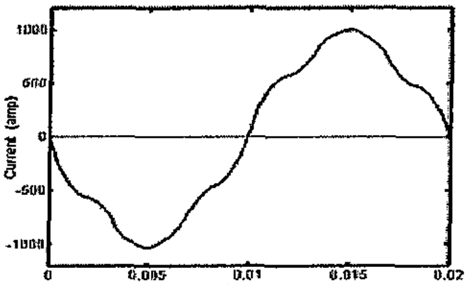

Fig. 15-a The current waveform at the PCC.

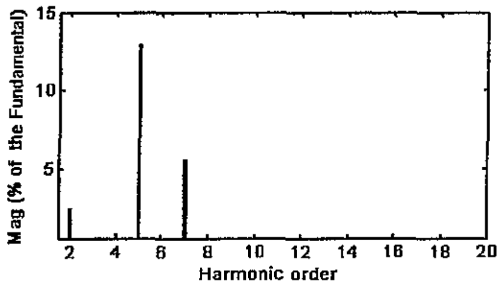

Fig. 15-b The current harmonic analysis at the PCC.

As a first step for the distributor power quality problem improvement, the characteristics for the existed two filters are studied. It is found that the first filter is a 3rd harmonic tuned filter, while the second filter is a band-pass filter and it resonates at the second harmonic frequency, as shown in Fig. 16.

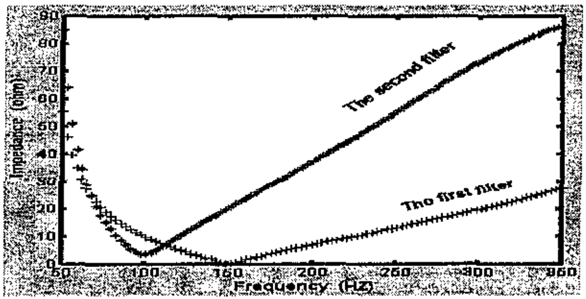

Fig. 16 The filter impedance versus frequency for each of the connected two filters.

Now, referring to Fig. 15-b, it can be shown that the 5th harmonic has the largest magnitude. Accordingly, it is proposed that a new 5th -tuned filter is designed and connected with the existed two filters.

With the aid of the MATLAB-Simulink, the considered distributor with the three connected filters is simulated as shown in Fig. 17. It is found that, when the parameters R = 0.42 Ω, L = 27 mH and C = 15 μF, are chosen for the new filter, the THD_i value is less than the IEEE-Std. 519 limits and the resulted current waveform and its harmonic analysis are given as shown in Figs. 18-a and b.

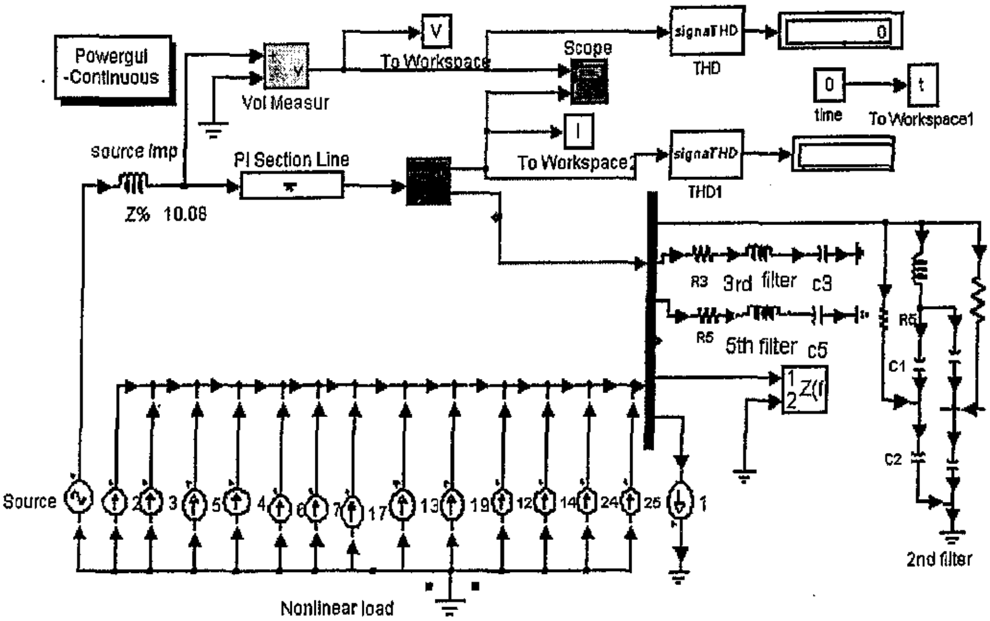

Fig. 17 The MATLAB-Simulink simulation for the distribution system with the three filters.

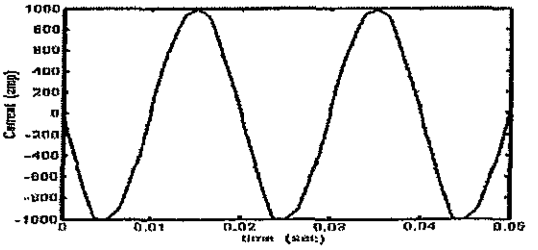

Fig. 18-a The current waveform at the PCC.

Fig. 18-b The current harmonic analysis at the PCC.

In order to check an occurrence of near parallel resonance conditions for the distributor with the connected three filters, it is computed the system total impedance for different frequency values. Fig. 19, shows the resulted impedance values, and from this figure it can be shown that the parallel resonance does not occur at, or near, one of the three filters tuned frequencies.

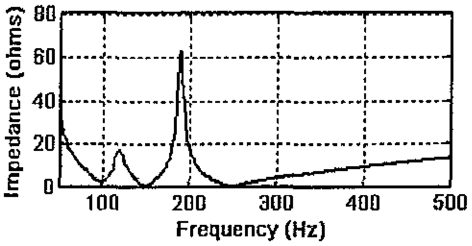

Fig. 19 Variations of the system equivalent impedance withy frequency.

Finally, considering the manufacturing tolerance for the capacitance and inductance, it is found that the THD_i is increased to 4.7 %, which is still less than the IEEE-Std. limits.

4. CONCOLUSION

In this paper, the power quality is improved for two considered real distribution systems. The first distribution system feeds a 12-puls converter load, while the second system is used for feeding an arc furnace load. The salient conclusions are:

1- The capacitor standard voltage limits can be exceeded when smaller capacitance values are chosen for the filter capacitors.

2- Values of the current and voltage THD increase sharply when the filters with smaller capacitances are used.

3- To avoid an occurrence of the parallel resonance near one of the frequencies to which the used filters are tuned, the filters should be designed such that their capacitances values are equal.

4- Considering the capacitor and reactor manufacturing tolerance may lead to an occurrence of parallel resonance.

5- A shunt capacitor may be used for improving the power quality problem resulted from an outage of one of the used filters.

6- Choosing the optimal values for the filters R, L and C parameters can lead to a decrease in the filters costs and their active power losses.

7- Two single tuned filters in addition to a band-pass filter should be used for improving the power quality problem resulted from an electric arc furnace load.

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