Harmonic Analysisof a Power Distribution Networkin Baghdad City

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ABSTRACT:

In electrical distribution systems, capacitors are used for reactive power compensation and reducing active power losses. With the presence of harmonic distortion the installation of shunt capacitors will amplify the harmonics distortion level. The objective of this study is to investigate the effect of capacitor placement on a certain feeder in AL_AMILdistribution network in Baghdad city with the presence of harmonics generated by a large non-linear load such as an ARC furnace. The CYMDIST software package was used for the implementation of this study. The results show the effectiveness of optimal capacitor placement on reactive power compensation, enhancing voltage profile, relieving the lines from over load conditions, and reducing active power losses. However the total harmonic distortion level is increased and methods are required for mitigation the harmonic effects. Several passive filters have been considered to tune out the harmonics; among these the double tuned filter has proven to be the most effective one for our particular case.

Keywords: Distribution network, harmonics, capacitor placement, reactive power compensation,CYMDIST software.

INTRODUCTION

The distribution network in Baghdad city is very old and the demand for electrical power is increasing rapidly. Nowadays large parts of the network are suffering from over load and under voltage conditions. One of thesolutions to this problemisto increase the capacity of certain feeders by the addition of capacitor banks at certain locations on the feeders. Capacitors are sinks for high frequency currents, since the impedance of a capacitor decreases with increasing frequency ($Z = 1/j\omega C$) [1].Non-linear devices draw current at the fundamental frequency 50 Hz and inject currents back into the network at higher frequenciescalled harmonics. Harmonic currents can cause excess heating in conductors, transformers and motors, due to the I^2R lossesbecause the resistance of the conductor increases with frequency. Harmonic voltages distort the voltage waveform, in severe cases causing peak values high enough to damage insulation and shorten the life expectancy of equipment. Protective devices such as fuses and relays can operate incorrectly in the presence of excessive harmonic currents [1].

This paper investigates the impact of connecting a relatively large non-linear load to a certain feeder in a local distribution network in Baghdad city. And the effect of allocating shunt capacitors for reactive power compensation, enhancing voltage profile, and reducing active power losses, on the harmonic distortion level and the methods required for mitigating harmonics effects.

Problem Formulation

The Backward/Forward Sweep Load Flow Algorithm

For a radial distribution network the Backward/Forward sweep algorithm solves the load flow equations iteratively in two stages:

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In the first stage the nodes and branches currents are calculated by the backward sweep starting from the end nodes back to the source node using Kirchhoff's Current Law. The end nodes currents are calculated as a function of the end nodes voltages and the given loads.

$$I_n = \left(\frac{S_n}{V_n}\right)^* \quad \text{………..} (1)$$

For the first iteration the initial end nodes voltages are taken as the nominal bus voltages at these nodes.The backward sweep calculates branch current and voltage drop in branches to update nodes voltages back to the source node.

$$V_k = V_n + Z_{k,n} \times I_{k,n} \quad \text{………..} (2)$$

The calculated branches currents are saved to be utilized in the following forward sweep calculations. Finally as a convergence criterion the calculated source voltage is compared to the specified source voltage for mismatch calculation.

$$\text{Error} = \left||V_s| - |V_1|\right| \quad \text{………..} (3)$$

In the second stage by the forward sweep starting from the source node to the end nodes the voltage is calculated at each node as a function of the branch current, using the currents calculated in the previous backward sweep.Kirchhoff's Voltage Lawis used for these calculations with the nominal voltage taken as the source voltage at the starting of each forward sweep[2],

$$V_k = V_n - Z_{k,n} \times I_{k,n} \quad \text{………..} (4)$$

The forward and backward sweeps continues until the calculated source voltage becomes within a specified tolerance with the nominal source voltage[3].

Optimal Capacitor Placement and Sizing

The optimal shunt capacitor size and locationin a radial distribution network should minimize the objective function; the total activepower losses [4]:

$$P_{loss(k+1)} \le P_{loss(k)} \quad \text{………..} (5)$$

Where: $P_{loss\,(k+1)}$ is the power losses after capacitor placement and $P_{loss\,(k)}$ is the power losses before capacitor placement.

And satisfy the following constraints:

1. Bus voltage limits:

$$V_{min} \le |V_i| \le V_{max} \quad \text{………..} (6)$$

Where:$V_{min}$is lower bus voltage limit, $V_{max}$is upper bus voltage limit, and $|V_i|$ rms value of the i^{th} bus voltage.

2. The line flow limits: The line load current (I) should be less than the line rated current (I_{rated}).

$$I \le I_{rated} \quad \text{………..} (7)$$

3. Power conservation limits: The algebraic sum of all incoming and outgoing power including line losses over the whole distribution network should be equal to zero:

$$P_G - \sum_{i=1}^{n} P_D - P_{lt} = 0 \quad \text{………..} (8)$$

Where: PG ispower generation, P_D is power demand; P_{lt} istotal power losses.

4. The number and sizes of permissible capacitor banks constraint:

$$\sum_{i=1}^{m} Q_c \le Q_t \quad \text{………..} (9)$$

Where: $Q_{c,}$ $_{is}$ kV Ar obtained from the capacitor bank, Q_t is total reactive power flow requirement, and m is total number of capacitor banks.

Individual Harmonic Distortion (IHD),is defined as the percentage of harmonics for order h with respect to the fundamental[5].

$$I_h(\%) = \frac{I_h}{I_1} \times 100 \quad , \quad V_h(\%) = \frac{V_h}{V_1} \times 100$$

Total Harmonic Distortion (THD), indicates the total harmonic current distortion of the wave form. [6]. *THD*is calculated as the percentage ratio of the sum of all the harmonic components (except the fundamental), divided by the magnitude of the fundamental current. According to the standard IEC 61000-2-2, the variable h can be limited to 50[7].

$$THD = \sqrt{\frac{\sum_2^n I_h^2}{I_1^2}} \qquad \text{……….. (10)}$$

When the current drawn by the load contains harmonics, the rms value of the current Irms, is greater than the fundamental I_1. The rms value of the voltage and current can be calculated as a function of the rms value of the various harmonic orders.

$$I_{rms} = \sqrt{\sum_{h=1}^{\infty} I_h^2} \quad \text{and} \quad V_{rms} = \sqrt{\sum_{h=1}^{\infty} V_h^2}$$

The definition of THD being[5]:

$$THD = \sqrt{\left[\frac{I_{rms}}{I_1}\right]^2 - 1} \qquad \text{……….. (11)}$$

or

$$I_{rms} = I_1\sqrt{1 + THD^2} \qquad \text{……….. (12)}$$

Relation between power factor and THD [5]

An initial indication that there are significant amounts of harmonics is a measured power factor PF that is lower than the measured $\cos\emptyset$.The power factor PF is the ratio between the active power P and the apparent power S,PF=P/S. While, the $\cos\emptyset$concerns exclusively the fundamental frequency and therefore differs from the power factor PF when there are harmonics in the installation,$\cos\emptyset=P_1/S_1$. Where, $P_1$is the active power of the fundamental, $S_1$is the apparent power of the fundamental.When thevoltage is sinusoidal or virtually sinusoidal,

$$P \approx P_1 = V_1 I_1 \cos\emptyset_1 \qquad \text{……….. (13)}$$

$$PF = \frac{P}{S} \approx \frac{V_1 I_1 \cos\phi_1}{V_1 I_{rms}} \qquad \text{……….. (14)}$$

From equation (12):

$$\frac{I_1}{I_{rms}} = \frac{1}{\sqrt{1+THD^2}} \qquad \text{……….. (15)}$$

Then

$$PF \approx \frac{\cos\phi_1}{\sqrt{1+THD^2}} \qquad \text{……….. (16)}$$

Resonance[5]

The simultaneous use of capacitive and inductive devices in distribution networks results in parallel or series resonance resulting in very high or very low impedance values respectively. Impedance Z for parallel resonance is calculated by:

$$Z = \frac{jL_s\omega}{1 - L_s C_c \omega^2} \qquad \text{……….. (17)}$$

where: L_s = Supply inductance (upstream network + transformer + line),
C_c = Capacitance of the power factor correction capacitors, R is neglected.

Resonance occurs when the denominator $1\text{-}L_sC_c\,\omega^2$ tends toward zero. The corresponding frequency is called the resonance frequency of the circuit. At that frequency, impedance is at its maximum and high amounts of harmonic voltages appear with the resulting major distortion in the voltage. The voltage distortion is accompanied by the flow of harmonic currents greater than those drawn by the loads.

Harmonic Filtering

To avoid resonance it is necessary to equip the installation with filtering systems. There are three types of filters; passive, active, and hybrid [5].

Passive Filters

Typical Applications[4]**:**

- Industrial installations with a set of non-linear loads representing more than 200 kVA (variable-speed drives, UPSs, rectifiers, ARC furnaces, etc.)
- Installations requiring power-factor correction.
- Installations where voltage distortion must be reduced to avoid disturbing sensitive loads.

- Installations where current distortion must be reduced to avoid overloads.

Operating Principle[8]:Passive filters are used to eliminate or control more dominant lower order harmonics specifically 5th, 7th, 11th and 13th. Passive filter is comprised of a passive L-C circuit (and also frequently resistor R for damping) which is tuned to a specific harmonic frequency which needs to be mitigated. Their operation relies on the "resonance phenomenon" which occurs due to variations in frequency in inductors and capacitors.The resonant frequency can be given as:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad \text{………..} (18)$$

where: f_r= Resonant frequency, Hz. L = Filter inductance, Henrys.
C = Filter capacitance, Farads.

The passive filters are usually connected in parallel with nonlinear load(s) and are tuned to offer very low impedance to the harmonic frequency to be mitigated.

Case Study

This study has been implementedonfeeder AMIL12which is one among14 feedersconstituteAl_AMIL11 kV distribution network which is a part of Baghdad city distribution network.Feeder AMIL12,as shown in figure (1), is a 26 bus system consisting of 26 sections;2 underground cables and 24 over head lines,8 normally closed switches and 16 spot loads (11/0.4 kV transformers),with one interconnection to feeder AMIL4 through node AMIL12_230.

Network Modeling

The modeling process begins with acquiring all the input data required for the modeling, and the combined processed data are imported from GIS software into CYMDIST to create the distribution system model.

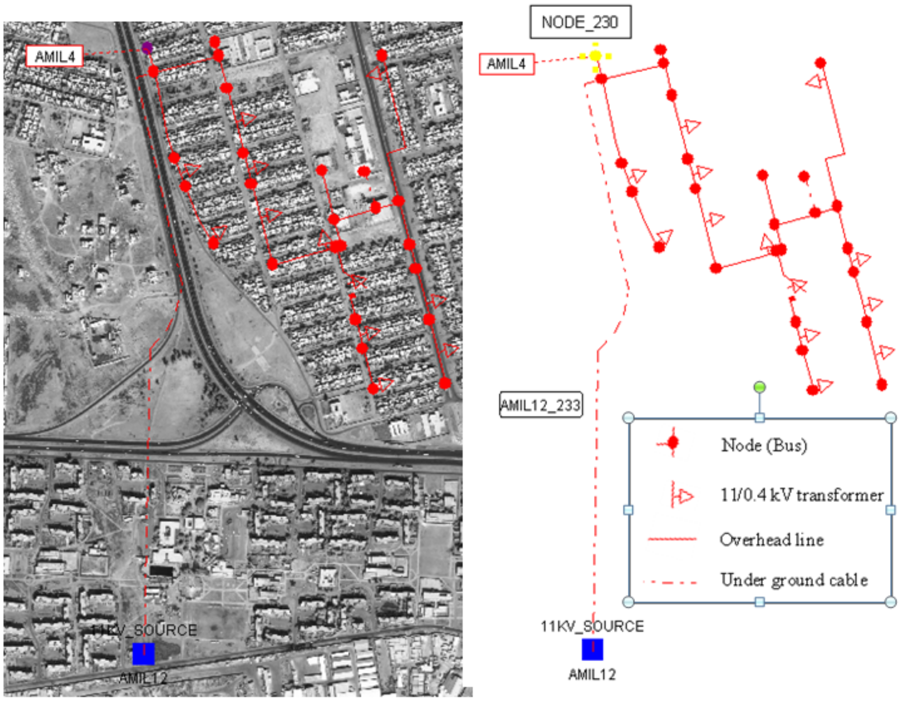


Figure (1): The layout and single line diagram of feeder AMIL12which is a part of Al_AMIL distribution network in Baghdad city.

Addition of an Industrial Customer

It is required to study the impact of the addition of an industrial customer to feeder 12 of AL_AMIL network. The industrial customer includes an ARC furnace (1.5 MVA) which acts as a harmonic current generating source.The ARC furnace industrial customerwillbe connected to node 254onfeederAMIL12 by closingthe switch on section 258asshown in figure (2).

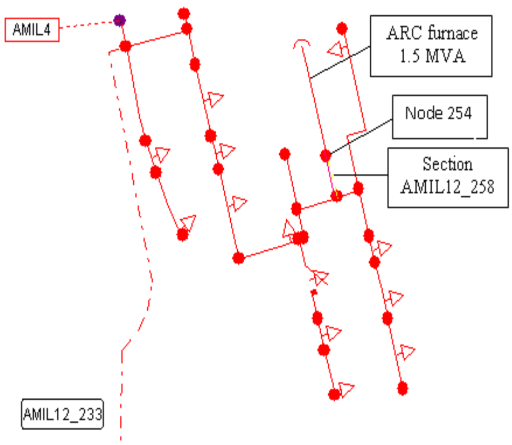


Figure (2): The ARC furnace industrial customer connectedtonode 254 on feederAMIL12.

Arc Furnace Settings

The arc furnace is modeled in CYMDIST as a constant MVA/PF industrial spot load rated at 1.5 MVA, with 3-phase star-grounded connection, and a fundamental power factor 0.8.

ARC furnaces are operating with different levels of harmonics they are showing a combination of ignition delays and voltage changes caused by random variations of the arc. This technical circumstances lead to a quite unusual harmonic spectrum with even and odd multiples of the fundamental frequency. These frequencies are additionally decreasing and increasing very quickly [8]. The harmonic spectrum generated by this load are given in table (1).

Table (1): The harmonic spectrum generated by ARC furnace[1]**.**

Harmonic Order (per fundamental frequency)	Current Magnitude (% of the fundamental current)
3	8
5	2
7	3
9	1
11	5

Before connecting the ARC furnace to the feeder the load flow analysis shows that there are no abnormal condition problems on the feeder. Table (2) gives the total loading of feeder AMIL12.

Table (2): Total load of feeder AMIL12 before connecting the ARC Furnace

Total load of feeder AMIL12-233,current capacity=292 A						
kW	kVAr	kVA	PF (%)	Total Loss (kW)	I/ph (A)	Loading %
3480.44	2611.43	4351.21	80	47.26	230.7	79

Connecting the ARC furnace: After connecting the ARC furnace to the feeder the results of load flow analysis show that the addition of this industrial customer cause over load problems on the feeder,as shown in figure (3) and in table (3).Table (4) gives the total loading of feeder AMIL12after connecting the ARC furnace.

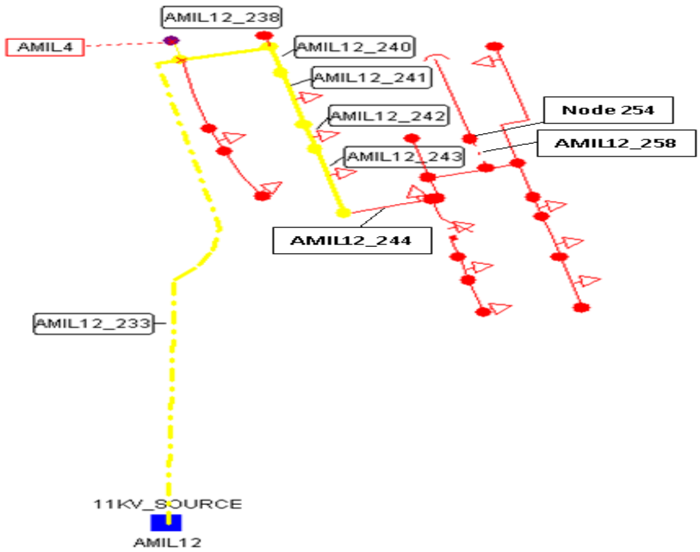


Figure (3): Overloaded sections (highlighted inyellow color) dueto connection of ARC furnace industrial customer to node 254on feeder AMIL12.

Table (3): Overloaded sections of feeder AMIL12 after connecting the ARC furnace

Section	Type	Loading %	kW/ph	kVAr/ph	P.F. %
233	cable	107.9	1577	1186	79.92
238	conductor	117.2	1380	1040	79.86
240	conductor	117.2	1376	1036	79.89
241	conductor	112	1315	989.5	79.9
242	conductor	106.9	1251	941.1	79.92
243	conductor	101.8	1190	894.6	79.93

Table (4): Total loading of feeder AMIL12 after connecting the ARC furnace

Total load of feeder AMIL12						
kW	kVAr	kVA	PF (%)	Total Loss (kW)	I/ph (A)	Loading %
4731.34	3558.99	5920.47	79.91	98.17	315.1	107.9

Harmonic Analysis after connecting the ARC furnace

Sections 258, 244, and 233 are selected to monitor the current harmonic content along the feeder. Figures (4) to (6) display the impedance versus the frequency, the current versus the frequency(harmonic spectrum**)**, and the current versus the time for the selected sections on the feeder. Table (5) show that the Total Harmonic Distortion (THD) is higher than the maximum allowable level 5% specified by the IEEE 519-1992 Standard, at section 258.

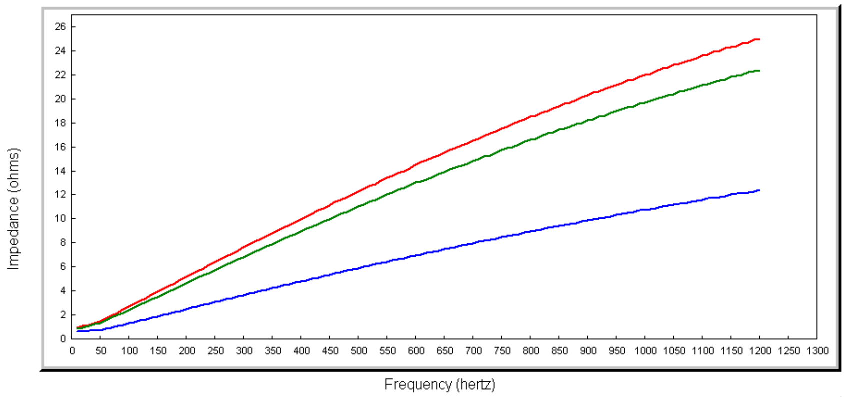


Figure (4):The impedance versus the frequency for feeder AMIL12 with ARC furnace.

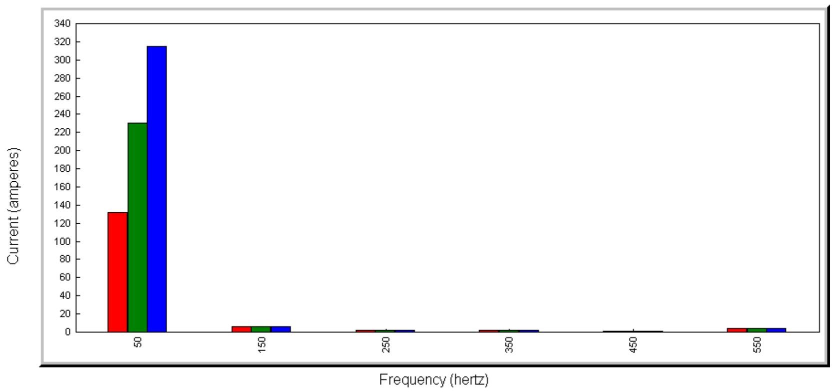


Figure (5):The current versus the frequency for feeder AMIL12 with ARC furnace.

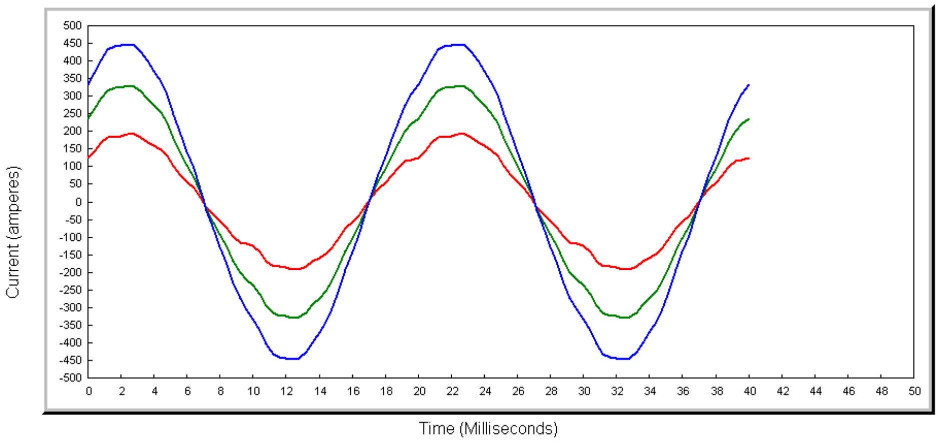


Figure (6):The current versus the time for feeder AMIL12 with ARC furnace.

Table (5): Harmonic current distortion for feeder AMIL12 with ARC furnace

Section	Fundamental Current (A)	150 Hz IHD (%)	250Hz IHD (%)	350 Hz IHD (%)	450 Hz IHD (%)	550 Hz IHD (%)	THD (%)
258	131.36	4.93	1.23	1.83	0.61	3.02	6.21
244	229.97	2.76	0.68	1.02	0.33	1.65	3.45
233	315.14	1.98	0.49	0.73	0.24	1.17	2.48

Mitigation Method

The effects of connecting the industrial customer to the network were:

- A low voltage problem in the network due to the addition of the new load.
- Harmonic current content upstream to the new load spot at section 254.

Capacitor Placement

To solve the low voltage problem we suggest the addition of shunt capacitor banks to the feeder. The optimum capacitor placement can be achieved using the capacitor placement analysis in CYMDIST. The analysis found the optimal locations to install the capacitors to be at sections 251 and 254. And the optimum capacitors rating are450kVAr/phand 150kVAr/ph respectively. As shown in Figure (7).

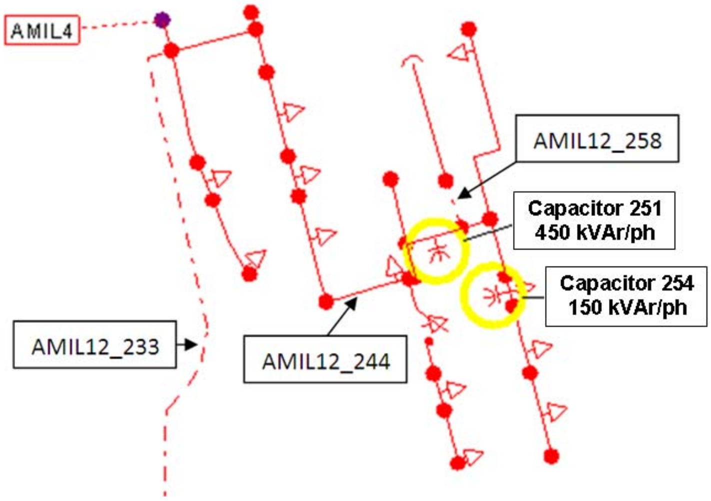


Figure (7): Capacitors placement at sections 251 and 254for mitigation of voltage drop resulting from the connection of the ARC furnace on feeder AMIL12.

The load flow analysis after capacitors placement shows that there are no overloaded conductors and low voltage problem son feeder AMIL12. Table (6) gives the total loading of feeder AMIL12after capacitors placement.

Table (6): Total loading of feeder AMIL12 after connecting the ARC furnace and capacitors placement C251=450kVAr/ph and C254=150kVAr /ph.

Total load of feeder AMIL12						
kW	kVAr	kVA	PF (%)	Total Loss (kW)	I /ph (A)	Loading %
4703.1	1973.9	5100.53	92.21	69.92	270	92.5

Harmonic Analysis with ARC furnace and capacitors placement

The harmonic analysis of feeder AMIL12 after connecting the ARC furnace and capacitors placement on sections 251 and 254, show the rise of a new situation. The impedance plot in figure (8) indicates that there is harmonic resonance at about the seventh harmonic (350 Hz) at the selected sections 258, 244, and 233on the network. Figure (9) shows the rise of current harmonic contents. These harmonic contents have considerable distortion on the current waveform as shown in figure (10). Table (7) shows that the Total Harmonic Distortion (THD) is higher than the maximum allowable level 5% at sections 258 and 244.

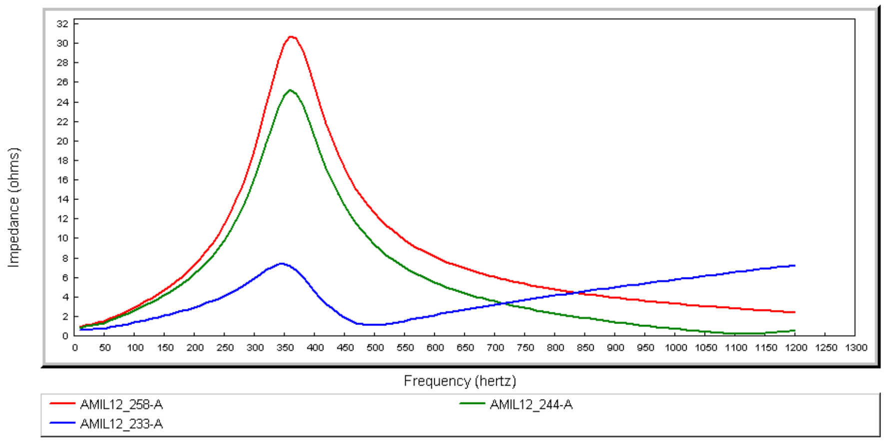


Figure (8):The impedance versus the frequency for feeder AMIL12 with ARC furnace and capacitors placement.

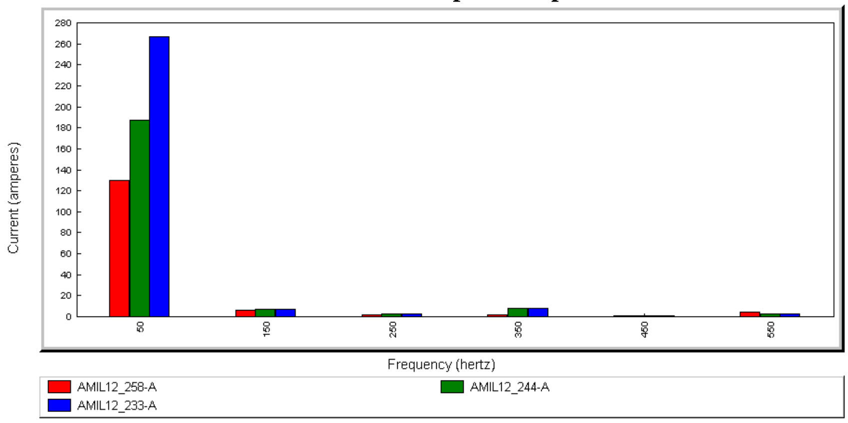


Figure (9):The current versus the frequency for feeder AMIL12 with ARC furnace and capacitors placement.

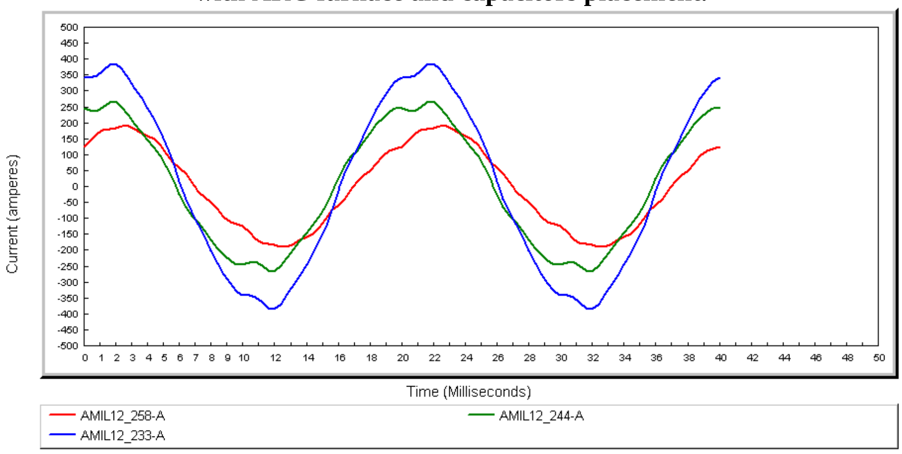


Figure (10):The current versus the time for feeder AMIL12 with ARC furnace and capacitors placement.

Table (7):Harmonic current distortion for feeder AMIL12 with ARC furnace and capacitors placement.

Section	Fundamental Current (A)	150 Hz IHD (%)	250 Hz IHD (%)	350 Hz IHD (%)	450 Hz IHD (%)	550 Hz IHD (%)	THD (%)
258	129.67	4.91	1.2	1.52	0.6	3.08	6.14
244	187.01	4.01	1.49	4.23	0.64	1. 51	6.23
233	266.87	2.77	1.02	2.91	0.44	1.04	4.29

Mitigation of Total Harmonic Distortion (THD)

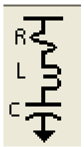
To reduce the THD to within the acceptable limit, filters can be used to tune out those harmonics [9]. Several types of filters are considered as follows:

Single Tuned Filter at Capacitor Location

Since the addition of the capacitors causes a resonance problem at the 7th harmonic, a solutionwould be to use a single-tuned filter. The tuned frequency of the filter is set at the 7th harmonic and the 3-phase filter is delta connected to match the configuration of the capacitor [10].

Single Tuned Filter Settings: In load flow analysis, CYMDIST treat the single-tuned filter as a constant kVA load.

$$Z = R + jX = R + j(wL - \frac{1}{wC})$$



The program computes the corresponding R, L and C values of the filter. For the rated total capacitor power 1650 kVAr, rated capacitor voltage 11kV, and nominal frequency 50 Hz. The Single tuned filter parameters at the 7th harmonic order are:

R = 0.960318 Ω, L=4.36684 mH, C=47.3519 µF

By assuming the single-tuned filter is balanced the equipment parameters R, L, and C can be used for each phase. Figure (11) shows the connection of the single-tuned filter to node 254 at the point of connection of the ARC furnace on feeder AMIL12.

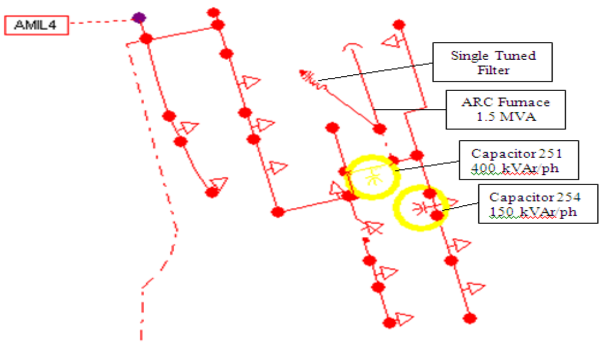


Figure (11): Single-tuned filter connected to node 254 at the point of connection of the ARC furnace on feeder AMIL12.

Harmonic Analysis with the Single Tuned Filter Installed

For the resonance at the 7thharmonic, installing a filter tuned to that frequency did not improve the situation since it creates a peak about the 3rdharmonic which has a higher harmonic current content, as shown in figure (12).Figure (13)shows the high harmonic current contents. Table (8) gives the Total Harmonic Distortion (THD) which is higher than the maximum allowable level 5% at section 258.

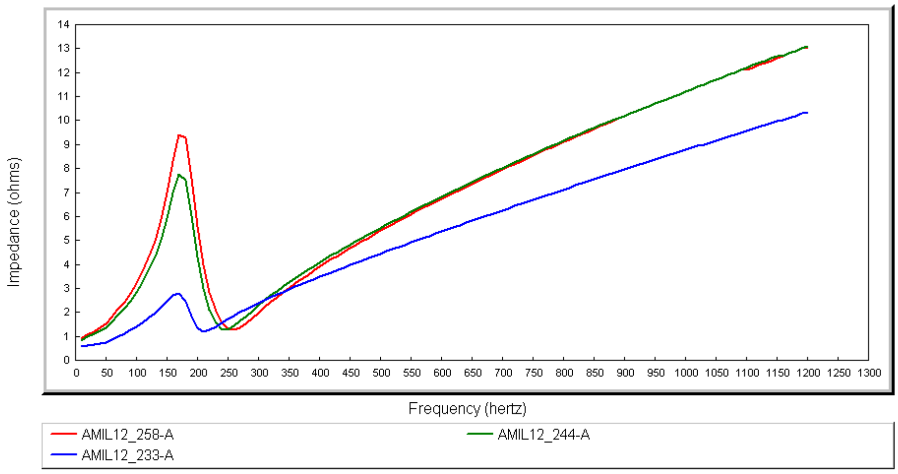


Figure (12):The impedance versus the frequency for feeder AMIL12 with ARC furnace and single-tuned (7th harmonic) filter.

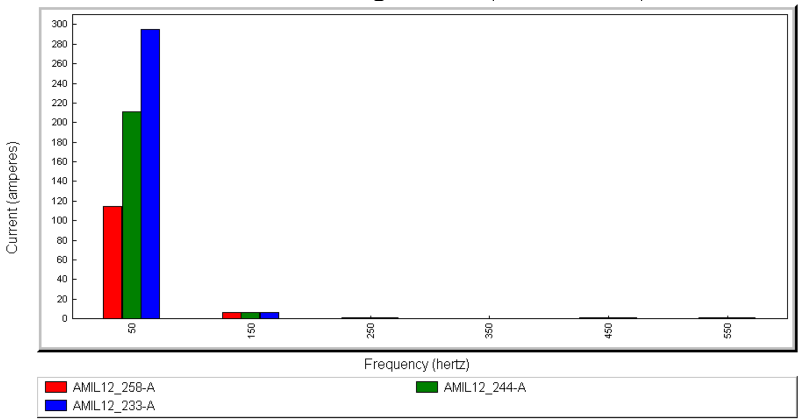


Figure (13):The current versus the frequency for feeder AMIL12 with ARC furnace and single-tuned filter.

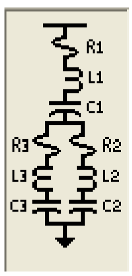
Table (8): Harmonic current distortion for feeder AMIL12 with ARC furnace and Single-tuned filter installed.

Section	Fundamental Current (A)	150 Hz IHD (%)	250 Hz IHD (%)	350 Hz IHD (%)	450 Hz IHD (%)	550 Hz IHD (%)	THD (%)
258	114.21	5.64	0.7	0.08	0.7	0.64	5.76
244	210.98	2.99	0.37	0.04	0.36	0.33	3.05
233	295.45	2.1	0.26	0.03	0.25	0.23	2.15

C-type Filter at Capacitor Location

It is obvious from the previous section that using the single-tuned filter did not mitigate the total harmonic distortion so we will investigate the use of a C-type filter. In load flow analysis, CYMDIST will treat C-type filter as a constant kVA load.

$$Z_1 = R_1 + jX_1 = R_1 + j(wL_1 - \frac{1}{wC_1})$$
$$Z_2 = R_2 + jX_2 = R_2 + j(wL_2 - \frac{1}{wC_2})$$
$$Z_3 = R_3 + jX_3 = R_3 + j(wL_3 - \frac{1}{wC_3})$$



$$Z = R + jX = Z_1 + \frac{Z_2 \times Z_3}{Z_2 + Z_3}$$

The C-type filter parameters, as calculated using CIMDIST, are:

R1 (Ω)	L1 (mH)	C1 (µF)	R2 (Ω)	L2 (mH)	C2 (µF)	R3 (Ω)	L3 (mH)	C3 (µF)
4.2	208	1.51	1.656	24	12.08	2.11	20	10.08

The harmonic analysis shows that installing a C-type filter did not improve the situation, since it creates a peak about the 5th harmonic which has a higher harmonic current content, as shown in figure (14).Table (10) shows that the Total Harmonic Distortion (THD) is higher than the maximum allowable level 5% at section 258.

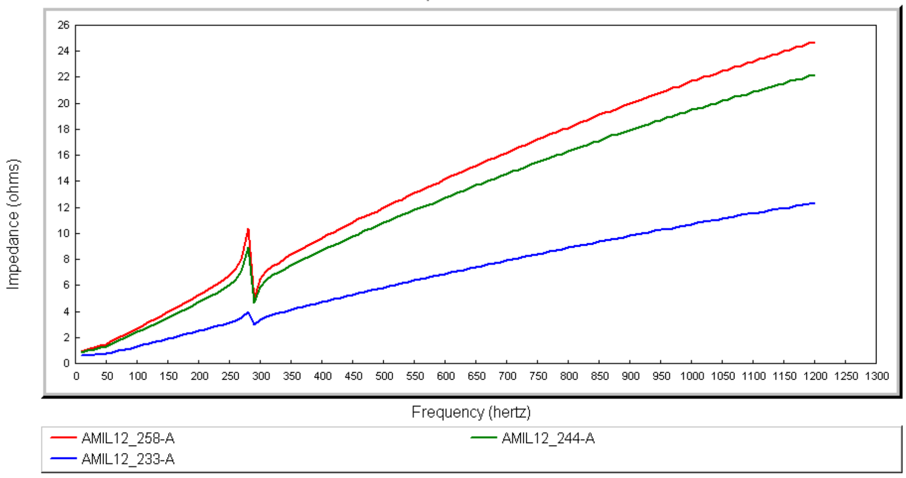


Figure (14):The impedance versus the frequency for feeder AMIL12 with ARC furnace andC-type filter.

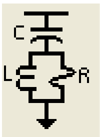
Table (10): Harmonic current distortion for feeder AMIL12 with ARC furnace and C-type filter.

Section	Fundamental Current (A)	150 Hz IHD(%)	250 Hz IHD(%)	350 Hz IHD(%)	450 Hz IHD(%)	550 Hz IHD(%)	THD (%)
258	129.52	5.03	1.32	1.76	0.6	2.99	6.28
244	228.08	2.8	0.73	0.97	0.33	1.62	3.47
233	313.22	2.01	0.52	0.69	0.23	1.16	2.48

High Pass Filter at Capacitor Location

Using the C-type filter did not mitigate the total harmonic distortion as shown in table (10) so we will investigate the use of a high pass filter instead. In load flow analysis, CYMDIST will treat high-pass filter as a constant kVA load.

$$Z_1 = jX_1 = j(-\frac{1}{wC})$$
$$Z_2 = jX_2 = j(wL)$$
$$Z_3 = R$$
$$Z = R + jX = Z_1 + \frac{Z_2 \times Z_3}{Z_2 + Z_3}$$



The High pass filter parameters, as calculated using CIMDIST, are:

R = 4.2 Ω, L= 208 mH, C= 1.51 µF

The harmonic analysis in figure (15) displays the impedance versus the frequency after installing the high pass filter to node 254, which is similar to figure (4) after connecting the arc furnace without any filtering. Installing the high pass filter did not improve the situation due to the high harmonic contents as shown in table (11),where the Total Harmonic Distortion (THD) is still higher than the maximum allowable level 5% at section 258.

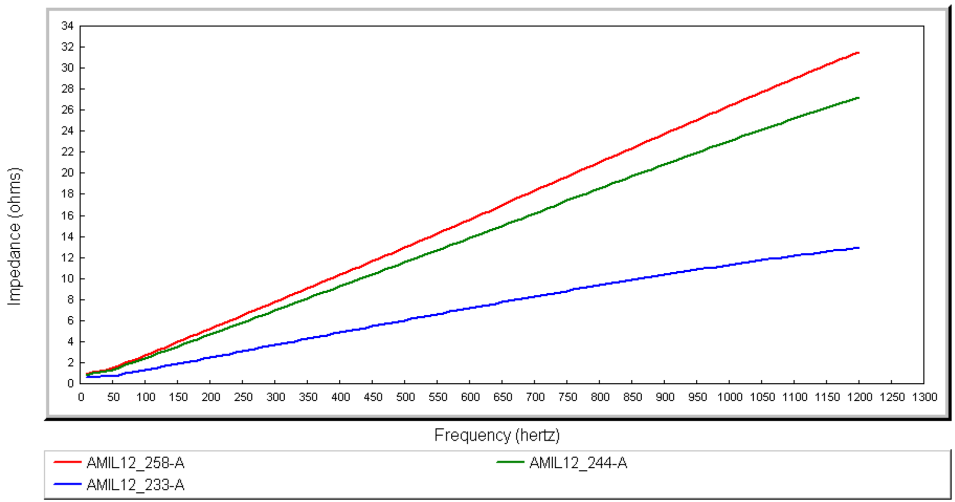


Figure (15): The impedance versus the frequency for feeder AMIL12 with ARC furnace and high pass filter.

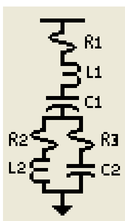
Table (11): Harmonic current distortion for feeder AMIL12 with ARC furnace and High pass filter.

Section	Fundamental Current (A)	150 Hz IHD (%)	250 Hz IHD (%)	350 Hz IHD (%)	450Hz IHD (%)	550 Hz IHD (%)	THD (%)
258	129.45	5.03	1.26	1.91	0.64	3.27	6.45
244	228.01	2.79	0.7	1.05	0.35	1.78	3.56
233	313.15	2	0.5	0.75	0.25	1.26	2.55

Double Tuned Filter at Capacitor Location

Finally we will investigate the use of a double tuned filter. In load flow analysis, CYMDIST will treat the double-tuned filter as a constant kVA load.

$$Z_1 = R_1 + jX_1 = R_1 + j(wL_1 - \frac{1}{wC_1})$$
$$Z_2 = R_2 + jX_2 = R_2 + j(wL_2)$$
$$Z_3 = R_3 + jX_3 = R_3 + j(-\frac{1}{wC_3})$$
$$Z = R + jX = Z_1 + \frac{Z_2 \times Z_3}{Z_2 + Z_3}$$



The filter is tuned for the first frequency at the 3rd harmonic order, for the3-ph rated capacitor power 1350kVAr,and tuned for the second frequency at the 7th harmonic order, forthe3-ph rated capacitor power 450 kVAr. The double tuned filter parameters, as calculated using CIMDIST, are:

R_1 (Ω)	L_1 (mH)	C_1(μF)	R_2 (Ω)	L_2 (mH)	C_2(μF)	R_3 (Ω)
0.353801	11.2618	47.3519	0.901932	7.66112	56.9801	0.911793

The harmonic analysis impedance plot in figure (16) indicates that the installation of the double tuned filter to node 254tuned out the 3rd harmonic at the bus and at the same time provided an attenuation of the impedance at the 7th harmonic. Figures (17) and (18) show reduction in the harmonic distortion at the chosen sections. And the Total Harmonic Distortion (THD) level is within the maximum allowable 5% as given in table (12).Table (13) gives the Total loading of feeder AMIL12 with ARC furnace and double tuned filter.

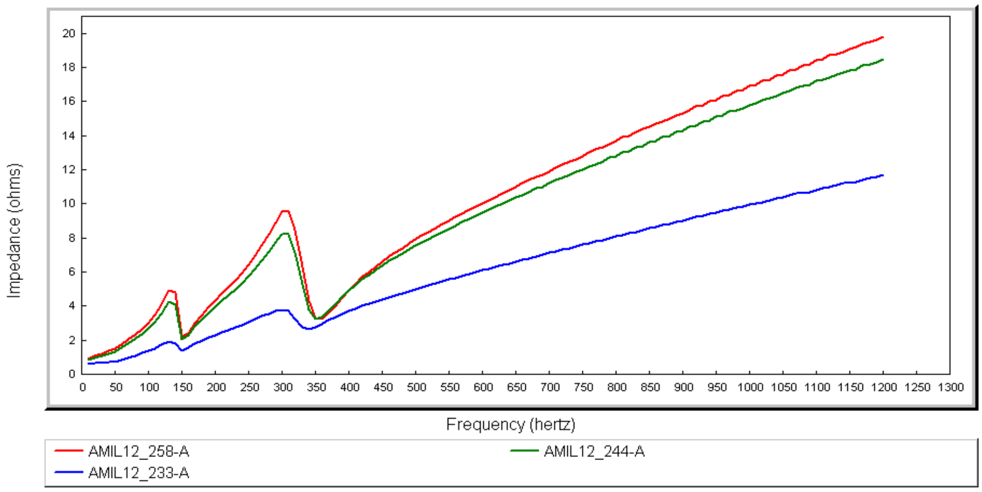


Figure (16): The impedance versus the frequency for feeder AMIL12 with ARC furnace and double tuned filter.

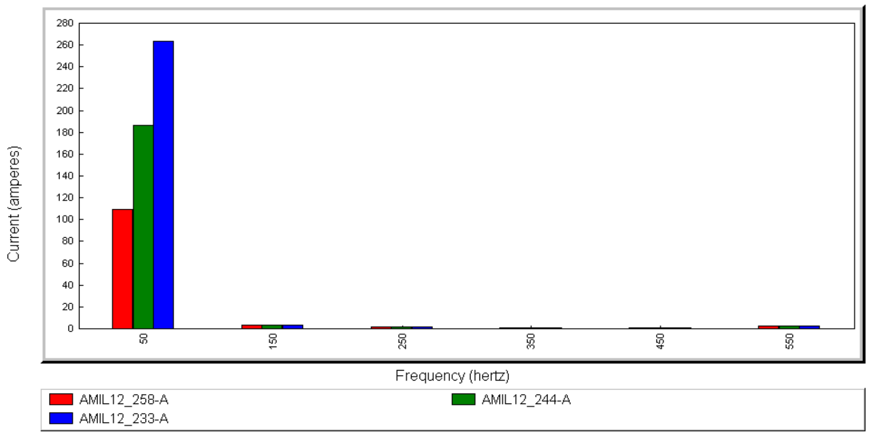


Figure (17):The current versus the frequency for feeder AMIL12 with ARC furnace and double tuned filter.

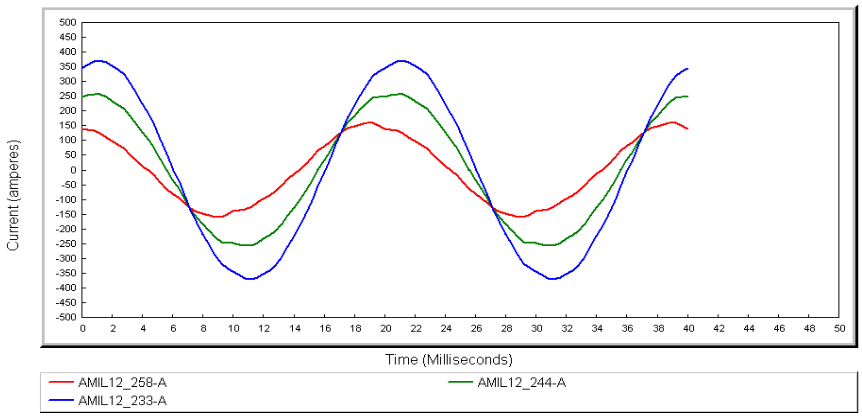


Figure (18): The current versus the time for feeder AMIL12 with ARC furnace and double tuned filter.

Table (12): Harmonic current distortion for feeder AMIL12 with ARC furnace and double tuned filter

Section	Fundamental Current (A)	150 Hz IHD (%)	250 Hz IHD (%)	350 Hz IHD (%)	450 Hz IHD (%)	550 Hz IHD (%)	THD (%)
258	109.72	3.33	1.46	0.82	0.42	2.39	4.45
244	186.06	1.93	0.84	0.47	0.24	1.35	2.55
233	263.84	1.34	0.58	0.32	0.17	0.93	1.77

Table (13): Total loading of feeder AMIL12 with ARC furnace and double tuned filter.

Total load of feeder AMIL12						
kW	kVAr	kVA	PF (%)	Total Loss (kW)	I /ph (A)	Loading %
4743.58	1553.56	4991.50	95.03	67.12	263.8	90.4

CONCLUSIONS

The simulation results verified that applying reactive power compensation to the distorted distribution system results in total active power loss reduction and power factor correction. However the installation of shunt capacitors with the presence of harmonic distortion amplifies the harmonics distortion level. The simultaneous use of capacitive and inductive devices results in a resonance situation of very high impedance values, in this particular network at the 7th harmonic. To avoid this resonance we equip the installation with passive filters. Among the different passive filters connected in parallel with the nonlinear load (the ARC furnace) only the double tuned filter proven to be effective in mitigating the harmonic resonance while decreasing the total harmonic distortion level below the maximum allowable level 5% specified in the IEEE 519-1992 Standard. These results were obtained from the simulation for the 34-bus system of feeder AMIL12 in AL_AMIL distribution network in Baghdad city.

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