Arc Furnace Load Harmonics Minimization using Shunt Passive Filters.

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Abstract – *The main objective of this paper is to determine the harmonics in the Arab Steel Company (Arco Steel) in Sadat City, Egypt. A Power Quality Analyzer device has been installed at the point of common coupling (PCC) and the data has been recorded during one month. The main loads of the station are: Electric Arc Furnace (EAF) and Ladle Refining Furnaces. Due to the presence of harmonics, the loads were disturbed, and few problems were recorded such as incorrect operation of devices, premature ageing of equipment, and additional power losses in addition to overvoltage and overcurrent. In order to mitigate the generated harmonics, Harmonics will be considered in this paper; a real distributed nonlinear load will be studied which produce sever harmonics. Passive filters will be designed to mitigate harmonics and keep it at the standard limits. The plant was modelled in MATLAB/SIMULINK using the measured data and then passive filters are designed to fulfil the standard limits.*

Key Words:
Electric Arc Furnace, Harmonics, Nonlinear load, Passive Filter, Power quality, Point of Common coupling.

1. INTRODUCTION

The amazing and rapid progress in electronic applications has increased the sensitivity of devices and equipment to any deviations in the input voltage of these loads. Hence, the science of Power Quality (PQ) has come to light since 1967 [1]. PQ is defined as "The concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment" [2, 3]. Voltage dips, voltage swells, transients, harmonics, unbalance, flicker and many other issues are recorded in the literature to cause significant loss in production for sensitive loads such as cement factories [4], textile factories [5], chemical and petrochemical stations [6], and mining industries [7].

In many cases, harmonics were reported to have adverse effects on industrial loads as well as the utility equipment [8, 9]. Harmonics are defined as: "A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency" [10]. For instance, Fig. 1 shows the 3rd, 5th, and the 7th harmonics for a generic fundamental waveform with a period of T seconds.

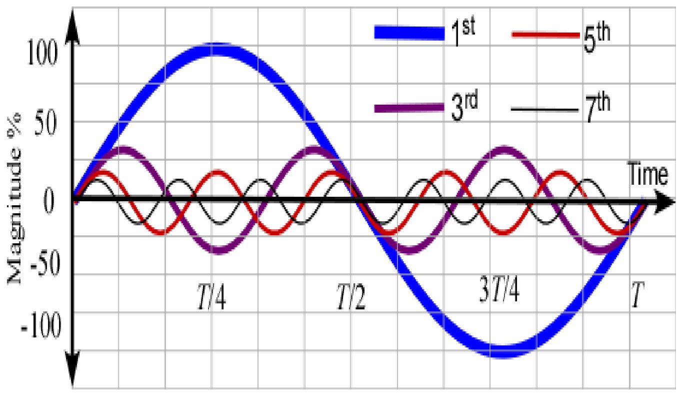

Fig -1: *Sinusoidal generic waveform and its 3rd, 5th and 7th harmonic.*

The main cause of harmonics is the existence of nonlinear loads such as power electronics-based loads. These include (but not limited to) AC motor drives, DC motor drives, Programmable-logic controllers and other controlled industrial process [11, 12]. Other system equipment may generate harmonics such as generators and transformers. In principle, the loads are the responsible for producing current harmonics which in turn most probably would produce voltage harmonics. On the other hand, the utility may produce voltage harmonics which in turn produces voltage harmonics at the load terminals. Due to the nonlinearity nature of most of the loads, voltage harmonics are normally different from current harmonics [13]. However, both voltage and current harmonics must be investigated in all cases.

One of the heavy nonlinear loads is the electric arc furnace which gives rise to harmonics. The arc furnace is characterized by time-varying, distributed and noisy parameters [14], which causes the generated harmonics to exceed the IEEE Standard 519-1992 [15, 16]. Generation of harmonics in the case of arc furnace is attributed to the non-linear voltage-current characteristic and the change of the arc length during the melting of the process [17]. In [18], individual harmonics were reported where the 5th and the 11th current harmonics were the most significant, 33.6 and 8.7 %, respectively.

The Egyptian Steel Company load is the case study in this paper where presents the measurements of harmonics were done for a one-month duration.

2. Simulation of the source and load using matlab-simulink

Electric Arc Furnace (EAF) is the most difficult load type in electrical distribution system. Electric arc furnaces are used for melting high melting point alloys such as steels as show in fig 2. In these furnaces, electric energy is used to form an electric arc which heats the metal by the radiant heat evolved. Heat is generated by electric arcs and in most types of furnaces also by resisting heating in the charge as the current passes from one arc to another. The basic of electrical operation of arc furnaces is the optimum current for the selected voltages or lower current as required by the power factor. Electric arc furnaces have founded wide applications in the steel industry for refining and making alloy steels and in the production of alloy [19].

Disturbances produces in electrical networks by electric arc furnaces can significantly affect the voltage quality supplied by electrical power companies.

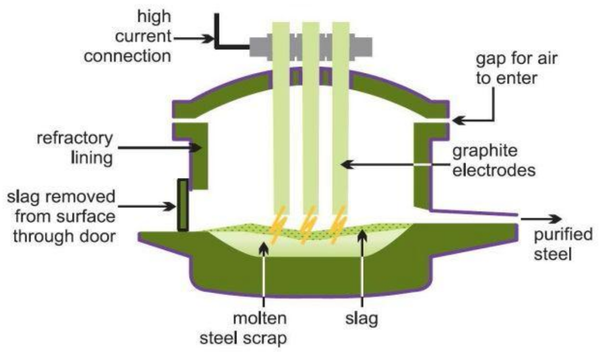

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Fig -1: Electric Arc Furnace.

Substation which connected with the network to supply Arc furnace load (Arco-steel company). There are 4- high voltage power circuits (220 k v). Fig 3 shows the single line diagram where the main source for loads are two power transformer, one of them feeds high nonlinear load (Arc furnace load), this load dived into two main load, EAF (Electrical arc furnace) and LRF (Ladle Refining Furnaces) of the transformer feed utility loads.

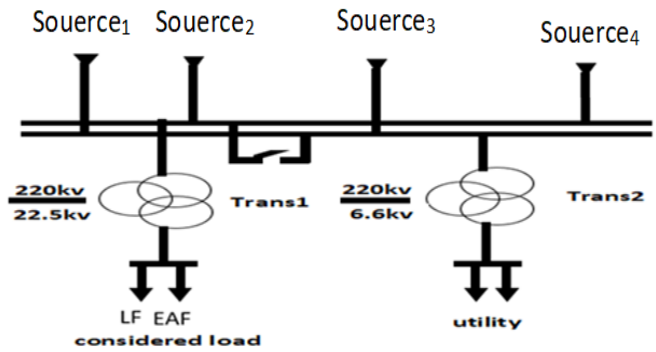

Fig -3: single line diagram for Distributed system with loads.

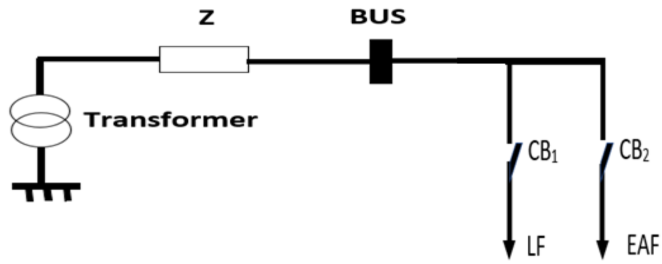

Fig -4: nonlinear load fed from power transformer.

Figure 4 represents a real practical load which located at Sadat city (Arab company for special steel). This load is Arc furnace load. This type of load can cause many power quality problems such as voltage sag, transient, harmonics,……etc, harmonic problem will be studied. Figure 4 shows nonlinear load fed from power transformer through underground cable. Power harmonic analyzer is used to measure these problems. Power Quality Analyzer device is used to the measure of harmonics which are recorded in table 1. Referring to this table, the considered load causes big power quality problem which produce each of odd and even harmonic, Also, it can be observed that the value of 5th harmonic exceeds the fundamental, in addition many individual harmonics are generated and exceed the standard limits.

Table -1: measured transformer individual harmonic current.

H.V SIDE 220K.V			M.V SIDE 22.5K.V		
HARMONIC ORDER	MAX. VALUE% OF FUN	IEEE 519/1992 MAX.LIMIT	HARMONIC ORDER	MAX. VALUE % OF FUN.	IEEE 519/1992 MAX.LIMIT
3	28	3	3	58.19	12
5	175	3	5	135.52	12
7	69.5	3	7	54.85	12
9	4.66	3	9	4.4	12
11	2.68	1.5	11	3.32	5.5
13	15.83	1.5	13	11.36	5.5
15	2.31	1.5	15	1.97	5.5
17	11.99	1.15	17	8.87	5
19	7.66	1.15	19	5.25	5
21	1.56	1.15	21	1.87	5
23	2.87	0.45	23	2.46	2
25	5.2	0.14	25	3.92	2
2	20	0.75	2	38.19	3
4	8	0.75	4	12.34	3
6	8.14	0.75	6	5.56	3
8	3.39	0.75	8	2.75	3
10	1.48	0.75	10	2.5	3
12	1.49	0.375	12	2.23	1.375
14	1.33	0.375	14	1.91	1.375
16	1.08	0.375	16	1.4	1.375
18	1.04	0. 287	18	1.24	1.25
20	0.91	0. 287	20	1.28	1.25
22	0.84	0.287	22	1.45	1.25
24	0.73	0.112	24	1.41	0.5

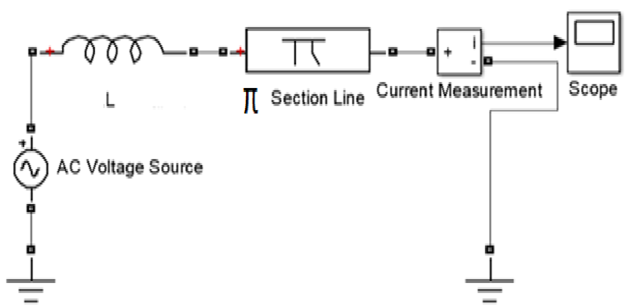

Fig -5: simulation the system.

Referring to figure 5, the internal impedance of the power transformer can be represented as inductive reactance cable can be represented π connection which its parameters (L, C). The considered underground sheet L=.118mh, C=. 318μf, R=.113Ω.

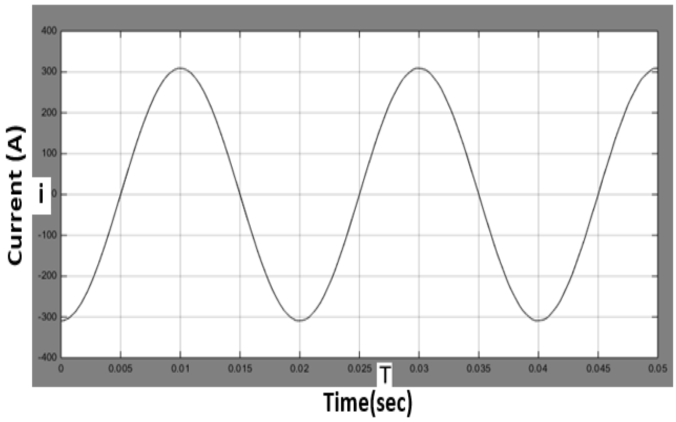

Fig -6: current waveform of the system without load.

Figure 6 shows the current waveform of the system without load, fundamental Waveform is the sinusoidal waveform that has the supply Frequency.

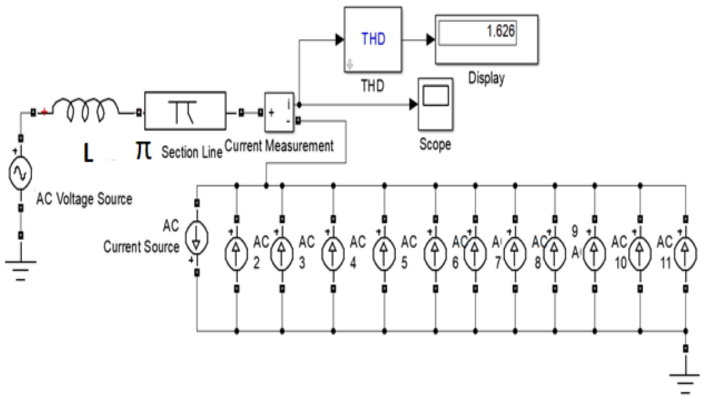

Fig -7: the system simulation considering nonlinear load.

Figure 7. shows a simulation of the studied network after connecting the considered arc furnace load. Referring to figure 7, the considered nonlinear load can be simulated as several current sources at different frequencies.

Figure 8 shows The current wave form at the pcc without filters. When EAF load is connected with the system at the pcc, highly distortion in current wave form is occurred. Fig 8 shoes the distortion in current waveform, this figure can be obtaining from Mat lab simulation shown in fig 8.

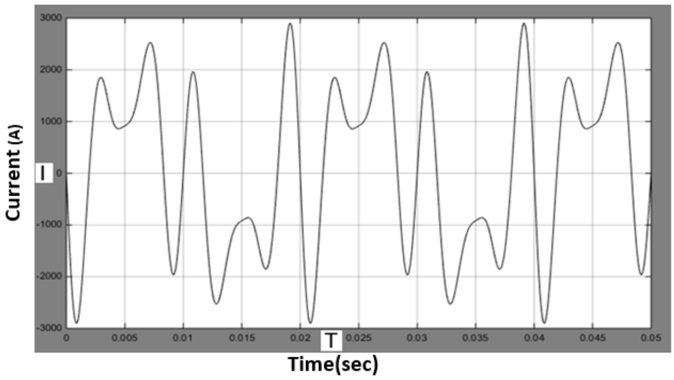

Fig -8: current wave form after connected load.

Using mat lab Simulink to determine the THD (total harmonic distortion), it is found that the current THDI is 162.6%.

The short circuit current at the PCC can be calculated. It is found that ISC=11750 A, and the maximum load demand is 1200 A.

$$\frac{I_{SC}}{I_L} = 9.9$$

Referring to IEEE 519, 1992 show in table, the measure value of current THDI after connecting the considered load is highly greater than the THD limit.

Table 1 shows IEEE519-1992 defines levels of harmonic currents that an industrial user can inject onto the utility distribution system.

Table -2: Current Distortion Limits as per IEEE Standard

I_{sc}/I_l	<11	11≤17	17≤h<23	23≤h<35	35≤h	THD
<20 *	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

All power generation equipment is limited those values regardless their Isc/I_l

The Short circuit current I_{SC} at the point of common coupling (PCC) corresponding to System MVA level.

Table 3 of IEEE 519-1992 defines the voltage distortion limits that can be reflected back onto the utility distribution system. Usually if the industrial user controls the overall combined current distortion according to Table 2, this will help them meet the limitations set forth in the guidelines [20].

Table -3: Voltage Distortion Limits

Bus voltage at PCC	Individual Voltage distortion	THD	Remarks
≤ 69kV 69 ≥161kV >161 kV	3.0 1.5 1.0	5.0 2.5 1.5	HV system may have up to 2 % THD, as in HVDC terminal that attenuates while tapped for a user.

The ratio $\frac{I_{SC}}{I_L} = 9.9$ which is less than 20. According to the first row in Table, it is found that the current THD limit equals 5 %. Therefore, the current THD value exceeds the IEEE-Std. limits. This essentially means that for the considered distribution system, with the two filters are connected, a power quality problem is existed.

Passive filters can be used to mitigate the harmonics, so the power quality problem can be damped There are two configuration of the passive filters, which are the series and shunt filters Using either the high series impedance filter or the low impedance shunt filter, the undesired harmonic currents can be prevented to penetrate into a distribution network. the series filters must carry a full load current and be insulated for the full line voltage.

However, the shunt filters carry only a fraction of the current that a series filter must carry. In addition, the shunt filters may supply reactive power at the fundamental frequency.

In practice, it is found that for harmonic reduction the shunt filters are more Suitable than the series filters. The most common shunt filters are the single tuned filter and the high pass filter. Shunt single tuned passive filter is the proposal which connected at the PCC.

Referring to the harmonic contents which show in table 3, it is noted that the individual value of the 2th3th 4th 5th harmonics exceed the standard limit, so passive single tuned filter be designed as flow.

Referring to the real measure measurements which applied on the considered load it is found the 5th exceeds the fundamental 162 %. while there are only two single tuned filter in the site to eliminate the2rd and the 3rd the harmonics. So, it can be observed that the THD of the load exceed the standard limit with the 2nd and 3rd harmonic filters so the proposal filters are four single tuned filter for damping each of the 2nd 3rd 4th and 5th harmonic.

The overall capacitance of the proposal filters can be calculated using the following equations;

$$Q_C = P(\tan\theta\,1 - \tan\theta\,2)$$

where: P is the 50 Hz load single-phase power, Ø1 & Ø2 are the load power factor angles before and after correction, respectively.

$$C = \frac{Q_C}{W_0 V^2}$$

Table -4: old and new Pf and total capacitance

Pf_1	.65
Pf_2	.98
Q_C	99343473.5
C	208uf

Passive filters are usually sized to provide VARS for power factor improvement as well as filtering the harmonic currents. Hence, in the filter design, there are two basic factors taken into consideration, which they are the filter size and the filter quality factor (or sharpness). Note that, the filter size is defined as the reactive power which the filter supplies at the fundamental frequency.

The single tuned filter is the most commonly used filter type and it contains a series RLC circuit as shown in Fig 9. This filter tunes to only one frequency of the low order harmonics as shown in Fig 10. It is to be noted that the filter capacitance must be capable of withstanding the arithmetic sum of the fundamental and harmonic voltages across its terminals, where the harmonic voltage is resulted from the harmonic current when the tuning occurred. Also, the filter coil must be able to withstand the RMS current going into the filter. This current includes not only the harmonic current to which the filter is tuned, but any other harmonic currents that might be present as well as the fundamental current [21].

Fig -9: single tuned filter configuration

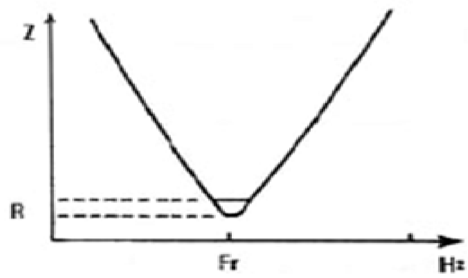

Fig -10: frequency response of single tuned filter

Then, the filter capacitance is computed as:

$$C = \frac{Q_C}{W_0 V^2}$$

where V is the supply phase voltage, $W_0 = 2\pi F_0$ and fo is the fundamental frequency. Referring to figure (a) the filter impedance for any frequency is given by

$$z = R + J\{WL - \frac{1}{WC}\}$$

where R and L are resistance and inductance of the filter coil respectively. The filter resonance occurs when the imaginary part of its impedance is equal to zero that is when Z= R. Hence, the filter resonance frequency (f.) is given by

$$F = \frac{1}{2\pi\sqrt{LC}}$$

For a harmonic number n, the filter inductive and capacitive reactance's are given as ,

$$X_{LN} = NX_L$$

$$X_{CN} = {}^{X_C}/_N$$

The filter quality factor (Q), which determines the filter sharpness by Q, is computed as,

Q= 2nfL/R

Table -5: the filters parameters values

Number of harmonic	L	C	R
2nd	.048	52	.75
3rd	.0216	52	.50
4th	.012	52	.37
5th	.007	52	.30

from calculation of filters design, the values of parameters can be obtained and recorded in table5.

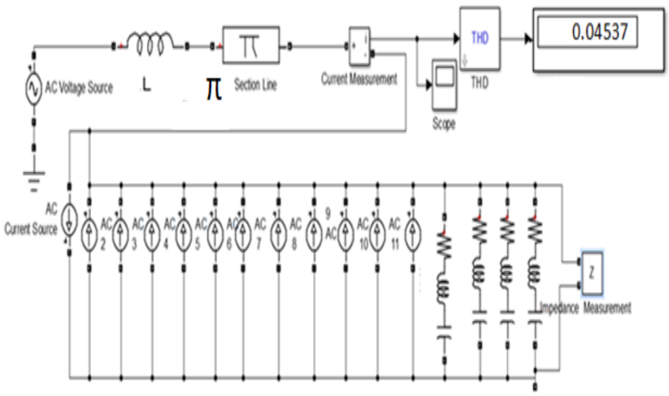

Fig -11: Mat lab simulation of the considered load with shunt passive filter.

After connecting the designed filter (2hd,3rd,4th,5th) at the pcc in parallel with the load it's found the THD for current is improved to 4.8% within the standard limit.

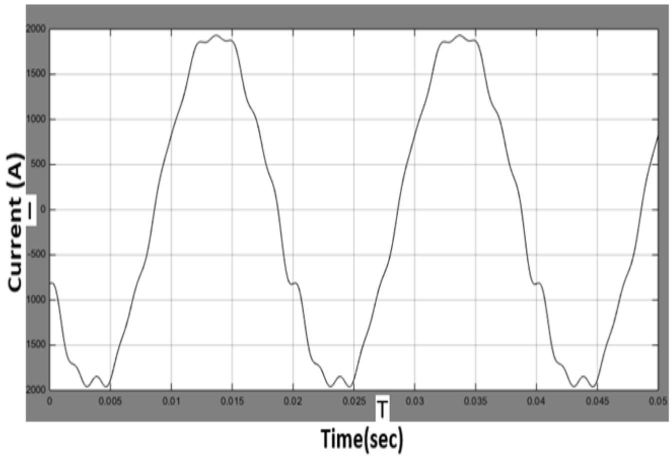

Fig -12: current wave form after connected filter.

Fig 13 shows the frequency impedance characteristic of the 4-designed filters where series resonance occurs at the 2hd,3rd,4th and 5th frequencies.

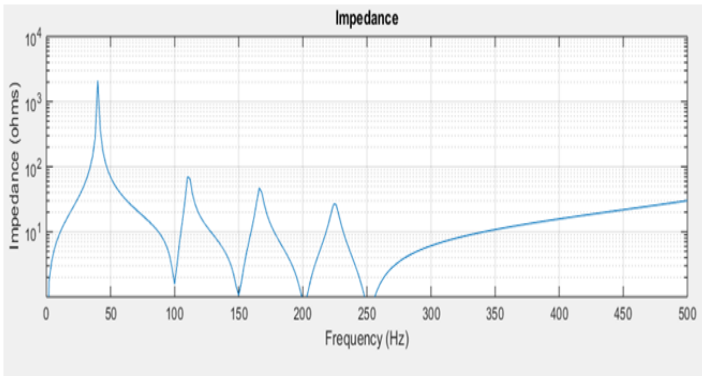

Fig -13: impedance characteristic of filter.

3. CONCLUSIONS

Arc furnace loads have deleterious effects on power systems which produce harmonics these harmonics are odd and even harmonics it's found that the THD for current and voltage exceed the fundamental.

Using of single tuned filter can element harmonics, so2hd,3rd,4th and 5th single tuned filter are designed and connected at the pcc. After connecting these filter, the THD is improved and become within limit.

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