PASSIVE MITIGATION TECHNIQUE FOR THE HARMONICS CAUSED BY LED LAMPS

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ABSTRACT

LED technology is being increasingly used in modern electricity distribution networks. Due to their low energy consumption they represent a sanctuary for the continuous increase in energy prices in Egypt. LED lamps require low DC power; hence they use power electronic converters in order to be implemented in local electricity distribution networks. These power supplies produce various harmonics profiles based on the ratings and brands of LED lamps. These accumulated harmonics could cause negative impacts on electrical equipment in electricity distribution networks. Therefore, an evaluation study for various types and brands of lamps is done in this research based on both magnitude and phase angle of each individual harmonic. After analysing the results, mitigation method will be presented and investigated depending on their effectiveness and feasibility. All measures are done using Network Analyser a-eberle PQ Box 200.

INTRODUCTION

Harmonics have several negative effects on electrical equipment. Despite of the overheating that harmonics may cause to conductors, capacitors, and transformers, they may also cause instability problems to generators. Harmonics may confuse measuring devices which lead to incorrect measurements. These false measurements may cause circuit breakers and fuses to miss-operate. Also for electric utility meters they may result in increased billing for customers. For sensitive electrical devices used in medical applications and in communications harmonics may cause interference and equipment malfunction [1].

One of the major sources for harmonics in electricity distribution networks is Power Electronic Converters (PEC) which convert AC power into more appropriate DC power required by certain types of loads [2]. LED lamps and chargers of smart phones, tablets, laptops, and power banks are various types of loads which use PEC to convert grid AC voltage into more adequate lower levels of DC voltage [3].

In 2011 and for four years after, Egypt has witnessed several long dark nights. Because of the gap between generation and consumption for the favor of consumption, vast load shedding was a must. The electricity sector in Egypt came with a complex plan to solve this catastrophe. In this plan there are short term solution and long term solution. The short term solution was based on energy saving and renewable energy projects. The long term solution was to construct new conventional power plants to fulfill the gap between generation and consumption.

The electricity sector aimed to increase the public awareness of energy saving and to facilitate embedding high efficient loads by the consumers. Therefore the electricity distribution companies started to distribute various types of LED lamps with lower prices than the local market to the consumers. More than 10 million LED lamps were sold by the electricity distribution companies all over Egypt within two years. Due to the several advantages of LED lamps such as long lifetime and lower energy consumption, they are now being increasingly used by consumers in Egypt. This growing numbers of LED lamps which are being inserted in the electricity distribution network may increase the harmonics' levels in the network. Hence, it may have some negative impacts on other equipment connected to the same network.

Therefore, in this paper, the harmonics' profiles of various common types of LED lamps are studied. Then based on the phase angles of each individual harmonic order, passive harmonics mitigation may occur [4]. By knowing which types of LED lamps can mitigate harmonics generated by other loads, a passive solution for the harmonics problem may be proposed. It is by inserting these certain types of LED lamps at some certain points of the electricity distribution network based on the harmonics profile at each point of the network. This solution will frequently require studying both the LED lamps and the grid. Then by distributing certain types of LED lamps for consumers based on their location at the electricity distribution network, harmonics can be mitigated passively at these specific points of the network.

Section II presents data of few common types of lamps which are being used in domestic and commercial applications in Egypt. In section III harmonics' profiles for each sample of these lamps is studied. Then a mitigation technique is presented in section IV. Finally section V is the conclusion and future work.

LAMPS UNDER STUDY

There are several types of lamps and for each type there are several brands and manufacturers. This research focuses on 8 lamps which are the most common types of lamps which are being widely used in domestic and commercial applications in Egypt. The brands of these lamps are chosen randomly. These lamps are:

1- LED Bulb E27.
2- LED Bulb E14.
3- LED 120 cm tube lamp.
4- LED 60 cm tube lamp.
5- Incandescent lamp.
6- Compact florescent lamp CFL.
7- 120 cm tube florescent lamp (Magnetic Ballast).
8- 60 cm tube florescent lamp (Electronic Ballast).

In the following Table I, Data for the LED lamps under study are presented and ordered as in the previous list. For the LED Bulb E27 two samples of the same type and manufacturer are used in order to prove that harmonics profile for the same type and brand of lamps are identical. Also for the LED Bulb E14 lamp two different brands of lamps are used.

The conventional matches for these LED lamps are still used and available in the local market [5]. Hence, their behavior is also studied in order to demonstrate the effect of the true mix of lamps connected in the electricity distribution network. Table II presents data for the conventional matches of the LED lamps which are presented in Table I. For Lamps 7 & 8 different types of ballasts are used, one for each lamp because their effect is the same on both lamps since they are both fluorescent lamps. As noticed from both tables, LED lamps have more THD in current than conventional lamps. CFL lamps and the electronic ballasts of fluorescent lamps both use PEC technology hence, they generate harmonics as high as LED lamps.

TABLE I
MEASURED ELECTRICAL DATA OF SEVERAL TYPES OF LED LAMPS

Lamp No.	1		2		3	4
	A	B	A	B		
Rated Power (W)	10	10	6	6	18	9
Actual Power(W)	10.2	10.6	5.47	5.41	18.83	10.18
Frequency (Hz)	50.2	50.1	50.1	50.1	50.1	50.3
Voltage (V)	227	225	227	224	223	227
Ampere (A)	0.08	0.08	0.05	0.04	0.09	0.05
THD (%) voltage	2.88	2.81	2.89	2.85	2.65	2.83
THD (%) current	115	113	65.7	113	22.28	41.08
P.F.	0.56	0.57	0.49	0.58	0.93	0.83

HARMONICS PROFILE CASE STUDY

In this section harmonics profile for each lamp is studied using Network Analyzer & Transient Recorder PQ-Box 200. High order harmonics are neglected then magnitude and angle of each odd current harmonic up to 11th order are recorded. Harmonics' profiles for each of the 8 samples of lamps are presented in the following tables and figures.

From the data shown in Table III & Table IV for the same types and brands of LED lamps, it is noticed that they have identical harmonics profile. Figure 1 and Figure 2 show their voltage and current waveforms.

TABLE II
MEASURED ELECTRICAL DATA OF SEVERAL TYPES OF CONVENTIONAL LAMPS

Lamp No.	5	6	7	8
Rated Power (W)	100	26	40	20
Actual Power (W)	94.907	15.171	56.585	20.013
Frequency (Hz)	49.942	49.991	50.328	50.114
Voltage (V)	225	224	224	226
Ampere (A)	0.425	0.113	0.386	0.149
THD (%) voltage	2.648	2.692	2.669	2.804
THD (%) current	4.74	90.1	9.96	96.23
P.F.	0.99	0.6	0.65	0.59

TABLE III
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 1-A

Order	Value (%)	Angle (°)
3	45	-128.022
5	16.25	112.073
7	22.5	50.118
9	31.25	-85.939
11	25	134.04

Figure 1. Voltage and current waveforms for lamp type 1-A.

TABLE IV
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 1-B

Order	Value (%)	Angle (°)
3	44.58	-127.82
5	16.87	113.90
7	22.89	50.60
9	31.33	-85.54
11	25.30	134.83

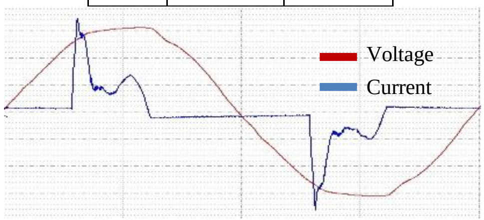

Figure 2. Voltage and current waveforms for lamp type 1-B.

Table V & Table VI show the data of the odd current harmonics for LED lamps type 2-A & 2-B. These two samples of lamps represent two different brands for the same type of LED lamp. It is noticed that they have completely different harmonics profile as shown in Figure 3 and Figure 4.

TABLE V
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 2-A

Order	Value (%)	Angle (°)
3	20.41	-9.77
5	34.69	-46.98
7	12.24	122.38
9	24.49	-60.94
11	6.12	96.49

Figure 3. Voltage and current waveforms for lamp type 2-A.

TABLE VI
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 2-B

Order	Value (%)	Angle (°)
3	52.38	-167.50
5	30.95	10.25
7	11.90	162.92
9	14.29	-98.57
11	21.43	69.95

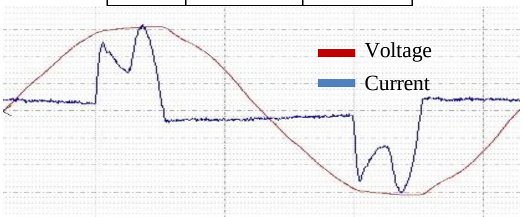

Figure 4. Voltage and current waveforms for lamp type 2-B.

Table VII & Table VIII present the odd current harmonics values for LED tube 120 cm & LED tube 60 cm respectively. Their harmonics are remarkably less than LED bulb lamps. Figure 5 and Figure 6 show their voltage and current waveforms.

TABLE VII
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 3

Order	Value (%)	Angle (°)
3	7.69	173.75
5	8.79	-76.13
7	13.19	156.31
9	8.79	-94.92
11	5.49	115.27

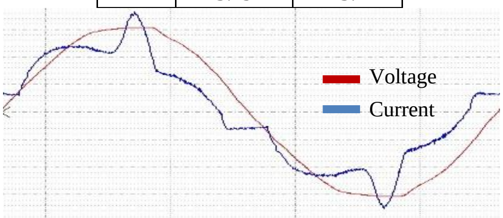

Figure 5. Voltage and current waveforms for lamp type 3.

TABLE VIII
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 4

Order	Value (%)	Angle (°)
3	12.96	-178.31
5	22.22	-59.60
7	16.67	142.96
9	16.67	-82.19
11	9.26	91.32

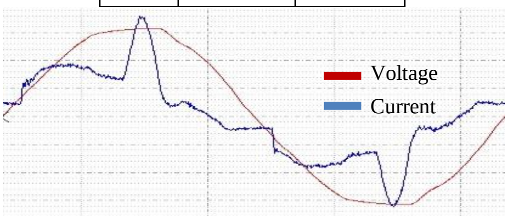

Figure 6. Voltage and current waveforms for lamp type 4.

Table IX presents the values of odd current harmonics for a 100w Incandescent lamp. These conventional types of lamps are still being used in Egypt due to their very low prices. They are like an ideal lamp under the prospective of power quality. But still they have a major deficit which is their very high power consumption. Figure 7 shows its voltage and current waveforms.

TABLE IX
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 5

Order	Value (%)	Angle (°)
3	2.59	130.02
5	0.94	-34.05
7	2.82	106.93
9	1.88	-92.68
11	1.41	92.84

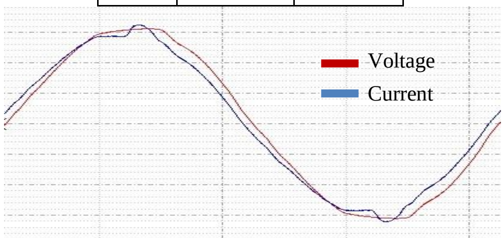

Figure 7. Voltage and current waveforms for lamp type 5.

The harmonics profile of the CFL lamp is shown in Table X. Figure 8 shows its voltage and current waveforms.

TABLE X
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 6

Order	Value (%)	Angle (°)
3	44.25	-100.99
5	19.47	-169.44
7	31.86	99.34
9	24.78	-28.57
11	6.19	-128.12

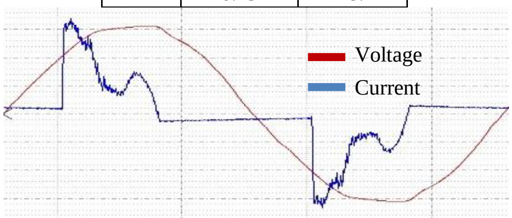

Figure 8. Voltage and current waveforms for lamp type 6.

Fluorescent lamps require ballasts in order to supply the lamp with an adequate voltage to operate properly. There are two types of ballasts; magnetic and electronic ballasts. The magnetic ballast consumed additional power in order to operate as it is obvious from the data shown in Table II; the rated power for the 120cm T12 lamp is 40w while the actual power that the lamp really consumed was nearly 56 w. While the electronic ballast used for the 60cm fluorescent lamp does not consume any extra power although it produces significantly high harmonics compared to magnetic ballasts. The harmonics profile for both fluorescent lamps 120& 60 cm are given in Table XI & Table XII. Their harmonics values are remarkably less than LED tube lamps, while Figure 9 and Figure 10 show their voltage and current waveforms respectively.

TABLE XI
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 7

Order	Value (%)	Angle (°)
3	8.29	-42.48
5	2.33	-72.78
7	3.11	118.87
9	1.81	-49.89
11	1.30	102.12

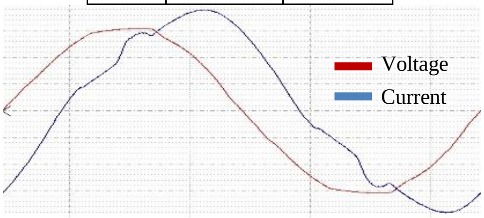

Figure 9. Voltage and current waveforms for lamp type 7.

TABLE XII
ODD CURRENT HARMONICS DATA FOR LAMP TYPE 8

Order	Value (%)	Angle (°)
3	44.97	-104.22
5	20.81	173.44
7	30.20	84.44
9	25.50	-40.80
11	10.74	-143.66

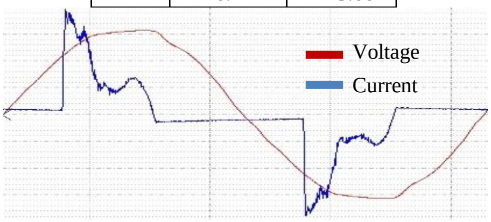

Figure 10. Voltage and current waveforms for lamp type 8.

MITIGATION METHOD

These lamps are being heavily used in electricity distribution networks [6]. They are randomly scattered and operated. If the same identical lamps are operated at the same time and supplied from the same grid, the accumulated harmonics will surly exceed the standard limit for THD allowed in this grid [7]. When the electricity sector in Egypt distributed LED lamps for the consumers in the past few years, these lamps were in different types and different brands. Distributing 10 million LED lamps of the same type and from the same manufacturer could have led to an increased THD all over the Egyptian electricity distribution network. The electricity sector was aware about this problem therefore; these lamps were distributed all over Egypt randomly. The key solution was to make these harmonics which are produced from different lamps to mitigate each other. As shown previously, lamps of the same type and brand 1-A & 1-B have an identical harmonics profile while different brands' lamps 2-A & 2-B have different harmonics profile. Therefore, if identical lamps are connected together, THD will be increased and if different lamps are connected together THD will be decreased. In order to prove this assumption we connected both LED lamps 1-A & 1-B to the same supply and measured the new THD for both lamps together. By comparing the results from Table I and Table XIII, it is noticed that the THD for both lamps 1-A & 1-B are increased from 115.48% and 113.6% respectively to 124.03% because both lamps 1-A and 1-B are of the same type and brand and they have identical harmonics profiles.

The harmonics profiles for both lamps 1-A & 1-B when connected together are shown in Table XIV. Their voltage and current waveforms are shown in Figure 11.

TABLE XIII
MEASURED ELECTRICAL DATA FOR LAMPS TYPE 1-A&1-B

Lamps	W	Hz	V	A	THD voltage	THD current	P.F.
1-A 1-B	18.5	50.1	226	0.15	2.84	124.03	0.54

TABLE XIV
ODD CURRENT HARMONICS DATA FOR LAMPS TYPES 1-A&1-B

Order	Value (%)	Angle (°)
3	46.41	-121.80
5	23.53	115.28
7	21.57	32.97
9	28.10	-89.58
11	24.18	138.36

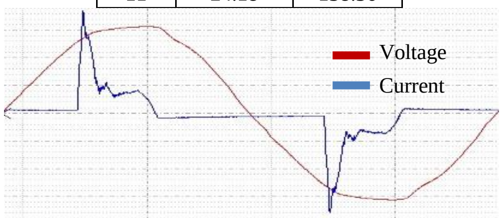

Figure 11. Voltage and current waveforms for lamps types 1-A & 1-B.

The variety in types and brands of lamps in Egypt partially mitigate the overall THD of individual lamps. Each lamp has different harmonics with different phase angles [8]. When these lamps are operated together, their harmonics of opposite phase angles mitigate each other. In order to prove this assumption several LED lamps are operated together. Samples 1-A, 1-B, 2-A, 2-B, 3, and 4 are connected to the same source and their accumulated harmonics are recorded. By comparing the results from Table I and Table XV, it is noticed that the THD for all lamps is 47.09% which is less than the average THD of the lamps 78.66%.

TABLE XV
MEASURED ELECTRICAL DATA FOR LED LAMPS TYPES 1-A, 1-B, 2-A, 2-B, 3 AND 4

Lamps	W	Hz	V	A	THD voltage	THD current	P.F.
1 to 4	53.7	50.1	226	0.29	2.72	47.09	0.82

The harmonics profile for all LED lamps 1-A, 1-B, 2-A, 2-B, 3, and 4 when connected and operated together are shown in Table XVI. While their voltage and current waveforms are shown in Figure 12.

TABLE XVI
ODD CURRENT HARMONICS DATA FOR LED LAMPS TYPES 1 TO 4

Order	Value (%)	Angle (°)
3	27.93	-112.96
5	10.00	102.55
7	6.90	6.62
9	16.55	-99.31
11	11.72	133.46

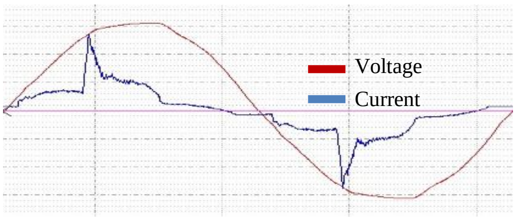

Figure 12. Voltage and current waveforms for lamps types 1 to 4.

Lighting applications are not yet pure LED lighting; the conventional types still exist in the grid. They are all generating harmonics into the grid hence; Table XVII presents the measured data for all the samples from 1 to 8 used in this research because this is the actual case of diversity occurring in the electricity distribution network in Egypt.

TABLE XVII

MEASURED ELECTRICAL DATA FOR ALL LAMPS TYPES 1 TO 8

Lamps	W	Hz	V	A	THD voltage	THD current	P.F.
1 to 8	141	50.2	225	0.69	2.4	42.01	0.9

The harmonics profile for all LED lamps 1-A, 1-B, 2-A, 2-B, 3, 4, 5, 6, 7, and 8 when connected together is shown in Table XVIII. While their voltage and current waveforms are shown in Figure 13.

TABLE XVIII

ODD CURRENT HARMONICS DATA FOR LAMPS TYPES 1 TO 8

Order	Value (%)	Angle (°)
3	31.60	-93.85
5	12.55	146.10
7	9.38	63.88
9	10.68	-57.63
11	5.34	-168.97

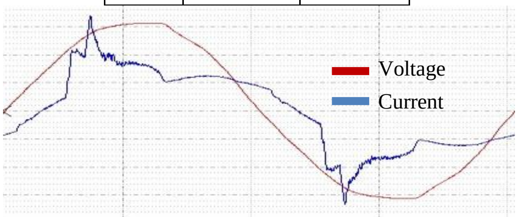

Figure 13. Voltage and current waveforms for lamps types 1 to 8.

THD in voltage is supply dependent [9, 10]. To study the effect of THD in voltage a PV cell is used supply of 250w. It has a THD in voltage of 28.3% as shown in Table XIX while the grid THD was about 2.4% as in Table XVII. Then all the lamps from 1 to 8 are connected and operated them together. The measured data is given in Table XIX.

TABLE XIX

MEASURED ELECTRICAL DATA FOR ALL LAMPS TYPES 1 TO 8 AND PV CELL

Lamps	W	Hz	V	A	THD voltage	THD current	P.F.
1 to 8	124	50.8	216	0.67	28.3	70.29	0.86

It is noticed that the THD in voltage waveform is 28.3% for the PV cell supply (background harmonics). This directly affected the THD in current waveform and increased it from 42.01% to 70.29% for all connected lamps.

CONCLUSION

LED lamps generate harmonics more than conventional lamps. Heavy penetration of LED lamps in lighting applications may cause harmonics standard violation. Due to non-linearity characteristics of power electronic converters, each lamp has different harmonics profile. When connected with other different lamps of different types and brands, these harmonics mitigate each other. So far the variety and allocation of these lamps randomly decreased the overall THD in the electricity distribution network. Yet, the THD can be decreased even more if these lamps are distributed optimally based on their harmonics' profiles. Therefore, in the future it is planned to distribute certain brands of certain types of lamps for consumers based on their locations' background harmonics at the electricity distribution network.

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