Investigation of the Effects of Compact Fluorescent Lamps in Power Distribution Systems

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***Abstract*— The desire to decrease electrical loading by using energy efficient lighting has resulted in a high level of attention to replacing conventional incandescent lamps with compact fluorescent lamps (CFL). In Iran from energy management point of view, people are encouraged by ministry of power to use CFLs. Also after elimination of subsidies, the substantial increase in electric energy price resulted in a high level of penetration of CFLs in electricity grid. CFL is a nonlinear load, therefore it injects harmonic to the network. In past, due to lower application of CFL, these harmonics were ignored, however today by the widespread application of CFLs; these small sources are combined and have high effect on power distribution networks. This paper presents the results of an investigation on the effect of widespread application of CFLs on a real power distribution system of Iran. CFL has some disadvantages that should rectify gradually. However at present great use of this component may cause adverse effects especially on the distribution network. Most of the CFL disadvantages are related to its high level of harmonics. In this paper the interference of the harmonics generated by CFLs to a real distribution network of Iran power grid will be simulated and studied. Since the CFL employed in these network have a relatively poor quality, in this study three samples of the brands which are in wider use in Iran market are selected. The characteristic current of these samples are experimentally determined. After that, CFLs are modeled with considering the attenuation effect. For harmonic mitigation, optimize capacitor placement is done and at the end, Simulation results are discussed.**

Keywords- Compact fluorescent lamps, Incandescent lamps, Harmonic, modeling, Attnution effect, Capacitor palacement.

I. INTRODUCTION

In our new world the energy consumption receives great importance because of the crises occurred in past, such as: sudden increase in oil price, population rise and decrease of irreversible energy sources. Due to these problems energy prices rise to a high level that forces electrical companies to focus on two different method for solving these crises. The first, to introduce new types of a reversible energy sources such as wind or PV. However, application of the renewable energies required high investment cost that is not feasible in Iran at present. From energy management point of view, other strategies i.e. consumer habit management is preferred. To enforce this strategy, it's widely advertised that, the application of CFL, will reduce energy consumption and consequently the related electricity bills. While there would be no reduction in the light intensity. Wide application of CFLs will reduce the peak of the demand curve and also decrease average demand. Those are no very popular due to the great energy saving for the consumer (about 4-5 times in comparison with incandescent lamps) [2, 3].

Gradually, investigations revealed that these lamps have lead to some crucial problems. Amongst, are defects such as low power factor (around 0.5 [4, 5]) and harmonics injection into the network [5]. However, blemishes would not be able to stop huge rate of trading this lamps due to their high advantages.

High level penetration of CFL has recently caused some difficulties in Iran power distribution network. In this paper, the effect of CFLs is investigated on a part of Iran's distribution network. In this way, the characteristics associated with common used CFLs of three different capacities are scrutinized by experimental results and are also modeled by a current source in parallel with a load. Analysis reveals that some network buses are more sensitive than the others. So, determination of sensitive buses is necessary for the load management procedure to be improved in power distribution system. Moreover, distribution network design incredibly depends on the penetration level of CFLs.

II. EXPERIMENTAL RESULTS AND MODELING

CFLs are developed of old fluorescent lamps whose diameters are variable in the range of 10mm-17mm in the global market. The lamp current frequency also ranges from 5 kHz to 40 kHz square wave. CFLs usually use inductive ballast in their normal operation and a starting capacitor to ignite the gas in the lamp [6]. Ballast enables electric arc to smoothly burn and filter voltage fluctuation in order to enhance the overall power quality of the network. So, to reach a more efficient effect, the ballast should place in series with the lamp. This accordingly results in poor power factor of CFLs or fluorescent. Some CFLs characteristics which are differentiated from the other kinds of lamps are described as bellow:

- Nonlinear concepts and harmonic injection into the network.
- The uncontrollability of the produced light via power electronic devices such as thyristor-controlled dimmers.

- Life span prolonging in comparison with the conventional lamps (almost 20 times).
- More resistance introduction to voltage fluctuations than old incandescent lamps.

Having noted some of the special benefits and features of CFLs, they are widely used all over the power distribution grid. Unfortunately, common used CFLs in Iran are of the low quality. Therefore, more harmonics are plausible to be injected into the network.

In the first step toward the goal, CFLs model have to be obtained. Many works and studies have been conducted in accordance with the topic and CFLs are modeled by then via some different methods. In the literature, modeled CFL characteristics are different from ones that are widely used in Iran distribution power grid. Hence, CFLs that are available in Iran markets are modeled in this paper. The goal is to determine the CFLs characteristics described in the following.

At first, 32-CFLs of a brand most used in the Iran market are selected randomly. In order to ensure that all the measurements will be done in their stable forms and to have the uncommon behavior of new lamps disappeared, they are set to be on about 100 hours. In the second step, CFLs are tested one by one and their parameters, such as current, power factor, light intensity are measured by variation of voltage. After experiment, a data set is obtained by then and CFL models are subsequently going to be found. The experimental results are depicted in Table I and the following figures. This is noticeable that, each CFL involves 32 data according to each characteristic. The data shown in Table I are their mean values. It is also noteworthy that all experimental tests are done by an Everfine HB-3A in 75% humidity and 25C^0 temperature.

TABLE I. EXPERIMENTAL RESULTS FOR DETERMINATION OF CFLS CHARACTERISTICS

	23W	55W	90W
V_{rms} (v)	229.4	229.4	229.4
I_{rms} (A)	0.187	0.251	0.417
P(w)	23.42	52.62	85.8
PF	0.546	0.915	0.898
Freqency(Hz)	50	50	50
Voltage sensivity (V/div)	326.69	326.75	331.63
Current sensivity (A/div)	0.377	0.308	0.549
Voltage peak (v)	326.7	326.8	331.6
Current peak(A)	0.753	0.615	1.098
start phase(deg.)	50.6	25.3	25.3
peak phase(deg.)	63.6	75.9	78.8
End phase(deg.)	99.8	154.7	154.7
V_{THD} (v)	1.1% (IEC)	0.9% (IEC)	1.4% (IEC)
I_{THD} (A)	138.3% (IEC)	42.7% (IEC)	47.3% (IEC)

The results indicate the high effects of CFLs on power quality; e. g. current THD is high for all the CFLs especially for the 23W lamp. CFL current wave forms, extracted from experimental results, are illustrated in Fig 1-3 for different CFL capacities. Also their harmonic contents are contrasted in Fig. 4. CFL model is also demonstrated in Fig. 5.

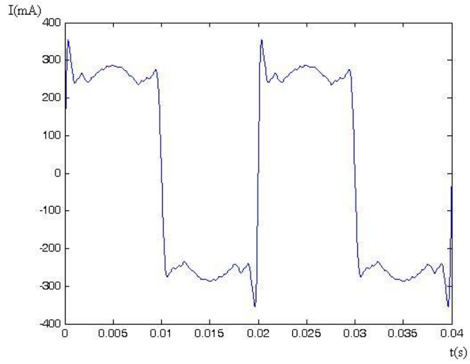


Figure 1. CFL current wave form (23 W).

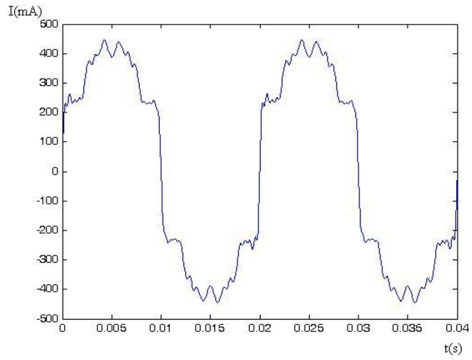


Figure 2. CFL current wave form (55 W).

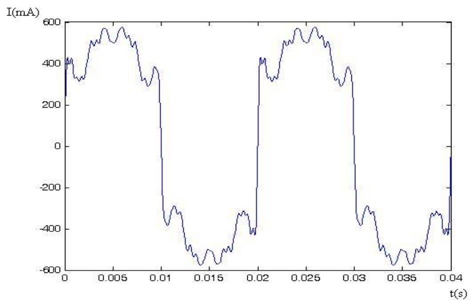


Figure 3. CFL current wave form (90 W).

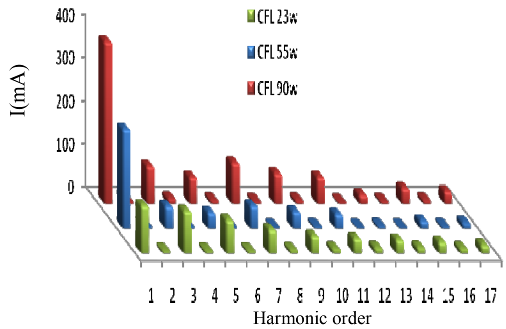


Figure 4. Experimental result of CFLs (harmonic content).

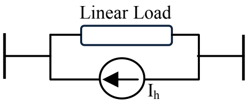


Figure 5. CFL model.

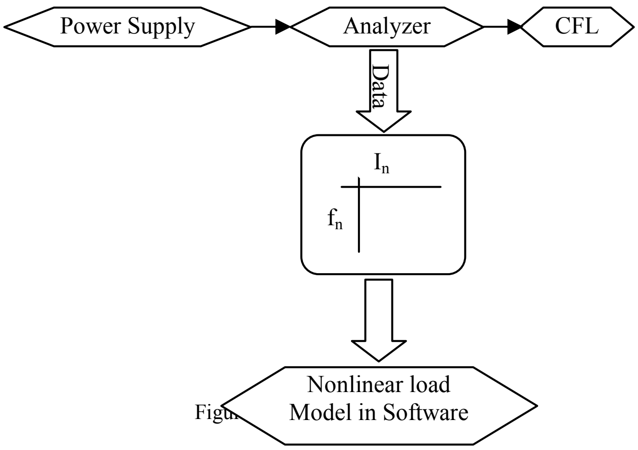
The shown model is applied to simulate several harmonic phenomena. This model includes two distinct parts. CFLs harmonic nature is described by a variable current source and their consumption is modeled by a linear load.

In addition, ideally construed, load voltages are considered to follow a sinusoidal waveform, while, practically said, distorted current results in load voltage distortion. This interaction of load voltage and current distortion is called attenuation effect which causes a great decrease in the current harmonic content. It is important to quantify the attenuation effect when assessing the collective impact of a large number of CFLs [7]. In the above described model, attenuation effect is considered through a dependent current source on the CFL voltage and subsequently, attenuation factor is obtained as [8]:

$$AF_h = \frac{I_h^N}{(N \times I_h^1)} \qquad (1)$$

where I_h^N is h^{th} current harmonic for N parallel units.

The traditional current-source model used to represent nonlinear devices ignores this effect, and leads to the harmonics overestimated. Therefore, the results can be too conservative. Fig. 6 deals with the process through which the CFL is modeled in software.



III. Case Study

Harmonic analysis is done on a part of Iran power distribution grid (see Fig. 7). Case study is consisted a 20kV grid comprised of XLPE cables. The required data in accordance with the parameters are provided in Table II. Because of simplicity, cables length is assumed to be 0.5 km. Loads details are shown in Table III.

For the harmonic investigation being accomplished, three conditions are considered as following:

A: without any harmonic sources

B: with a harmonic source in bus 8

C: with a harmonic source in bus 16

Table II. Cable Characteristics

R(Ω/km)	0.76
X(Ω/km)	0.138
C(µF/km)	0.17
B(µS/km)	53.407

In each case, several parameters such as overall network parameters, capacitor placement, loss, and current and voltage spectrum in specific places in the network are surveyed.

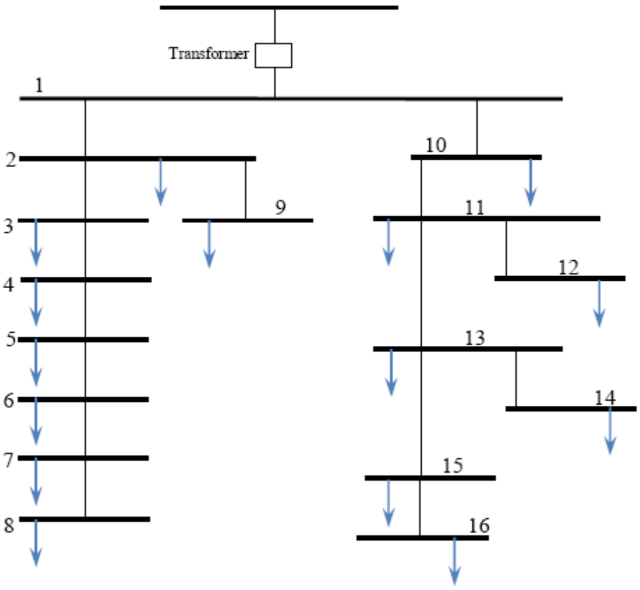


Figure 7. Studied case study: a 20kV electricity grid.

Table III. Load Details

Connected bus	P(Mw)	Q(MVar)
2	0.2	0.1
3	0.4	0.3
4	0.5	0.9
5	3	2.3
6	0.8	0.5
7	0.2	0.1
8	1	0.6
9	0.5	0.3
10	1	0.6
11	0.3	0.2
12	0.2	0.1
13	0.8	0.5
14	0.5	0.3
15	1	0.6
16	0.2	0.1

For nonlinear loads, a more practical point of view is involved in the studies. Personal computers (PC) are considered because of their wide applications in both residential and industrial places. PC is modeled just like a CFL but with different harmonic content oriented from experiment (see Table IV.).

Table IV. Harmonic Content For 32-personal Computer [9]

3^{th}	5^{th}	7^{th}	9^{th}	11^{th}	THD (%)	I_{rms}(A)
56.8	12.5	9.1	10.1	0.06	61.6	34.2

TABLE V. FINAL RESULTS OF HARMONIC ANALYSIS

	Case A	Case B			Case C		
	III	I	II	III	I	II	III
Total Active Loss(kW)	225.66	291.02	230.38	219.93	290.03	289.86	290.12
Total Reactive Loss (kVAR)	-392.59	-246.9	-380.32	-414.19	-247.23	-247.74	-246.95
Trans. Active Loss (kW)	69.85	86.68	71.26	67.52	86.66	86.59	86.70
Trans. Reactive Loss (kVAR)	488.94	606.75	498.8	472.68	606.66	606.14	606.92
Voltage in bus 1(V)	19643.8	19451.8	19625.8	19691.7	19451.8	19451.6	19452
Max THD (%)	0	0.13	0.28	0.04	0.08	0.24	0.02
Capacitor (kVAR)	1290	3150	1070	1290	3150	3150	3150
Bus of capacitor	13	5	6	13	5	5	5
Loss decreasing after capacitor place. (%)	4.78	22.2	4.46	4.36	22.3	22.3	22.3

CFL model is discussed in the previous section. To have an improved investigation, the combination of the CFLs, PC and incandescent lamp in three states are considered.

I. 100 CFL + 200 incandescent lamp

II. 300 CFL

III. 300 incandescent

Harmonic analysis is done in different cases, as mentioned before (case A, B and C), and in different combination of loads (I, II, and III). The obtained results are shown in Table V. Results reveal several important issues about distribution system. Comparing the results associated with case A and case B demonstrates that the bus 8 is more sensitive than bus 16 in different combination of loads. In other words, in harmonic analysis, there are sensitive buses to nonlinear load that need to be found.

When all lamps are incandescent (III), the loss value associated with the lines is less than the case in which nonlinear loads are added (I and II). It is just due to the harmonics and lower power factor of CFLs.

THD is increased by the load nonlinearity augmentation (between III and II or I in each case). The obtained was vividly predictable.

A very important result is obtained by comparing THD related with the states I and II. As can be seen in Table V, THD in case I is much smaller that of condition II for each case. Combination of linear and nonlinear loads and the less portion of nonlinear load are the main reasons.

Transformer loss is a function of two current parameters i.e. magnitude and frequency. CFLs have lower current but more harmonics and frequencies. Whilst, incandescent lamps have more current and lower frequency values. Interaction between the two parameters determines the loss rate of the trnasfomres.

To have the harmonics mitigated, capacitor placement is done. Another important point that is obvious from Table V is that different optimized places as the capacitor placement candidates which are dependent on the variation in number of CFLs in each case.

IV. CONCLUSION

Subsidies allocated to CFLs in Iran have lead to their increasing utilization and accordingly harmonic flowing escalation in power distribution networks. In this paper, the effects of CFLs in Iran's power network were studied. To have this goal thoroughly accomplished, CFLs were modeled by a narrow consideration into the attenuation effect. The studies were implemented on a practical distribution network in Iran's power grid. Thereby, simulation results associated with harmonic analysis indicated that there are some sensitive buses in which feeder parameters are more sensitive to load variation. Practically researched, the loads were considered to be a combination of linear and nonlinear loads. Capacitor placement was done afterward. It was indicated that this procedure is directly dependent on the number of CFLs. Moreover, the results demonstrated that the interaction of CFLs and incandescent lamps determines the transformer loss value and THD variation.

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