ANALYSIS OF HARMONIC DISTORTION IN DISTRIBUTION NETWORKS INJECTED BY NONLINEAR LOADS

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ABSTRACT

This paper attempts to show the impacts of rapidly increasing number of nonlinear loads on low voltage feeders. The first part gives a brief overview of nonlinear loads in distribution feeders such as energy saving lamps, switch-mode power supplies (SMPS) in Television, computers, etc. A simple statistical survey is used to categorize these devices. Moreover, field measurements in some distribution substations are done by power quality analyser. Simulations are also made to overcome these drawbacks and a set of methodologies for harmonic distortion modification is presented.

INTRODUCTION

One of the most significant current discussions in electric energy distribution systems is power quality. Meanwhile, the issue of harmonics has been a controversial and much disputed subject within the field of power quality. Harmonic current emissions originate from all types of non-linear loads. Non-linear loads include broadly arc furnaces, fluorescent lighting and power electronic loads. Power electronic loads due to the advantages of increased efficiency as well as controllability are the most considerable harmonic sources [1]. Some of the more common power electronic loads include:

- Switch mode power supplies in computers, televisions, etc.
- Rectifiers in dc motor drives, regulated power supplies, battery chargers.
- Inverters in adjustable speed drives.

In recent years there has been a considerable increase in the number of nonlinear loads connected to the electrical networks. From the viewpoint of the electric utility industry, it is important to understand the impacts of such devices on distribution network.

This can be illustrated briefly by Compact Fluorescent Lamps (CFLs). CFLs can provide consequential energy savings over incandescent lighting. As a result, CFLs are being promoted by electricity supply utilities as a part of energy conservation programs. On the other hand, they can increase the level of disturbances that might affect customer equipments [1], [2]. The presence of harmonics in power system can lead to various problems such as equipment overheating, reducing the power factor [3], failure or malfunction of electrical equipments and protective relays, interference with communication circuits, and in some cases, circuit resonance to cause electric apparatus dielectric failure and other types of severe damage [1].

A survey was carried out in the city of Mashhad to classify nonlinear devices. Sixteen items such as CFL, television, personal computer, refrigerator, air conditioner, on the questionnaire measured the extent to which nonlinear loads are commonly used. Over 500 customers (residential and commercial) were surveyed. Apart from the CFLs which were 1977 in households and 1469 in commercials, the other results are shown in figure 1.

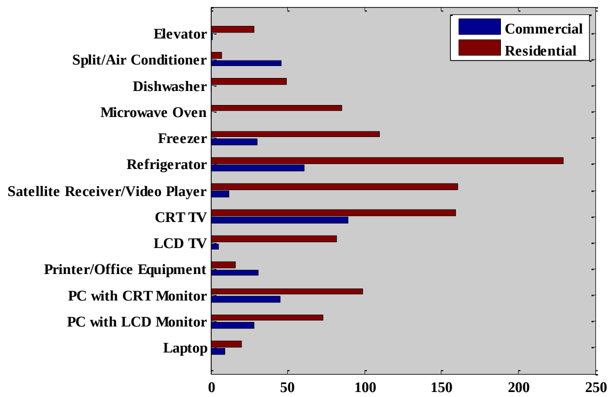


Fig. 1. Statistical survey results.

It can be clearly seen that CFL, refrigerator and audio/video devices are the most used nonlinear loads. The next step is to investigate harmonic distortion and power factor of such devices.

Total Harmonic Distortion (THD) is a measure of effective value of the harmonic components of a distorted waveform. This index which can be calculated for either voltage or current is defined below [4]:

$$THD = \frac{\sqrt{\sum_{h=2}^{h_{\max}} M_h^2}}{M_1} \qquad (1)$$

There is a large volume of published studies representing the role of nonlinear devices in distribution networks. The study of the effects of fluorescent lighting was carried out by Pileggi [5], Mielczarski [6] and Atkinson-Hope [7]. Chang provides the common models of power electronic converters either in time-domain or frequency-domain [8]. Preliminary works on harmonic investigation were undertaken in [9, 10]. However, much of the research up to now has been descriptive in nature.

In order to deliver electric power to the consumers appropriately, various standards were published by national or regional authorities [11], [12]. Mitigation methods are also required to suppress the levels of harmonic emissions resulting from the aforementioned power electronic equipment.

HARMONIC MEASUREMENTS

Measurement of harmonics requires a power quality analyser. In the laboratory of Mashhad Electric Energy Distribution Company (MEEDC), custom nonlinear devices were analysed (Fig. 2). In addition, field measurements in some distribution substations were done by power quality analyser as shown in figure 3. Data were gathered from multiple sources at various time points. Table 1 lists the substations along with their transformer information as well as the measurement results.

Table 1. List of substation analysed and results.

Substation	Transformer ratio	S_r (kVA)	THD_V (%)	THD_I (%)
Site 1	20 / 0.4 kV	630	3.7	10.4
Site 2	20 / 0.4 kV	1600	4.5	18.3
Site 3	20 / 0.4 kV	315	7.6	35.8
Site 4	20 / 0.4 kV	630	2.8	26.1
Site 5	20 / 0.4 kV	1250	2.4	5.2

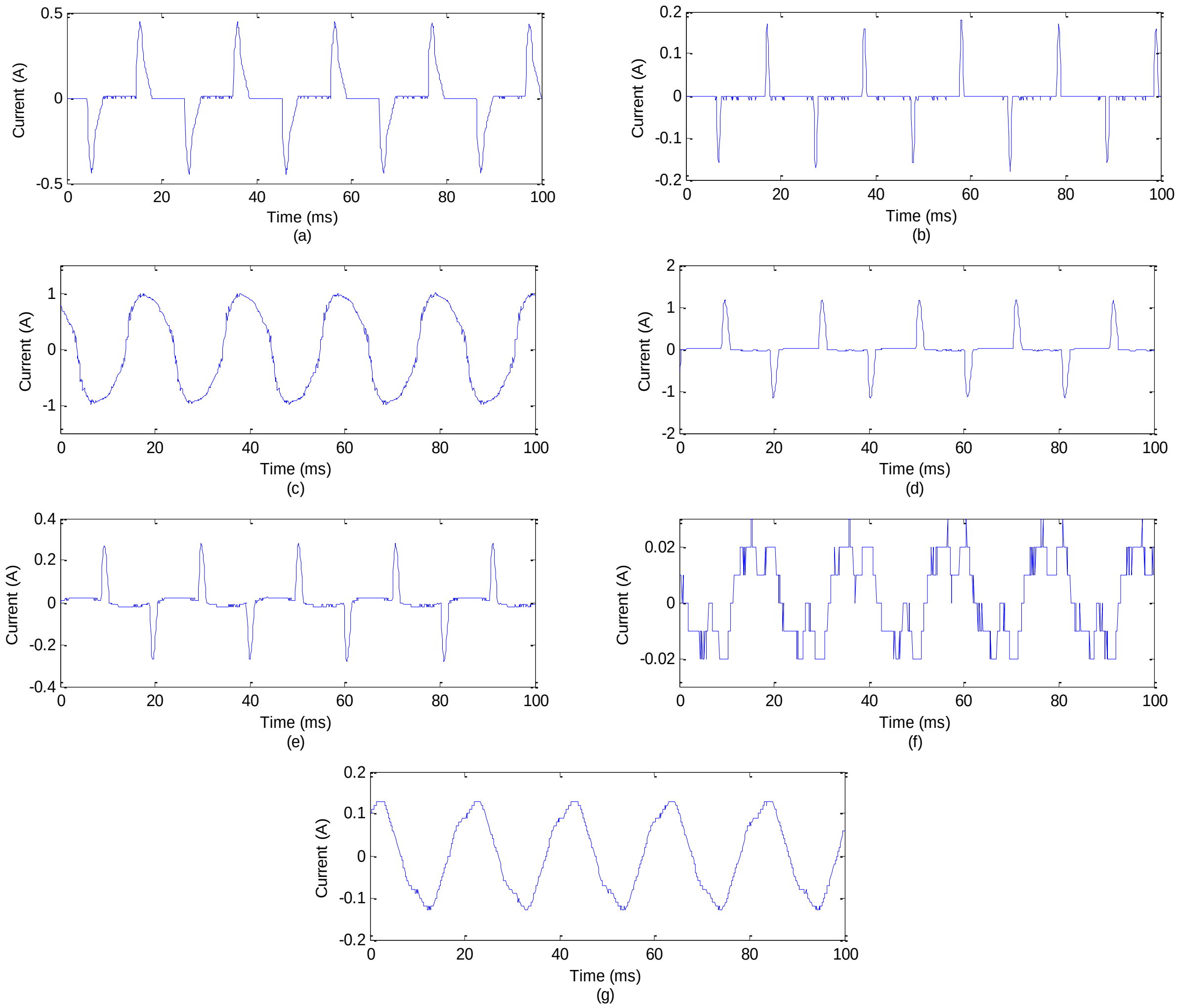


Fig. 2. Current waveforms of customer equipments,
(a) CFL (b) PC (c) LCD TV (d) CRT TV (e) Satellite receiver (f) Air conditioner (g) Refrigerator

Figure 3 shows the distorted current waveform of a commercial site. In figure 4, for a residential site the recorded current THD and voltage THD in four days period are presented. The purpose of this measurement is to record any time-varying changes in voltage and current THD. It is clear that there is low harmonic distortion in the off peak hours. The voltage THD is less than 2.5 percent while the current THD exceeds 5.5 percent once.

Table 2. THD_I and power factor of electric devices.

	CurrentTHD (%)	Power Factor
CFL	102	0.62
PC	127	0.63
LCD TV	16	0.96
CRT TV	150	0.52
Satellite Receiver	142	0.50
Air conditioner	18	0.95
Refrigerator	15	0.96

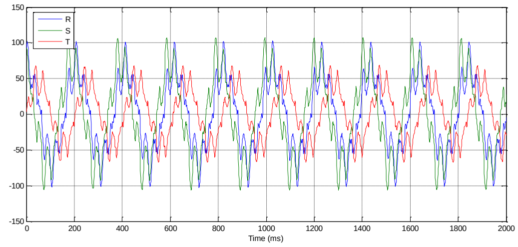


Fig. 3. Distorted load current of a commercial site.

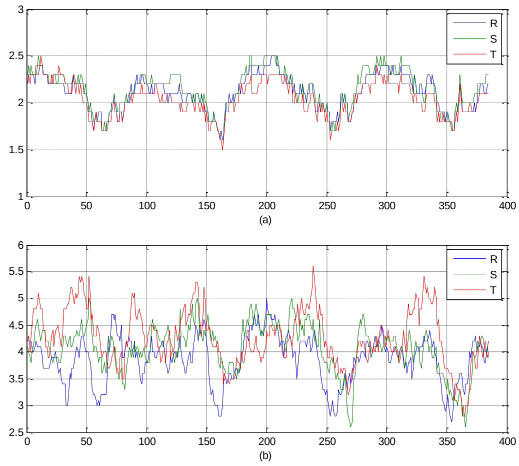
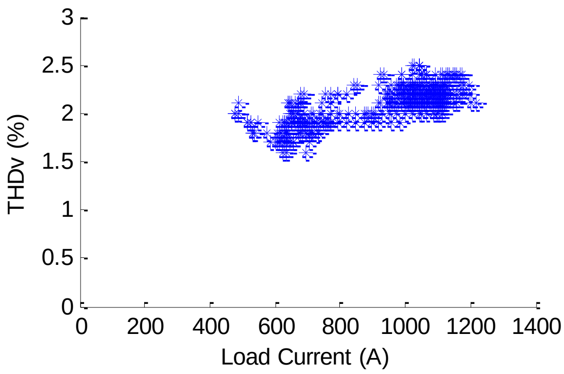


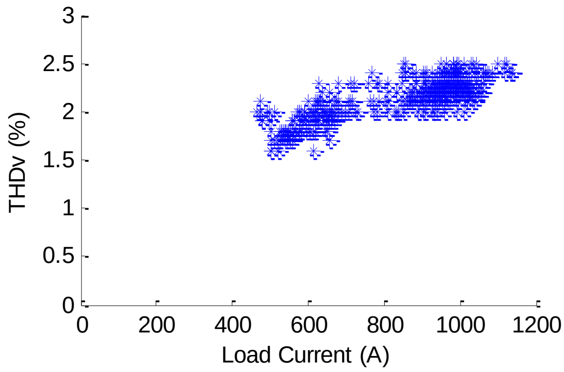
Fig. 4. Total harmonic distortion in a period of four days for a residential site, (a) THD_V (b) THD_I

RESULTS AND DISCUSSIONS

Having considered table 1, it can be obviously seen that the voltage THD (THD_v) is less than 5 percent. The noticeable exception is site 3, where a much larger distortion is recorded in both voltage and current. Site 3 is feeding four industrial consumers. There is generally a high level of distortion in the studied distribution feeders. Furthermore, in figure 5 a scatter plot is used for the investigation of correlations between voltage THD and load current [13], [14].



(a)



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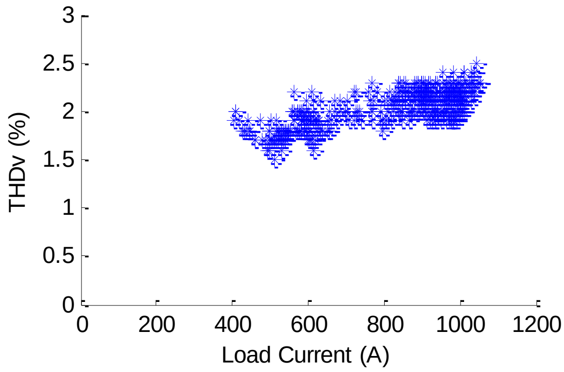

(c)

Fig. 5. (a-c) Relationship between voltage THD and load current for three measured sites.

According to the results shown in figure 5, as the load current increases, the voltage THD increases as well. This can be explained by correlation coefficient [14].

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 (y-\bar{y})^2}} \quad (2)$$

Correlation coefficients are also computed for three sites to be 0.74, 0.75 and 0.75 respectively.

PROPOSED SOLUTIONS

Harmonic pollution in distribution networks is generally caused by nonlinear loads. Corrective strategies fall broadly into three groups; passive filter, isolation and harmonic reduction transformers and active solutions. Each approach has advantages and disadvantages, so there is no single best solution. A planning approach to distribution system harmonic filtering could be proposed in five steps [15]:

I. Perform preliminary system analysis.
II. Develop and conduct a measurement program.
III. Determine harmonic source models.
IV. Determine filter location and tuning based on system characteristics.
V. Conduct switching studies, determine filter performance requirements.

As a result, case studies data are used to develop a harmonic filter using MATLAB/Simulink as represented in the figures 6 and 7.

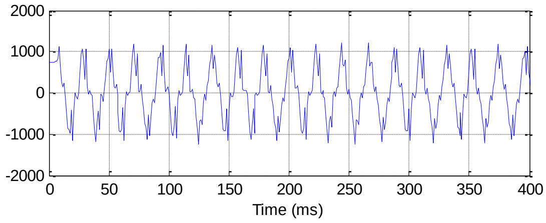

Fig. 6. Current waveform without filtering

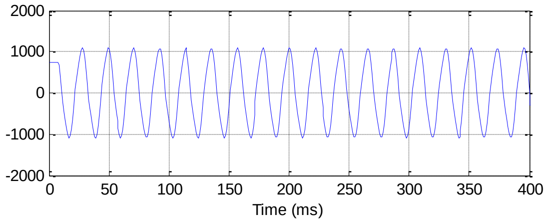

Fig. 7. Current waveform after filtering

CONCLUSION

This paper has given an account of and the reasons for the widespread use of nonlinear loads in customer utilities. Harmonics problems are now common in not only industrial applications but in commercial buildings as well. This is due primarily to new electronic devices. An analysis of the proposed problem was presented based on field measurements. Measurements were taken to characterize the nonlinear loads and overall loads characteristics.

In general, current harmonics cannot be eliminated; they are generated by the loads. They must therefore be confined to an area as close to the polluting loads as possible in order to prevent them from reaching the overall network. In the current study, comparing voltage THD with load current showed that there is a correlation about 0.75.

The present study, however, makes several noteworthy contributions to deliver electric power to the consumers appropriately. A number of harmonic mitigation techniques were listed to be used. As the quantity of installed equipment rises, it is likely that harmonic pollution will continue to increase. Consequently, strong standards and mitigation methods are recommended.

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