HARMONIC PENETRATION ASSESSMENT IN RESIDENTIAL AREAS

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ABSTRACT

Although the present distribution systems have achieved a high level of development, harmonics still constitute a significant challenge to such systems. With this development, electronic devices and system are considered the major sources of harmonics. Harmonics are studied and analyzed on low-tension networks operated by a local distribution company in Jordan. Total Harmonic Distortion (THD), voltage, current and other values are measured at transformer side using Power Quality Analyzer (PQA). The examined transformers feed various classes of residential customers within this area. All records were analyzed using a special program called Top View. Then, the obtained values are classified into groups according to the type of residential customers. The relationship between THD and transformers loading is studied. The trend of change, shown by THD, is studied to evaluate the increase and decrease modes of such factor with time at different loading levels. Finally, the harmonics spectrum is investigated for the transformers in residential areas. Once the analysis is completed, the areas with high level of harmonics are shown on a map with transformer locations. In this paper, the potential of solutions is studied for future planning to reduce harmonics effect. The problems are identified and optimum solutions are suggested..

INTRODUCTION

The effect of harmonics on power systems has been known for several decades. The issue has, however, recently become significant due to the increased concern to improve power factor to avoid penalty, and due to the dramatic addition of power electronic equipments in modern industry seeking higher system reliability and efficiency.

The distribution utility's increased use of power factor correction capacitor, and large-scale addition of non-linear devices have resulted in current and voltage harmonics. The effects of these harmonics are the failure of electrical/electronic components, overheating of neutral wires, transformer heating, losses in power generation and transmission and interference with protection, control and communication networks.

The impact of harmonics on distribution system was discussed by several researchers [1-3]. Despite, the value of previous works their results were based either on laboratory testing or mathematical models built for the analysis purposes. Even the harmonic measurements taken were limited in number and duration. However, in the present work the amount of data and the number of transformers considered for testing were high enough to draw various conclusions about the impact of harmonics on distribution system. Moreover, different classes of distribution transformers ratings were employed for harmonic measurement. In the present work, it was tried to map the harmonic penetration levels on the geographical location of studied transformers. Despite the clarity of the aim, the execution of the task was not easy.

OVERVIEW OF THE EXAMINED SYSTEM

The examined distribution utility is responsible for MV and LV supply of four provinces with a total area of 23000km^2 having a total consumption of more than 400 MW. Irbid District Electricity Company (IDECO) provides electricity for various types of loads including industrial, commercial, agricultural and residential. The annual increase in demand exceeds 10% in this area due to the increase of population and industry growth.

The major focus of this study was on transformers, feeding various loads inside the main city in this area (Irbid City). For this study, all 11kV transformers with various ratings were selected. The study area was demonstrated by AutoCad drawing. The transformers in this area feed residential loads with various population intensities.

The number of examined transformer was 191 (more than 56% of the total transformers in the area) and the ratings were 1500 kVA, 1000 kVA and 630 kVA as shown in Table 1.

Table 1:Examined residential load transformers

Transformer Ratings	Number of Transformers
1500 kVA	10
1000 kVA	74
630 kVA	89
400 kVA	17
250 kVA	1
TOTAL NUMBER	**191**
TOTAL POWER	**152120 kVA**

Data collection and treatment

To study the harmonic distribution over the electric network, THD values related to voltage and current for individual transformers were considered. Initially, the maximum values of THD of each voltage were taken and determined by six categories shown by the AutoCad plan for transformers within the area under study. Transformers were given the same colors as their respective categories so as to clearly demonstrate harmonics spread out, taking in mind that the allowable value is 5% for THD depending on IEEE-519 recommendation [4]. Table 2 illustrates these categories.

Table 2: Categories of obtained THD

Category No	Percentage of THD value, %
1	>50
2	40- 50
3	30- 39
4	20-29
5	10-19
6	1-9

Results

The study of the AutoCad map reveals the quantity of transformers for which THD values exceed the IEEE standard value (5%) as follows

1- 97 % of transformers within the area under study exceed the IEEE standard value of THD (5 %).
2- 8.3 % of transformers exceeds 50 %
3- 3 % of transformers is less than 9 %.
4- 65.5 % of transformers lie between 10%-19%.

Table 3 shows maximum, minimum and average values of THD of residential area transformers.

Table 3 THD Values in the Residential Transformers

Transformer Class	THD Min	THD Max	THD Average
400 kVA	12	85	22.5
630 kVA	9	54	20.84
1000 kVA	9	53	19.53
1500 kVA	10	18	13.1

The analysis of the obtained results has revealed several facts. Firstly, the THD values were higher than the acceptable limits (5%). This indicates a real harmonics problem. Secondly, the maximum value of THD was 85%, measured for one of 400kVA transformers, whereas the least one was 9%, which was obtained for 630kVA and 1MVA transformers. Thirdly, the average values of THD were around 20%. Finally, all THD values whether upper, lower or average for 1000 kVA and 630 kVA transformers were almost similar.

The relationship between THD and loading ratio was also considered in this study. It was found that the increase in loading ratio leads to less THD, provided that no other factors are considered. Figure 1 illustrates such relationship for 400kVA residential transformer, where a loading ratio of 5 % corresponds to a THD of 85%, but a loading ratio of 85% produces a THD of 12 %. Figure 2 shows another example of relationship between transformer loading and THD level. This example is for 1000kVA residential transformer. In this case, it was noticed that at loading ratio of 2%, the THD is 53%, which exceeds the acceptable limit by ten folds. However, when the loading ratio reached 70%, the THD became 10 %.

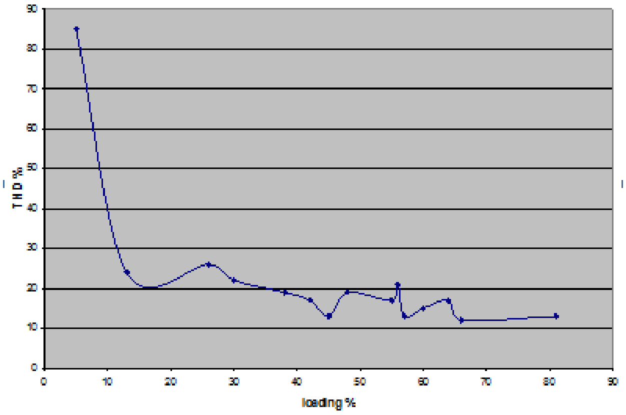


Figure 1: Relationship between THD and loading for 400 kVA residential transformers

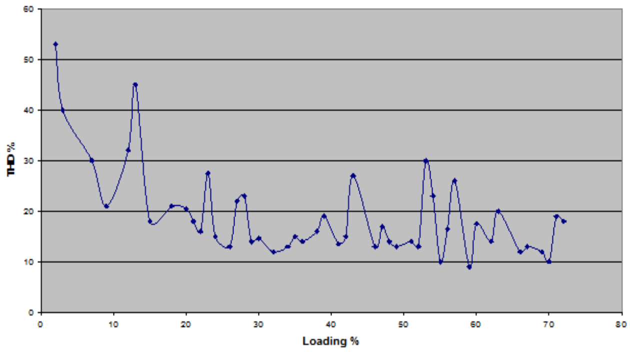
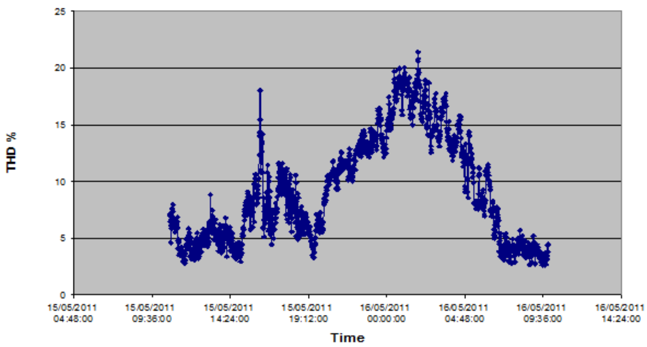


Figure 2: Relationship between THD and loading for 1000 kVA residential transformers

The next step was to study the time dependence of THD variation within 24 hours. To achieve this goal, the harmonic analyzer was continuously connected to the examined residential transformers. A relationship between current THD_i and recorded time was established. A representative sample of residential load was selected for such relation to be plotted.

For a sample of 400kVA transformers, the loading ratio was 77 % and the THD_v was 21%. Figure 3demonstrates the relationship between THD_i and time. It shows that a harmonic value at 09:36 am was minimum (5%), then the value increased gradually until it reached the peak value of 20 % at 01.00 am in the next day. The harmonics value, thus, starts decline reaching the lowest value of 5% at 07:00



am.

Figure 3 THD in 400 kVA residential transformer for 24 hours (May 15, 2011)

The second example was for 630kVA transformer but with loading ratio of 31% and THD_v of 52% Figure 4 shows the relationship between THD_i and time. Initially, the THD increased gradually starting on 04:00 pm until 07:12 pm where the value reached 280%. Then, the THD was greatly increased up to 360% on 08:30 pm then a gradual decrease was noticed reaching 50% on 07:00 am of the next day.

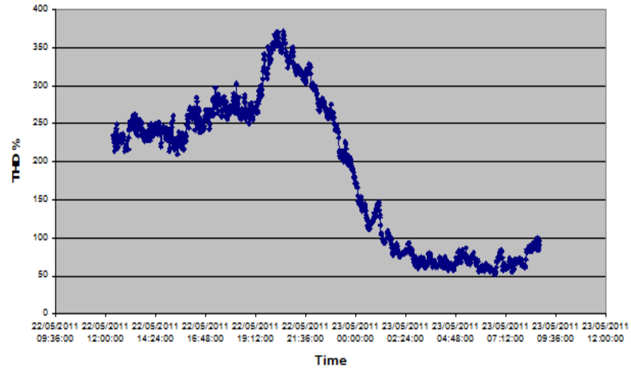
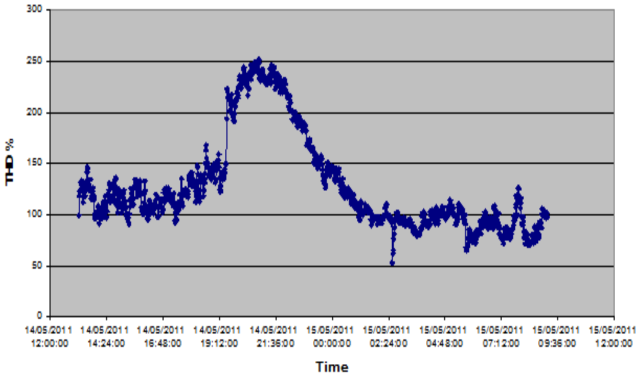


Figure 4: THD in 630 kVA residential transformer for 24 hours (22/23 May 2011)

The third example was for 1000kVA transformer with a loading ratio of 65 % and THD_v of 40 %. Figure 5 shows the relationship between THD_i and time. As discussed earlier, THD increases during sunset period at 07:00 pm when there is an intensive use of lighting units, mainly florescent lamps (source of harmonics) which in turn increase THD throughout the network. THD values start to decline gradually after midnight, when there is less use of light. THD values will go high from 07:00 pm until 12.00



midnight for only five hours.

Figure 5: THD in 1000 kVA residential transformer for 24 hours (14/15 May 2011)

The final part in this work was the study of harmonics spectrum of a sample of residential transformers having different capacities. The measurements were taken every minute for 24 hours and then were analyzed using Excel Sheets. Figures 6 and 7 illustrate such spectra for 630kVA, and 1500kVA, respectively. In both figures a comparison was made between the maximum values of obtained individual harmonics and the standard values based on IEEE-519.

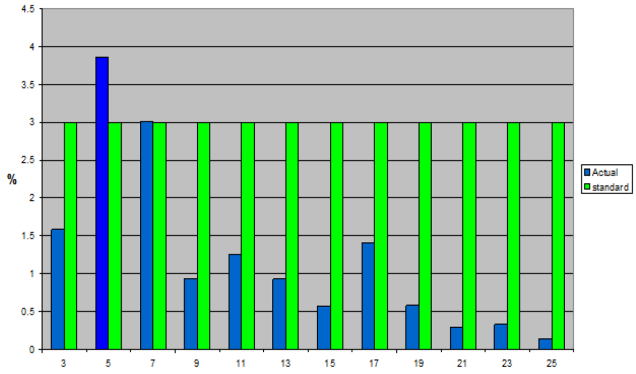


Figure 6: Harmonics spectrum in 630kVA transformer

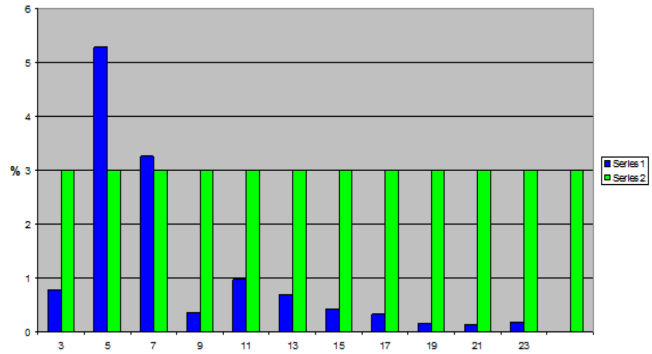


Figure 7: Harmonics spectrum in 1500kVA transformer

DISCUSSION

In non-industrial country, like Jordan, the dominant load is a residential one with a clear evening peak starting after sunset time. On the other hand, the widely distributed non-linear loads (mainly computers) have a significant effect on harmonics penetration. The harmonic voltages affect the core and they are responsible for iron losses due to hysteresis. The magnetizing current required to establish the AC magnetic field in the core, and hence the core losses associated with maintaining the magnetic field, are independent of the load connected to the secondary winding. The magnetic field flux density in the core is always constant and independent of the load current. Thus the core loss is the same for all levels of transformer loading, whether there is no load, half load or full load. On the other hand, any higher harmonic components in the exciting voltage will cause increased core losses. Load loss is also dependent on the frequency content of the load current. When higher frequency harmonics are present in the load current due to non-linear loads, for example, eddy currents are generated in the windings and these cause higher levels of loss. The higher the harmonic frequency content, the greater the load loss.Therefore, at lower loads such losses make a higher percentage of the total loading which is associated with higher THD.

The hourly change of THD for different classes of transformers within 24 hours gave a time map THD distribution. It discloses the times when the THD will be minimum, maximum and average. Although this distribution depends on the type of load and the group of population living where the measurements where taken, it still shows a useful information about THD distribution. The slight differences shown are attributed to the type of population fed from such transformers, whether they live in the city centre or superb.

Figures 6 and 7 demonstrate harmonic spectrum of two 630kVA and 1500kVA respectively. In both cases the highest harmonic was the fifth followed by the seventh. The analysis of examined load expects a large number of 6 pulse converters existing in the examined areas.

CONCLUSIONS

By reviewing the results of the above study a number of conclusions can be drawn. Firstly, all examined transformers have shown a THD value exceeding the acceptable limit specified in IEEE-519. More specifically, about 65% of transformers had THD values between 10% and 19%. Secondly, the transformers' loading was a significant indicator of harmonic presence. The low level of loading resulted in higher THD values. Thirdly, the duration of influence of high THD in residential load is relatively short. Finally, the main harmonics orders recorded in the study area are the fifth and seventh. The fifth harmonic was the highest value and most often exceeded the allowable limit of 3%.

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