A CASE STUDY OF POWER ESTIMATIONS OF DISTRIBUTION TRANSFORMERS IN RESIDENTIAL AREAS AND EFFECTS OF TRANSFORMER LOADS TO POWER QUALITY

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ABSTRACT

This paper investigates the harmonic amplification problems in residential and commercial plants. Estimating the composite harmonic current generated by the operation of multiple linear and non-linear loads connected to single power distribution transformer. A field survey was carried, where approximately 4000 consumers plus 14 distribution transformers daily load profiles measured. Short-circuit calculation was carried out to PCC (Common Coupling Point) point. Using ABB SIMPOW simulation program carried out these calculations. These results are compared to standard on IEEE 519-1992 for Turkish distribution systems.

I. INTRODUCTION

It is important to know the residential and commercial customers' load curve and power quality level for the distribution network planning and mainly for the choice of the distribution transformers rating. Although these transformers have a low unit cost, they appear in large number, and a criterion of choose with a lower margin is desirable.

And also power quality (PQ) has become a major concern to both electric utilities and consumers. The effects of the lack of PQ can be strongly felt in some countries, where billions of dollars have been wasted every year. This occurs mainly because most industries are in an endless race to upgrade their plants. In many cases, industries have their productivity indices, foreseen by projects, not achieved due mainly to PQ problems. Generally, this is caused by incompatibility between the power supply system and the operational requirements of this new generation of equipment.

To characterize the residential customer load curves, a field survey is necessary. It may only include questionnaires that identify the type of appliance and the timing their use, or even measurements with electronic equipments that record the values for periods as long as 7 or 15 days, for example. This measurement has been continued for six months.

This work is carried out a housing estate where is located in Kocaeli city. To take measurement, a protocol is made by local electric distribution system administrators. There are 4000 dwelling, 2 primary school, 1 high school, 3 commercial building, 2 social building and 1 mosque. This work is supported by the University of Kocaeli's research fund. The study is became widespread on Kocaeli city's all consumers.

II. POWER QUALITY STANDARTS

The power quality industry recognizes that power quality standards are critical to the viability of the industry. Therefore stakeholders in the power quality industry have developed several power quality standards in recent years [1,2].

The harmonic voltage distortion on the system will be function of the total injected current and the system impedance at each of harmonic frequencies. The total injected harmonic current will depend on the number of individual consumers injecting harmonic currents and size of each customer. Therefore, a reasonable approach to limiting the harmonic currents for individual customers is to make the limits dependent upon the customer size [3,4].

This part describes the current distortion limits that applied to individual consumers of electrical energy. This recommendation based on IEEE Std. 519-1992 and focuses on the PCC with the consumer utility interface [5]. Recommended harmonic distortions are characterized by the following:

- Individual and total voltage distortion
- Individual and total current distortion

IEEE 519-1992 defines harmonic limits on the utility side of the meter as the total harmonic distortion (THD) and the end user side of the meter as total distortion demand (TDD). These standards set the voltage distortion limits or THD that the utility can supply to the end user at the point of common coupling. Table 1, from IEEE 519-1992 sets limits on the utility system at various voltages. The same IEEE standard sets limits on the harmonic current that the end user can inject into the utility's system at the point of common coupling. Table 2 provides the TDD limits in IEEE 519-1992 [5].

Table 1. Voltage distortion limits

Bus Voltage at (PCC)	Individual voltage distortion (%)	Total voltage distortion (%)
69 kV and below	3	5
69-161 kV	1.5	2.5
161 kV and above	1.0	1.5

Table 2. Current distortion limits

I_{sc}/I_L	h<11	11<h<17	17<h<23	23<h<25	35<h	TDD
<20	4	2	1.5	0.6	0.3	5
20<50	7	3.5	2.5	1	0.5	8
50<100	10	4.5	4	1.5	0.7	12
100<1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20

I_{sc}: Maximum short-circuit current at PCC
I_L: Maximum demand load current at PCC
h: Harmonic order (1, 2, 3, 4 etc.)
I_h: Load current at the harmonic order

IEEE 519 sets limits on total harmonic distortion (THD) for the utility side of the meter and total demand distortion (TDD) for the end user side of the meter. This means the utility is responsible for the voltage distortion at PCC between the utility and the end user. Total harmonic distortion is a way to evaluate the voltage distortion effects of injecting harmonic currents into the utility's system. The formulas for calculating THD and TDD are as follows:

Total Harmonic Distortion (THD): The ratio of the root-mean square of the harmonic content to the root mean square value of the fundamental quantity, expressed as a percent of the fundamental [6].

$$\%THD = \frac{\sqrt{\sum_{h=2}^{50} I_h^2}}{I_1} x100 \quad (1)$$

Total Demand Distortion (TDD): The total root sum square harmonic current distortion, in percent of the maximum demand load current (15 or 30 min. demand)[6].

$$\%TDD = \frac{\sqrt{\sum_{h=2}^{50} I_h^2}}{I_L} x100 \quad (2)$$

III. FIELD SURVEYS FOR POWER QUALITY

Distribution system primer side voltage is 34.5 kV and secondary side voltage is 0.4 kV. Distribution system's has 14-distribution transformer and worked open ring. The ratings of 12-distribution transformer are 1000 kVA, and the other two is rated 630 kVA. Medium voltage distribution system cable section is 4(1x95/16)mm^2 2xYS underground cable. Corresponding single line diagram of the distribution system that is surveyed is represented in Fig. 1.

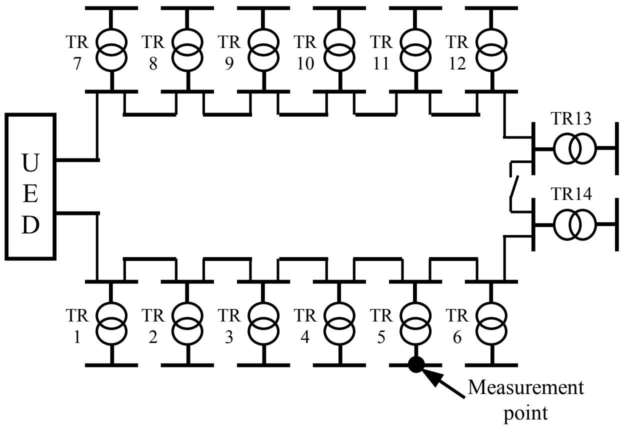

Figure 1. Single line diagram of distribution system

UED stands for 154/34.5 kV substation centre. UED's short circuit power is 500 MVA. The parameters of transformers and distribution lines are shown in Table 3 and 4, respectively. Distribution line parameters are given as effective alternative current resistance/unit length (Ω/km), inductance/unit length per conductor (mH/km)[7].

Table 3. Transformer parameters

Transformers	Power (kVA)	$\%u_k$	Connection
From T1 to T12	1000	6	D-Yg
T13-T14	630	4,5	D-Yg

Table 4. Distribution line parameters

Lines	R	X	L(m)	Lines	R	X	L(m)
UED-TR1	0.423	0.678	350	UED-TR7	0.423	0.678	320
TR1-TR2	0.423	0.678	395	TR7-TR8	0.423	0.678	260
TR2-TR3	0.423	0.678	425	TR9-TR10	0.423	0.678	280
TR3-TR4	0.423	0.678	340	TR10-TR11	0.423	0.678	450
TR4-TR5	0.423	0.678	925	TR11-TR12	0.423	0.678	300
TR6-TR14	0.423	0.678	425	TR12-TR13	0.423	0.678	420

Energy analyzers are installed to measure 7 day the load variations of the transformers. If the memories of analyzers were large enough, the measurement period would have been extended. The peak power determined for each power transformer of the sample is the average power within 15-minute intervals. Sample measurement result for the distribution transformer 5 is represented at Fig. 2.

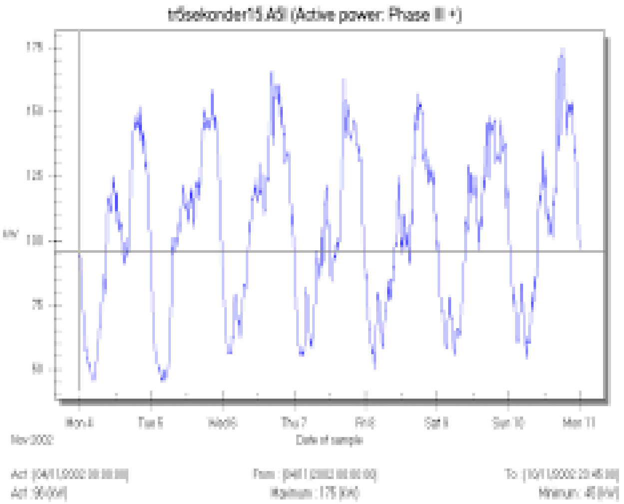

Figure 2. TR5 secondary load variations

Distorted current and voltage values are measured as waveforms and bar graphics. These values are shown at Fig. 3,4,5, respectively. Fig. 3 shows that due to strong UED system voltage waveform is pure sinusoidal, while current waveform is not sinusoidal.

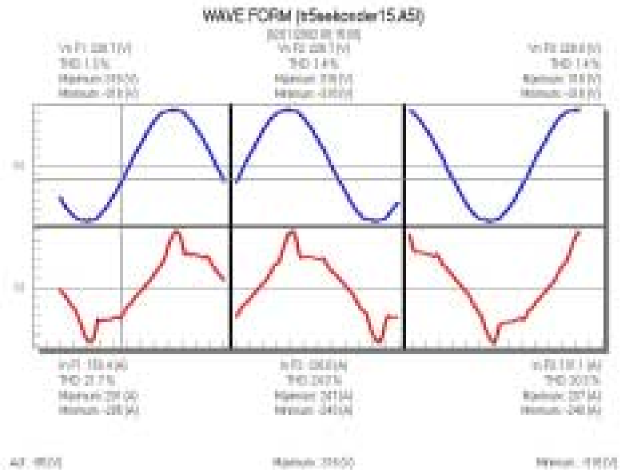

Figure 3. Defined time TR5 secondary side voltage and current waveform

Per phase THD and peak values of current, voltage are represented in Fig. 3. It illustrates that defined time current and voltage distortion in one week measurment. THD values recorded in a week are shown in Fig. 4.

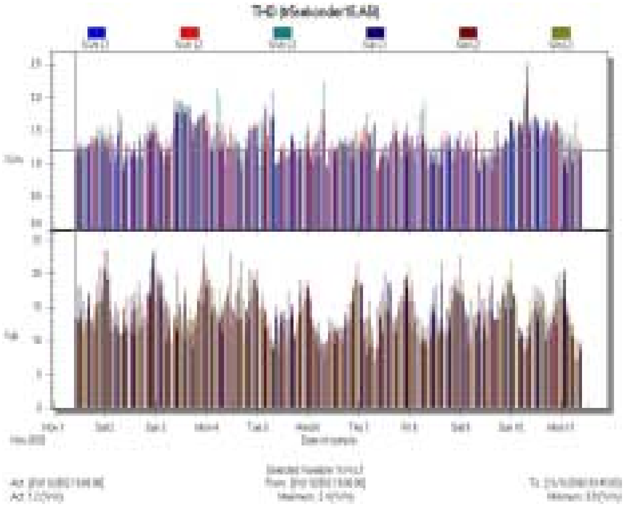

Figure 4. TR5's weekly THD variations

Current harmonic distortions are changed from 10% to 25%. Deviations are represented at Fig. 4. Current, voltage and THD measurements are taken from secondary side of transformers. Due to the connection type of transformers, triple harmonics are absent on primary side. But the other harmonics, for example 7th, 11th, 13th etc., are added to the system. In this way, total harmonic distortion level is may be much higher.

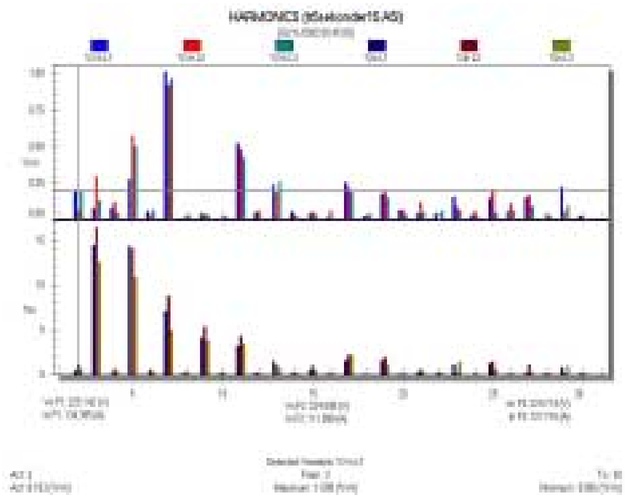

Figure 5. Defined time TR5 secondary side voltage and current harmonic spectrum

Current and voltage waveform spectrums are represented in Fig. 5. This figure is used to find TDD levels. The highest voltage distortion level is observed at the 7th harmonic. The voltage distortion is mainly due to the 7th harmonic. However, current distortion is highest 3rd harmonic. Analyzer spectrum capability is extended up to 51st harmonic. The harmonics of 31st and higher are less in value therefore; they are not considered in calculations.

IV. PCC POINT SHORT CIRCUIT CALCULATION

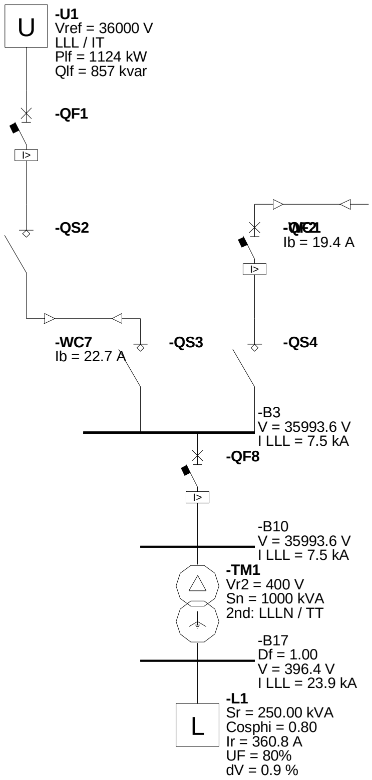

Figure 6. Short circuit calculation single line diagram

The most common type of fault by far is the single line to ground (SLG) fault, followed in frequency of occurrence by line-to-line (LL) faults, and balanced three phase (3ϕ) faults. Usually, the biggest short circuit is found as a three-phase short circuit in the systems [7].

Calculations are based on the single line of distribution system as shown at Fig. 1 for TR 5. Between TR5 transformer and medium voltage connection point is represented as a single line segment. All short circuit calculations are made using ABB Simpow power analyzer program. Calculation results are also given in Fig. 6.

Calculation results from ABB Simpow program [8] are shown in Table 5. The highest short circuit value is calculated as three phase balanced fault. The lowest short circuit is calculated from the line-to-line fault for the PCC point.

Table 5. TR5 secondary side fault values

Fault Types	**I_{sc} (kA)**	**I_b (kA)**
3ϕ	23.902	51.72
SLG	23.821	50.60
LL	20.686	44.79

V. EVALUATION OF THE RESULTS

The highest short circuit current for PCC is found 23.902 kA. The results of the measurements taken at PCC showed that the load current is to be 401A. Increasing the demand load current percent of 25%, new maximum demand load current is to set 500 A.

$$\frac{I_{sc}}{I_L} = \frac{23902}{500} = 47.8$$

I_{sc}/I_L value is calculated 47,8.

From Table 2, division the highest short circuit value to load current could be among 20 to 50. In this case total demand distortion is lower than 8%. But distribution system measurement results are approximately 20%. The calculation procedure for the case h<11 is represented as follows. The other results not calculated separately are shown in Table 6. Measurement and calculations are shown in a bold style in Table.

If h<11;

$$\%TDD = \frac{\sqrt{I_3^2 + I_5^2 + I_7^2 + I_9^2}}{I_L}.100$$

$$\%TDD = \frac{\sqrt{60^2 + 53^2 + 34^2 + 21^2}}{500}.100 = 17.9$$

Table 6. Comparison to measurement result and standards

I_{sc}/I_L	h<11	11<h<17	17<h<23	23<h<25	35<h	TDD
20<50	7	3.5	2.5	1	0.5	8
47.58	**17.9**	**4.1**	**2.7**	**1.3**	**1**	**18.9**

These measurements and calculations are done for all transformers shown in Fig. 1. Approximately same results were taken.

V. CONCLUSION

The aim of this work is to provide both utility and customer planning engineers to achieve compatibility between industrial processes requirements and the quality of the electrical supply, taking into account the influence of harmonics.

The paper presents a real example of distribution system. The measured load harmonics are considered according to IEEE 519-1992 standard. It is observed there may be a big disturbance because of power quality problem in the future.

National power quality standards have not existed yet in Turkey. In this way all kinds of load are added to distribution system as haphazardly. National power quality standards are to become, as soon as possible. Consumers have to obey international standards.

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