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Assessment of power quality terms on energy distribution systems: a case study of Istanbul

***Abstract**. Power quality is the most import concern for electrical power distribution systems. The power quality terms have become more harmful in common increasing end-use equipments that have non-linear current-voltage characteristic on energy distribution systems. In this study, power quality terms are investigated on energy distribution systems, Also, as a case study, power quality measurements are shown on Istanbul Electrical Power Distribution System. The measurements conducted under The Power Quality National Project*

***Streszczenie.** W artykule omówiono analizę jakości energii w sieci energetycznej, na podstawie systemu dystrybucji energii elektrycznej Stambułu (ang. Istanbul Electrical Power Distribution System). (**Ocena czynników jakości energii elektrycznej w systemach energetycznych na przykładzie Stambułu**)*

Keywords: power quality, energy distribution systems, harmonics, flicker, power quality events
Słowa kluczowe: Jakość energii, systemy energetyczne, harmoniczne, migotanie.

Introduction

The task of energy distribution companies is to provide the customers with energy which is uninterrupted and with the desired voltage and frequency limits. However, correlated to the technologic developments, semi-conductors which are integrated with the energy systems, adversely affect the quality of energy. These changes in energy systems have made the Energy Quality Subject sustain its importance. The basic problems of Energy Quality can be sited as follows: Sags, Swells, Voltage Unbalance, Harmonics and Flicker.

In the literature, many studies conducted on the power quality of energy distribution systems were presented. Ian Hunter analyzed the power quality terms on Scottish Power Distribution System [1]. Carlo Muscas has offered an overview of the methods and instruments currently used in PQ measurements on distribution systems [2]. E. A. Mertens Jr. et. al. showed electric power system behavior to power quality disturbances[3]. S. Gheorghe and V. Branescu presented the power quality analyses results on Romanian National Power Distribution System [4].

In this study, power quality terms are investigated on energy distribution systems and Istanbul Energy Distribution System is evaluated in terms of power quality. After the measurements conducted under the “Power Quality National Project”, the resultant figures obtained from 9 sub-stations are presented

Definition of power quality terms and standards

Power Quality Events (Sag, Swell, Voltage Unbalance), Flicker and Harmonics are the power quality terms that are analyzed in this study.

Harmonics

Harmonics are components of distorted waveform the frequencies of which is the total multiplication of fundamental frequency [5]. Basic factor which causes harmonics is non-linear loads. Definitions of electrical parameters cannot be used under non-linear circuit conditions. All electrical parameters must be redefined for non-sinusoidal conditions.

Instantaneous values of voltage and current with harmonic components can be expressed as Equation 1 and Equation 2, respectively [5],[6].

$$v(t) = \sum_{n=1}^{\infty} v_n(t) = V_0 + \sum_{n=1}^{\infty} \sqrt{2}\, V_n \sin(n\omega_1 t + \theta_n) \quad (1)$$

$$i(t) = \sum_{n=1}^{\infty} i_n(t) = I_0 + \sum_{n=1}^{\infty} \sqrt{2}\, I_n \sin(n\omega_1 t + \delta_n) \quad (2)$$

where, V_n – voltage value for harmonic order of n, I_n – current value for harmonic order of n, V_0 and I_0 – DC component of voltage and current, respectively, ω_1 – angular frequency of fundamental component, θ_n – phase angle of voltage, δ_n – phase angle current.

Fundamental parameter which determines the effect of harmonics on power system is Total Harmonic Distortion (THD). THD is defined for both voltage and current. THD value is calculated by means of Equation 3 where, V1 and I1 are fundamental components of voltage and current respectively [7].

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1}, \quad THD_I = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \quad (3)$$

Other major parameter which determines the effect of harmonics is Total Demand Distortion (TDD). TDD is defined for current and calculated with Equation 4.

$$TDD_I = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_L} \quad (4)$$

where, I_L – maximum demand load current at the point of common coupling (PCC).

Standard harmonic limits are identified with ratio of short circuit current to maximum demand load current at the point of common coupling.

According to Turkish standard of “Regulations on Supply Reliability and Quality in Electricity Transmission System” acceptable harmonic limits are shown in Table 1 [8].

Table 1. Standard harmonic limits

	Medium Voltage $1<U_n \le 34.5$				
	I_k/I_L				
	<20	20-50	50-100	100-1000	>1000
TDD(%)	5	8	12	15	20

Flicker

Loads that can exhibit continuous, rapid variations in the load current magnitude can cause voltage variations that are often referred to as flicker. The term flicker is derived from the impact of the voltage fluctuation on lamps such that they are perceived by the human eye to flicker [9].

Many types of end-use equipment can cause flicker problem [10].

According to IEC 61000-4-30 standard, Flicker level is evaluated by short-term flicker measurement (P_{st} – calculated every 10 minutes) and long-term flicker measurement (P_{lt} – a combination of 12 short-term values).

P_{st} and P_{lt} values are calculated by using Equation 5 and Equation 6 respectively.

(5) $$P_{st} = \sqrt{0.0314P_{0.1} + 0.0525P_{1s} + 0.0657P_{3s} + 0.28P_{10s} + 0.08P_{50s}}$$

(6) $$P_{lt} = \sqrt[3]{\frac{\sum_{i=1}^{N} P_{sti}^3}{N}}$$

where, $P_{0.1}$, P_{1s}, P_{3s}, P_{10s}, P_{50s} – the flicker levels that are exceed 0.1, 1.0, 3.0, 10 and 50 percent of time respectively, N – the number of P_{st} readings [5].

P_{st} level cannot exceed standard limit during %99 of measurement duration. P_{lt} level cannot exceed standard limit during %95 of measurement duration.

Power Quality Events

The most considerable power quality events are *Voltage Sag, Voltage Swell and Voltage Unbalance*.

Voltage Sag is a decrease to between 0.1 and 0.9 pu in rms value of voltage at the power frequency for duration of 0.5 cycle.

Voltage Swell is an increase in rms value of voltage of more than 10 percent of the nominal voltage at the power frequency for duration of 0.5 cycle [9].

Voltage unbalance is defined as a ratio of negative sequence voltage to positive sequence voltage [11]. Voltage unbalance is caused by unbalance loads on power systems.

All power quality event measurements are achieved according to IEC-61000-4-30 standard.

Measured Substations and Power Quality Measurements

There are many measurements conducted in the points of Turkish Electrical Distribution System within Power Quality National Project supported by The Scientific and Technological Research Council of Turkey with reference number of 105G129. The points that have power quality problems on distribution system have been fixed by means of these measurement results and actions to eliminate these problems will be made by means of these results.

Fig.1. Measured Points

In this study, power quality measurement results of 9 substations which are the part of Istanbul Energy Distribution System are shown. Measurement points are given in Figure 1.

Harmonic, flicker, voltage sag, voltage swell and voltage unbalance data are collected for these points.

The rated values of measured power transformers are shown in Table 2.

Table 2. Measured power transformers' rated values

Substation	Power (MVA)	%U_k	Voltage Ratio	Harmonic Limit – TDD (%)
Substation 1	80	11,6	154/33,6	5
Substation 2	80	13,17	154/34,5	8
Substation 3	80	11,8	154/35,5	8
Substation 4	135	12,61	154/34,5	5
Substation 5	90	14,45	380/33	5
Substation 6	16	11,18	154/31,5	5
Substation 7	80	12	154/34,5	5
Substation 8	100	12,06	154/34,5	5
Substation 9	50	11,8	154/34,5	5

The ratio of short circuit current to maximum demand load current at the point of common coupling is used to determine the harmonic level (Table 3).

Table 3. Measured poınts' Ik/IL ratıo

Substation	I_k/I_L
Substation 1	19,09
Substation 2	28,93
Substation 3	23
Substation 4	7
Substation 5	12,63
Substation 6	7,4
Substation 7	12,51
Substation 8	7,8
Substation 9	17,8

The limits belonging to the second of step-down transformers which have been measured previously are analyzed.

Each substation has been continuously measured for 7 days. During the measurements of power quality parameters sag, swell, voltage unbalanced, harmonic and flicker were recorded.

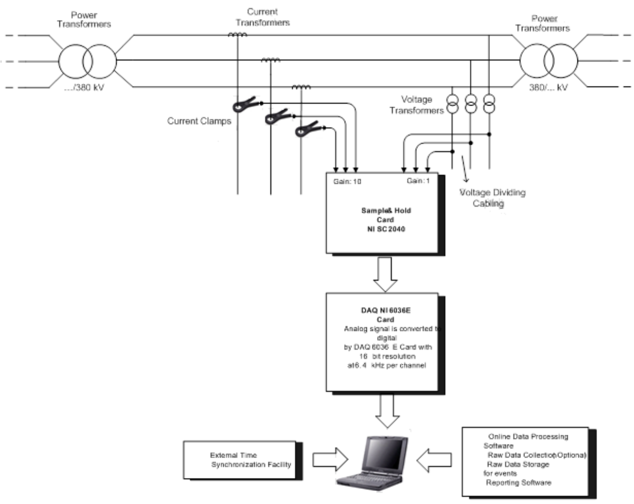

Fig.2. Measurements System's Schematic

The implemented power quality measurement system is shown in Figure 2.

The system consists of the following items: National Instruments DAQ Card 6036E, National Instruments SC-2040 S/H Card, 3 current probes, voltage divider cabling, Laptop computer, Labview software, Matlab Software, uninterruptible power supply for current probes, and isolation transformer. The measurement hardware is placed in aluminum cases, in modified test vehicles, carrying the equipment and personnel to different measurement sites all over the country [12].

Measurement Results

In this paper, Power Quality Events (Sag, Swell, Voltage Unbalance), Flicker and Harmonics measurement results are presented for considered substations.

Power Quality Events

Among these substations, the one in which the worst events were observed is Substation 4. During the period of measurements 12460 sag and 870 swell were observed. In addition, Substation 5 is the best measurement point which has only 2 sag and 1 swell.

In 7 day period of measurements, the events results from the test which one conducted according to IEC 61000- 4- 30 standards are shown in Table 4.

Table 4. Power quality events

Substation	Sag	Swell	Unbalance
Substation 1	22	39	6
Substation 2	6	-	3
Substation 3	6	-	-
Substation 4	12460	870	-
Substation 5	2	1	-
Substation 6	12	-	16
Substation 7	15	3	16
Substation 8	1	3	6
Substation 9	2	-	2

Flicker

In the majority of these test points flicker values exceed the standard limits. Especially the results of Substation 4 and Substation 9, short term and long term flicker measurements show that flicker is above the standard values for these 2 substations. The measurements of Substation 5, Substation 7 and Substation 8 are not encountered any flicker problem.

Table 5. Short term flicker measurement results

Substation	P_{st}		
	A	B	C
Substation 1	2,282	1,984	1,885
Substation 2	0,893	1,389	0,992
Substation 3	0,641	0,641	0,733
Substation 4	98,700	98,700	98,700
Substation 5	0,099	0,099	0,099
Substation 6	0,700	1,200	0,900
Substation 7	0,694	0,893	0,694
Substation 8	0,600	0,600	0,200
Substation 9	60,374	56,262	57,851

Table 6. Long term flicker measurement results

Substation	P_{lt}		
	A	B	C
Substation 1	15,476	15,476	14,285
Substation 2	7,143	8,333	5,952
Substation 3	5,376	5,376	5,376
Substation 4	100,000	100,000	100,000
Substation 5	1,190	1,190	1,190
Substation 6	2,400	7,100	4,800
Substation 7	2,381	4,762	4,762
Substation 8	3,600	2,400	1,200
Substation 9	78,022	78,022	78,022

In Table 5 and Table 6, the results of short term and long term flicker measurements are shown respectively. These tables show in what percentage flicker values are above the standards.

Figure 3 presents change of the short term flicker results which belong to Substation 4, and figure 4 presents change of the long term flicker results which belong to Substation 8.

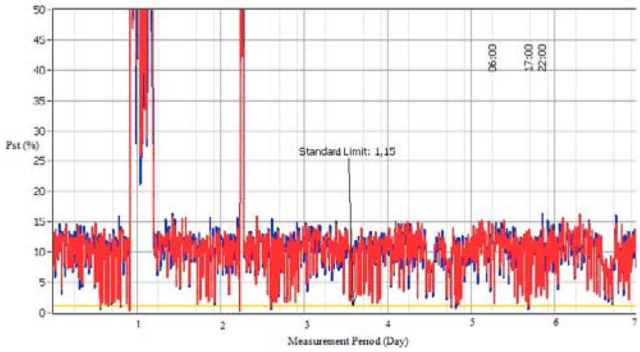

Fig.3. Short time flicker measurement results of substation 4

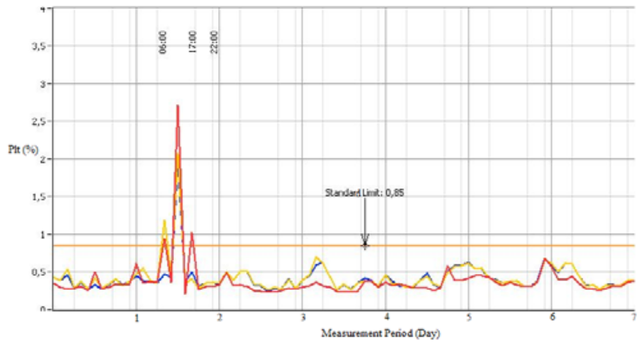

Fig.4. Long time flicker measurement results of substation 8

Harmonics

Considering the whole measurements, THD and TDD values are between the range of limiting numbers in all test points except Substation 4, Substation 6 and Substation 7.

According to Substation 4 measurements, TDD is always above the maximum standard value during the whole test period. Additionally, THD exceeds the maximum in different certain periods of measurements.

In Substation 6, TDD values go beyond the acceptable limit most of the measurement time. In Substation 7 measurements, THD value exceeds the maximum limit.

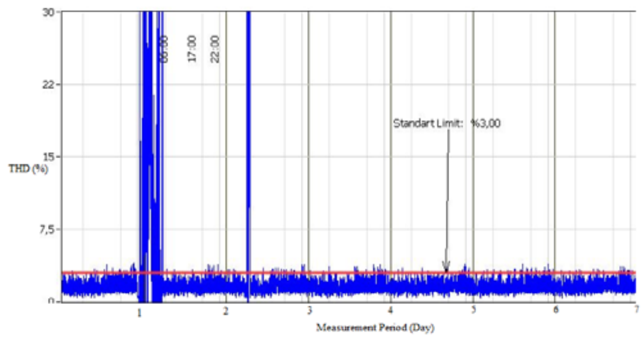

Fig.5. THD measurement results of substation 4

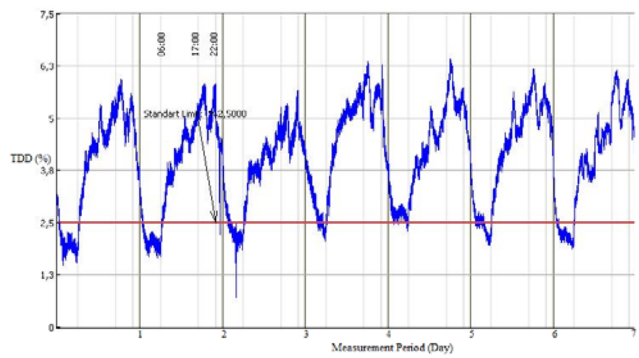

Fig.6. TDD measurement results of substation 6

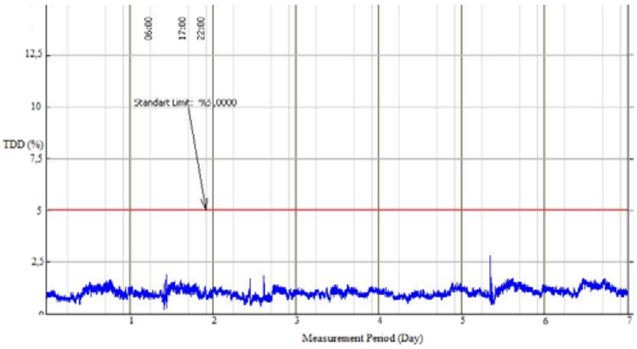

Fig.7. TDD measurement results of substation 7

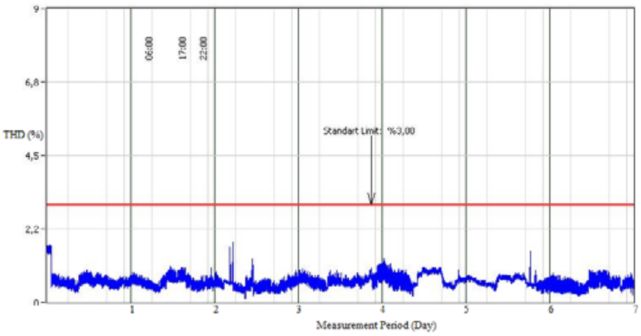

Fig.8. THD measurement results of substation 9

In Figure 5, THD measurement results of Substation 4 are shown. Similarly TDD measurement results of Substation 6, TDD measurement results of Substation 7 and THD measurement results of Substation 9 are given in Figure 6, Figure 7 and Figure 8, respectively.

Conclusion

In this study, power quality measurements of 9 points on Istanbul Electrical Power Distribution System are shown, conducted under The Power Quality National Project.

It is seen that, there are flicker problem on most of measured points. Harmonic problem has been observed on Substation 4, Substation 6 and Substation 7. THD and TDD measurements often exceed the limit values. The biggest number of power quality events occurred on Substation 4.

The result of measurement and analysis of Istanbul Energy Distribution System show that the most dominant power quality parameter was observed to be flicker.

In order to avoid problems in the system preventive measures must be necessarily taken. STATCOM and Active Filter have been applied to fix the power quality problems on electrical power distribution systems.

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