

# Analysis of Harmonic order levels at Power Lines to Improve the Power Quality

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## **Abstract—**

*This work aims at analysis and establishing harmonic levels at various points of KPLC power lines. It involved collection of harmonic order levels from generation, distribution and point of common coupling (PCC). The data were collected using Zera portable reference equipment which provided an instantaneous values and power quality analyzer (PQA) which logged data at specified time interval. Different power stations, substations and large power consumers were visited and data collected. The analysis has ascertained that large power consumers supplied on low voltage (415V) have their harmonics current levels far beyond the threshold limit as defined by the IEEE 519-1992, as compared with the power consumers supplied with medium (11,000V) and high voltage (above 66,000V). In addition, voltage distortions on transmission lines were noted to be more severe vis-a-vis the current distortions. The reasons for these are presumed to be because low voltage consumers feed the harmonics direct to the power line as opposed to the medium and high voltage consumers where most of the harmonics are filtered out at step down transformers at the consumer's premises. On the other hand, high voltage distortions on transmission lines can be as result of high line voltage hence voltage harmonics tends to be higher than the current. The power utility needs to define the admissible harmonic levels to be met by the large power consumers supplied on low voltage to reduce the adverse effects of high harmonic levels in the power electrical distribution.*

**Keywords: harmonics filters, IEEE 519-1992, power quality, total harmonic distortions**

## I. INTRODUCTION

Harmonics are one of the power system parameters which have not been intensively investigated despite its immense adverse effects on both the power utility and the power consumers. Harmonics distortion can be defined as an electrical noise or electrical pollution. It is usually a superposition of signals which are exact multiples of fundamental frequency. The amplitude of a harmonic is quoted as a percentage of the fundamental frequency. An important characteristic of harmonics is that they are transmitted upstream from the load to the transformer's secondary windings, back to the service entrance and eventually to the utility distribution line. Source of harmonics are from non linear loads which draws current in short pulses rather than in sinusoidal waveform [1]. Most of the dominant harmonics in the system are triplens which are generated mainly by single phase non linear loads and usually causes overloading of the neutral conductors. Others are odd harmonics levels generated by three phase non-linear loads. The harmonics has adverse effects on both the power utility and the power consumer which includes transformers overload and failure of capacitor banks among other immense effects [2-4].

The primary purpose of research was to establish the harmonic order levels at various points of power lines and power quality being supplied to the power consumers by the power utility. This has been as result of frequent power outages which could be attributed to system breakdown due to high harmonics contents distributed through the power lines. In additional, there

has been perpetual complains of high bills from large power consumers mainly because of power factor surcharge. With the latest advances in integrated circuit development, energy meter designers can now provide energy measurement encompassing the harmonics level at low cost to satisfy the emerging requirements from the energy providers. The electronic/ digital meter can be designed to measure upto at least 25<sup>th</sup> harmonic orders. This causes an increase of the apparent power which consequently reduces the displacement power factor which may be below the statutory level of above 0.9.

The data was collected from different power stations, substations and large power consumers. Instantaneous values and logged data were analyzed as were captured

by Zera portable and power quality analyzer respectively. From the data collected, it was found out that the power consumers supplied on low voltage have their current highly polluted with harmonics which are higher than the admissible levels as defined by the power quality international standard IEEE 519-1992. This may call for the power utility to define the admissible threshold limit of harmonics pollution both the voltage and current waveforms to the various categories of the power consumers. Consequently, the power consumers generating high harmonics will take the necessary measure to mitigate the harmonics pollution to the admissible level.

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**i. Points of data collection**

The research was being conducted from the power generation points, transmission/ distribution lines and at the PCC for low and medium voltage consumers as illustrated below:-

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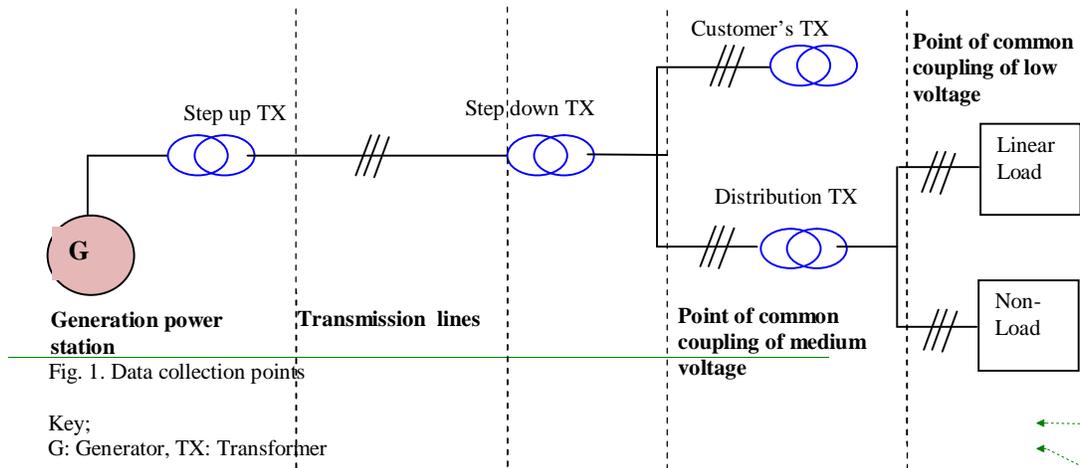


Fig. 1. Data collection points

Key;  
G: Generator, TX: Transformer

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**2. RESEARCH METHODOLOGY**

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**2.1 Points of data collection**

The harmonic data were collected at selected points of power lines by use of judgmental sampling. The collection points were grouped into three stratus; generation, substation and PCC of large power consumers. Stratified sampling method was employed to sample each stratum. For each stratum, only a few points were judgmentally sampled. For substations, data was collected in only two regions, Nairobi and Mt. Kenya south. This was due to limitation of resources (time, finances, and human resources) which hampered wide coverage of data collection. Apparently, data collected from these two regions was correlating, hence there is high likely that the same applies in other feeders and transmission lines.

ii. The substations; Embakasi, Baba dogo, Makuyu, and Thika substations.

iii. The large power consumers; High voltage power consumers (Bamburi cement, and Athi river mining), medium voltage power consumers (Devki steel mills, the Agkan Hospital, and Twiga Chemical Industries) and low voltage power consumers (Doshi Enterprises, product Building Materials, Stima plaza, Malplast Industries, AON Minet Insurance Brokers Ltd, Meter Central Laboratory- KPLC and Teacher service commission).

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## 2.2 Methods employed to collect data

The research was conducted using the Zera portable equipment and power quality analyzer. The reasons for using these equipments for collection of harmonics data, were the accuracy and reliability of the data collected (both equipments were of accuracy class 0.5) and wide ranges of the harmonics data they can display/ log. These include; harmonics spectrum, harmonics waveform and individual harmonic order level and the angle.

### i. Zera portable reference equipment

The portable provided instantaneous percentage order of harmonics levels and displacement angle up to 40<sup>th</sup> order and Total Harmonics distortion on each of both line current (THDi) and line voltage (THDv). The displayed parameters were recorded for analysis (see annex 1 for some of the captured data using the Zera portable).

### ii. Power Quality analyzer

The equipment was installed at customer premises for specified period of time (at least two days) and parameters were captured at defined time intervals (15 minutes). Both voltage and current lines harmonics were recorded independently. (see annex 2 for some of the captured data using the PQA).

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## 3. RESULTS OF THE RESEARCH

The following are the data obtained from the exercise of collecting harmonic distortions at various generation stations, substations and large power consumers.

## 2.3 Specific points data were collected

Data were collected at various points as listed under;

i. Power generation stations; Tana Hydro power station, Ibrafrica Ltd thermo station, Kipevu thermo station, and Olkaria geothermal power station.

i. Generation power stations.

The table 1a under depicts the level of harmonics generated at each power station;

No.	Power generation	(THDi%)	IEEE 519 THDi%	(THDv%)	IEEE 519 THDv%
1	Tana power station (66kV)	2.81	3.5	0.59	5.0
2	Kipevu III (132kV)	0.86	2.5	0.85	2.5
3	Iberafrika E.A ltd (66kV)	1.02	3.5	0.42	5.0
4	Olkaria power stations (132kV)	1.74	2.5	1.42	2.5

Where:

**THDi**: Current Total harmonics distortion, **THDv**: Voltage total harmonics distortion

Observations noted from the instantaneous data collected:

In all power generation stations, both THDi and THDv were within the admissible levels as defined by the international power quality standard IEEE 519 -1992. Tana hydro power station, current harmonic distortion was noted is relatively high comparatively with other power stations. This could be due to the type of generators installed. At generation points, both current and voltage harmonics content are well within the required threshold as shown in table 1 above.

Table1b. Individual Harmonics levels at Iberafrika power generation.

Frequency (Hz)	150	250	350	450	550
Amplitude (A)	0.12%	1.03%	0.16%	0.01%	0.07%

Each harmonic level order contents were well within the allowed limits.

ii. Feeder and transmission lines data collected.

The data collected at various substations were as illustrated below.

a)Baba dogo substation: Feeder 2 (66000V) voltage harmonics.

Table 2a: individual Harmonics levels for Feeder 2

Frequency (Hz)	150	250	350	450	550
Amplitude (A)	3.64%	0.78%	0.09%	0.58%	0.69%

The 3<sup>rd</sup> harmonic order level was noted was high relative to other harmonic order level which is mainly caused by the negative sequence components as results of line unbalance.

b) Makuyu substation; Makuyu feeder current harmonic distortions: The current harmonic spectrum for Makuyu feeder was as under;

Table 2b. Makuyu feeder current harmonic orders

Frequency (Hz)	150	250	350	450	550
Amplitude (A)	1.51%	0.75%	1.37%	0.38%	4.69%

From the data collected 11<sup>th</sup> harmonic order was notably high while other orders were low and well within the recommended limit.

Substation	No.	Power line	Current Total Harmonics distortion (THDi%)	IEEE 519 REC (THDi%)	Voltage Total Harmonics distortion (THDv%)	Voltage level (V) line -line	IEEE 519 (THDv%)
<b>Embakasi</b>	1	Dondora 220,000V	1.93	2.5	4.38	220,000	1.5
	2	Kiambere 220,000V	1.24		4.89	220,000	
<b>Thika</b>	3	Incomer 1	1.74	8.0	1.32	11,000	5.0
	4	Incomer 2	1.93		1.2	11,000	
	5	Industrial 1	4.08		0.90	11,000	
	6	Industrial 2	3.43		1.09	11,000	
<b>Baba dogo</b>	7	Kasarani feeder	7.42	8.0	1.35	11,000	5.0
	8	Kariobangi feeder	6.09		1.33	11,000	
	9	KBL Feeder	12.26		1.24	11,000	

From table 2c it is noted that except transmission lines, the voltage distortion contents for feeders and distribution lines were well within the IEEE 519 threshold limit. Current distortions at Baba dogo substation were noted to be high vis-a- vis the other substations and especially KBL feeder line. This could be presumable is due to combination of industrial loads (Kenya Brewery Ltd with high harmonic levels) and many domestic non linear loads (Gumba estate) supplied by the line.

#### ii. Large power consumers

The harmonics data collected at some of the large power consumers were as depicted in table 3 below.

Table 3. Summary of some of large power consumers' harmonics levels data collected

No.	Customer Name	THDi%	(THDv%)	Supplied voltage (V) Line - Line
1	Bamburi - Mombasa	3.02	2.26	11,000
2	Athi river mining - Mombasa	5.61	1.75	33,000
3	Devki Steel mill - Mombasa	9.25	1.58	11,000
4	Doshi Enterprise - Mombasa	93.59	4.27	415
5	KPLC- Stima Plaza- Nairobi	11.45	3.58	415
6	Product building materials- Mombasa	15.32	2.59	415

Observation from table 3 shows that medium voltage supplied large power consumers, harmonic levels are

well within the threshold limit as per the IEEE 519. Low voltage power consumers, current harmonic

distortions were beyond the defined limit (THDi =12% for current) with the highest noted at Doshi Enterprise (93.59%) but voltage harmonic distortions were well within the limit (THDV 5% for voltage).

Some of the instantaneous values captured by Zera reference equipment were as shown below.

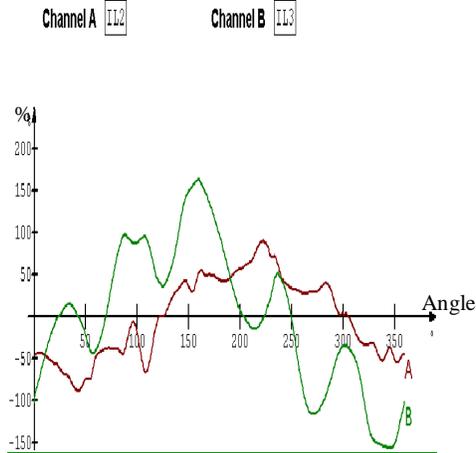


Fig. 1. Instantaneous harmonic distortions .

Current waveforms for KPLC- ruaraka were as displayed as fig 1. Only two waveforms could be displayed at time. Channel A is yellow phase current waveform (IL2) and Channel B is blue phase current waveform (IL3). Harmonic contents due to non linear loads have caused the current waveforms to be distorted. This nature of waveform is disastrous to electronic devices including digital energy meter. Such high level of harmonic distortions causes low power

factor and system voltage and current unbalance due to the present of negative and zero components sequence. Being a three phase four wire configuration, it overloads the neutral conductor.

Channel IL3 Sum 50.48 %

	Absolute value	Angle
0	0.045838 %	0.000000°
1	100.000000 %	0.000000°
2	0.133724 %	151.709183°
3	18.316422 %	44.820435°
4	0.168817 %	0.222137°
5	44.460537 %	47.472992°
6	0.036898 %	57.853088°
7	14.767476 %	23.820271°
8	0.029694 %	13.259857°
9	2.028663 %	21.934540°
10	0.048422 %	20.155304°
11	2.844601 %	11.392731°
12	0.034679 %	7.909332°
13	1.358825 %	23.325529°
14	0.070770 %	6.100202°

Fig. 2: individual harmonic absolute value and displacement angle.

Some of individual harmonic levels and correspondence angle for KPLC –Ruaraka were as fig. 2. The data displayed were for Blue phase current distortion with the THDs of 50.48%. The instrument displays 40 harmonic order levels. The absolute values is higher on odd harmonics but decreases as harmonic frequency increase.

#### 4. RESULTS DISCUSSION AND FUTURE WORK

From the research carried out, it can be deduced that there is cause for alarm on the level of harmonics specifically on large power consumers supplied on low voltage (415V) vis-a-vis power consumer supplied on medium voltage and high voltage (11000 – 66000V). The findings shows that most of the large power consumers have high harmonics content which are far above the admissible levels as defined by the IEEE 519-1992. Some of the feeder lines had high current harmonic distortions beyond the required limit. There is need to identify all those feeders especially the feeders supplying industrial loads and domestic non loads (70% of industrial load are non-linear; switch mode power supply (SMPS), rotating machines, variable frequency drives (VFDs), saturable devices and domestic loads which include TV sets, DVD drives, computers, ballast lightings).

Apparently, medium voltage supplied consumers total harmonic distortions were found were well within the recommended limits as per the IEC power quality standards. This could be due to installation of mitigating transformers at the substations and consumer premises which filter most of the harmonic currents contents. Voltage distortion at transmission lines were found to be higher than admissible level which could be attributed to high transmission voltage and small line current to reduce the power technical losses ( $I^2R$ ). The research can be extended to the direct connected three phase commercial and single phase connected power consumers as the research concentrated on power consumers with load of above 100A per phase and voltage of above 415V phase to phase.

#### 5. CONCLUSION AND RECOMMENDATIONS

The harmonics data collected shows that only subtle effort which has been done to mitigate the harmonic contents on the power utility system. Consequently, this

has resulted to enormous problems to both power utility and power consumers which among them includes power losses on power distribution lines and on energy measurement, transformer overheating, and power factor surcharge respectively. To improve the power quality to achieve a world class power quality, it is imperative that the power consumers be compelled to mitigate their harmonics order levels. This can be achieved by power utility defining what are acceptable normal system characteristics which need to be met by individual consumer. This will compel the power consumers to mitigate the harmonic levels to be within the acceptable harmonic distortion levels by installation of either passive harmonics filters, active filters or harmonic mitigation transformers (HMTs) depending on the level of harmonic distortions and economical viability of the method to be adopted. This will considerably minimizes the immense effects of harmonics on both the power utility and the power consumers.

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