Real-Time Measurement and Analysis of Power Quality Issues in Distribution System

Sai Mounika Ramireddi, Narasimha Rao Kolipaka, Santosh Kumar Nagalla, and C. Venkata Krishna Bhanu

Abstract There is a growing concern for power quality with the increase in use of power electronic-based equipment in all sectors of electricity consumption. Besides causing maloperation/degradation of equipment, power quality problems are causing huge economic losses. A lot of work has been carried out on the impact of poor power quality on the equipment and the consequent financial implications. This paper presents analysis on extensive field data collected from various locations of LT distribution system in Visakhapatnam, Andhra Pradesh. Monitoring of power quality has been performed at PCC or secondary side of the transformer by using YOKOGAWA CW240 Clamp-on Power Meter. No power quality data is available in the literature on Indian LT distribution network. A comparative study on the harmonic characteristics of residential, industrial, agricultural and commercial feeders is also conducted. So, here an attempt is made to measure and analyze the power quality issues under different categories.

Keywords Power quality · Harmonics

1 Introduction

Due to increase in use of nonlinear loads, the effect of harmonics increased. The nonlinear equipment such as fluorescent lamps, computers, air conditioners, welding machines and mobile chargers used in residential, industrial and commercial loads causes distortions in voltage and current. These harmonics cause reverse effects in the various power quality surveys have been carried out to analyze all these issues [1]. It provides how the harmonic voltages and currents are presented at sending end of feeders, i.e., distribution substations [2]. It analyzes the comparison of harmonic

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characteristics of residential, industrial and commercial loads by conducting the extensive field survey [3]. They have monitored harmonic distortions present in the residential area LV network [4]. They provide existing level of harmonic characteristics of residential and commercial loads [5]. It presents the influence of harmonics on MV distribution system.

An attempt was made in this work to measure and identify power quality issue under different categories. Here extensive field survey has been carried out from residential, industrial, commercial and agricultural loads which are presented in LT distribution system to know the existing level of harmonic pollution presented in the distribution system. This paper provides continued research in the field of power system harmonics.

This paper is organized as follows. Section 2 describes field measurement activities. Section 3 provides comparative analysis of power quality parameters for multiple loads at different locations of a power system. Section 4 gives conclusions.

2 Field Measurements

2.1 Features of Power Quality Measurement Locations and Duration

Power quality survey was carried out in Visakhapatnam, Andhra Pradesh. Here totally 5 residential, 4 industrial, 2 agricultural and 1 commercial loads and individual equipment were collected. The measurement locations are at service panels and secondary side of the service transformers. The measurements were taken from each load for the duration of 24 h but 8 h for agricultural loads because the supply has given to these loads for 8 h.

2.2 Instrument and Software Used to Analyze the Data

The voltage and current measurements were taken at LV side of the distribution systems. The data was collected by using YOKOGAWA CW240 power quality analyzer. Measuring the power quality parameters, Clamp on Power Meter—YOKOGAWA CW240 is used. The instrument is capable of measuring three-phase voltages and currents, frequency and power factor and also can carry out power quality analysis. The power quality parameters like voltage sag/swell, interruptions and harmonics (up to 50th order) can be measured using meter. It has a measurement voltage range of 150–1000 V and a current range of 200 uA–3000 A with seven different current probes.

Current Setting

The current ranges selected differ depending on the clamp-on current probe. For all the residential and agricultural loads, 50 A current probe is used. For industrial and commercial loads, 500 A current probe is used.

Voltage Setting

Standard voltage (V_{Std})	Voltage sag (setting w.r.t. V_{Std})	Voltage swell (setting w.r.t. V_{Std})	Voltage interruption (setting w.r.t. V_{Std})
240 V (RMS)	90%	110%	10%

2.3 Standards for Power Quality Parameters

In this paper, for all loads total harmonic distortion in voltage is compared with IEEE 519 standards and total harmonic distortion current is compared with IEC standards.

The unbalancing voltage is compared with IEEE 519 standards. Here power is also calculated whether it is good or bad. Different voltage quality events like voltage sag, voltage swell, over voltage, under voltage and interruptions are observed.

3 Analysis of Power Quality Parameters

3.1 Residential Loads

The power quality survey was conducted for 5 residential loads. Among all, 3 loads are completely residential and other 2 are hostel-based loads. Load details are lighting, air conditioners, computers, lift, motors, fans, etc. Out of 5 residential loads, one load consists of more distortions in voltage and current as shown in Figs. 1 and 2.

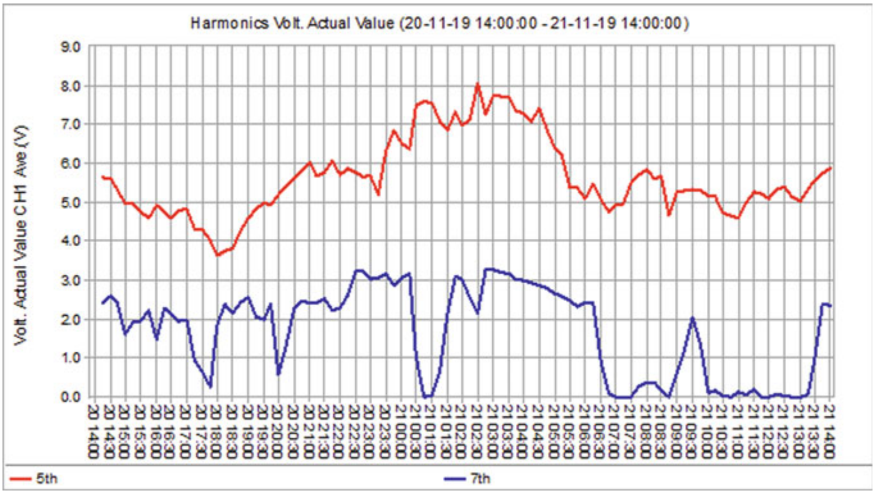


Fig. 1 Voltage harmonic distortions versus time

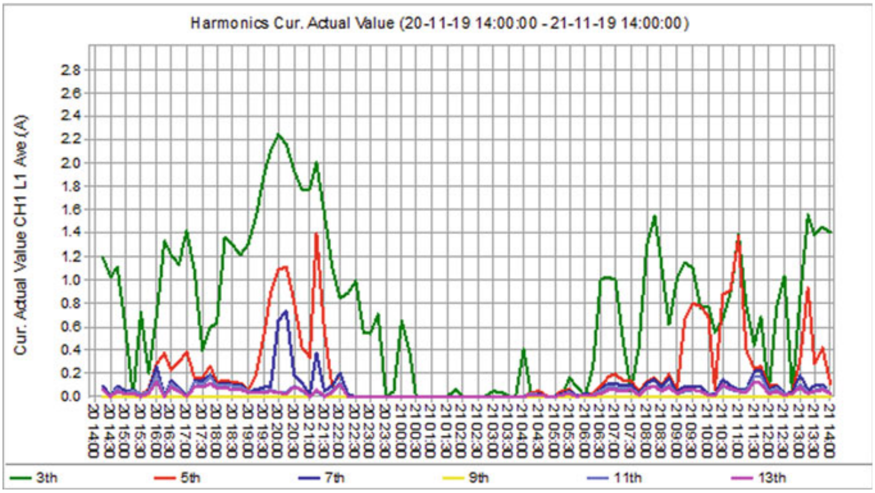


Fig. 2 Current harmonic distortions versus time

In voltage harmonics, 5th and 7th order harmonics presented and 5th order harmonics are dominant one. In current harmonics, up to 13th order harmonics presented in the system and 3rd order harmonics are dominant one. The voltage harmonics are within the limits, and current harmonics slightly violates its limits. Duration of current harmonics which violates its limits is 12 h: 50 min, and these harmonics are more during daytime and less during nighttime due to more usage of power electronic devices during daytime.

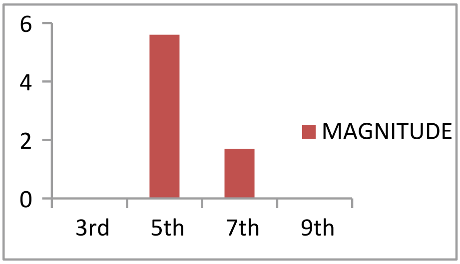


Fig. 3 Voltage harmonic spectrum

The voltage and current harmonic spectrums are shown in Figs. 3 and 4.

The unbalancing ratio and power factor in the system are shown in Figs. 5 and 6.

The power factor is unity for 75% duration of time, and unbalancing ratio in voltage is within the limits.

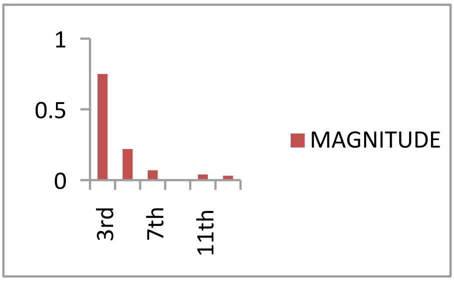


Fig. 4 Current harmonic spectrum

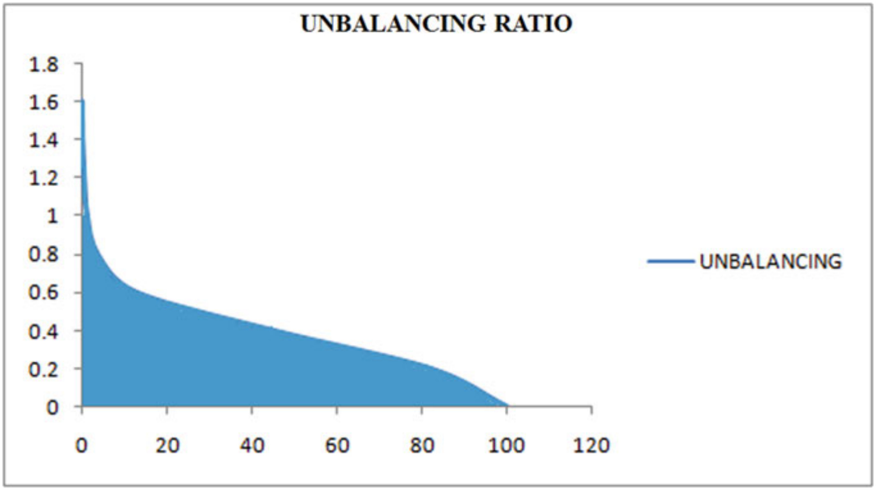


Fig. 5 Unbalancing ratio

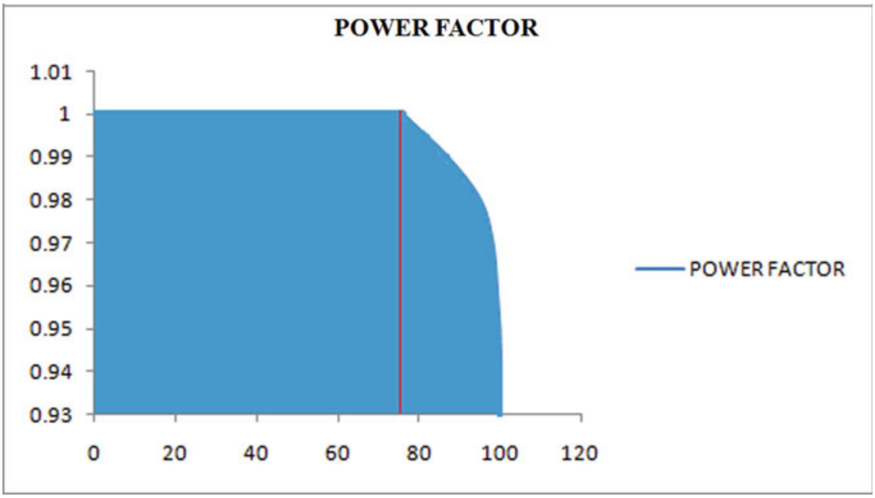


Fig. 6 Power factor versus duration of time

3.2 *Industrial Loads*

There are 4 industrial loads, named as sea food industry, ice plant, crab factory and steel industries. These all are located in Visakhapatnam. The two industries sea foods and crab factory are food processing units. Ice plant is manufacturing ice. Steel industry is one of the large manufacturing of steel in Visakhapatnam. Out of all these industries, ice plant is having more distortions in voltage and current (Figs. 7 and 8).

In voltage harmonics, 3rd and 7th order harmonics are dominant in voltage and 5th order harmonics are dominant in current. The duration of harmonics violates its limits. These harmonics are continuously presented in the system throughout the day. These harmonics are mainly due to motors.

The voltage and current harmonic spectrums are shown in Figs. 9 and 10.

The unbalancing ratio and power factor in the system are shown in Figs. 11 and 12.

The power factor is unity in the system, and unbalancing ratio in voltage is more and beyond the limits.

3.3 *Agricultural Loads*

The survey was conducted for 2 agricultural loads. One load is having 4 connections, and other load is having 9 connections. All the loads are motor loads. The voltage and current harmonics in voltage and current are shown in Figs. 13 and 14.

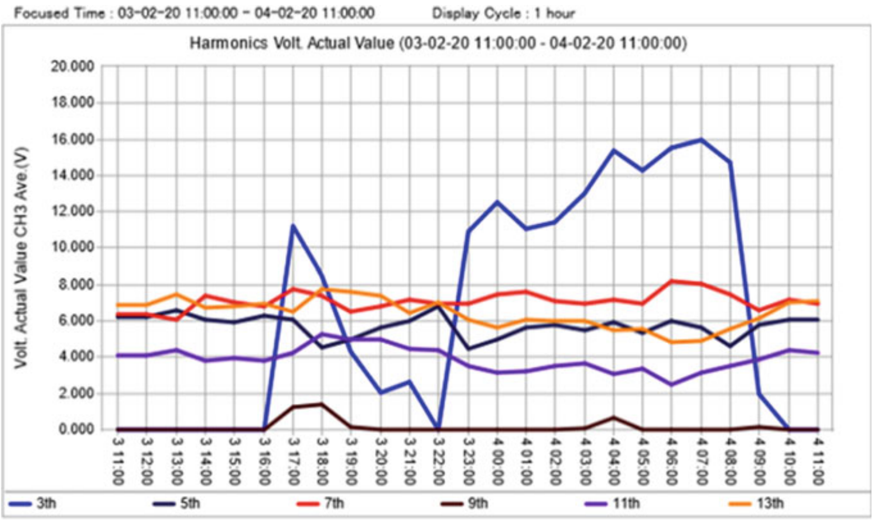


Fig. 7 Voltage harmonic distortions versus time

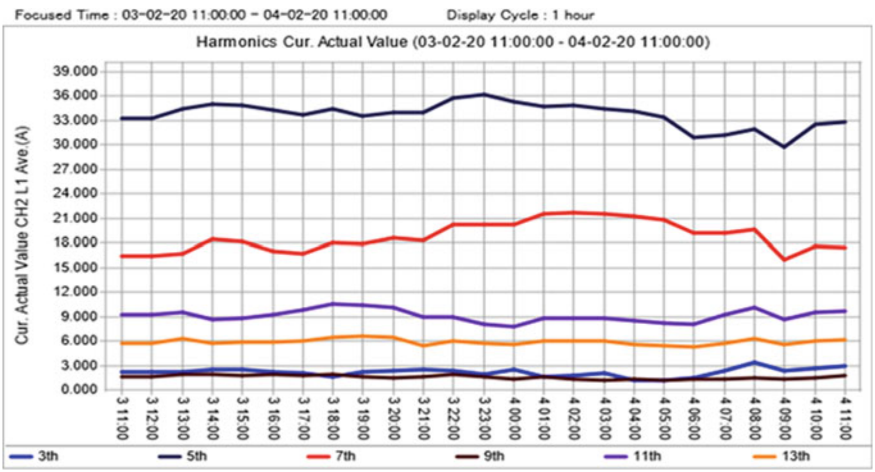


Fig. 8 Current harmonic distortions versus time

In both voltage and current, 5th order harmonics are more. These harmonics are more due motors.

The voltage and current harmonic spectrums are shown in Figs. 15 and 16.

The unbalancing ratio and power factor in the system are shown in Fig. 17.

The power factor is poor in the system, and the unbalancing ratio in the system is within the limits (Fig. 18).

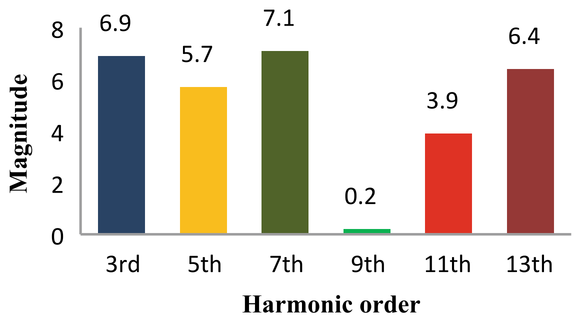


Fig. 9 Voltage harmonic spectrum

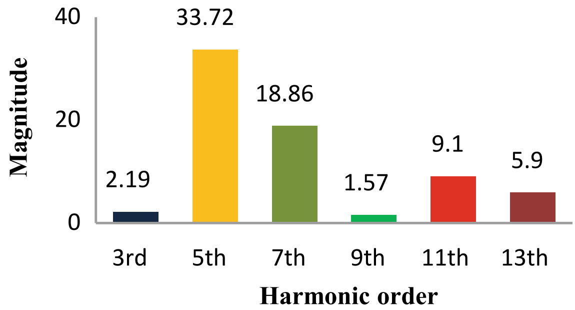


Fig. 10 Current harmonic spectrum

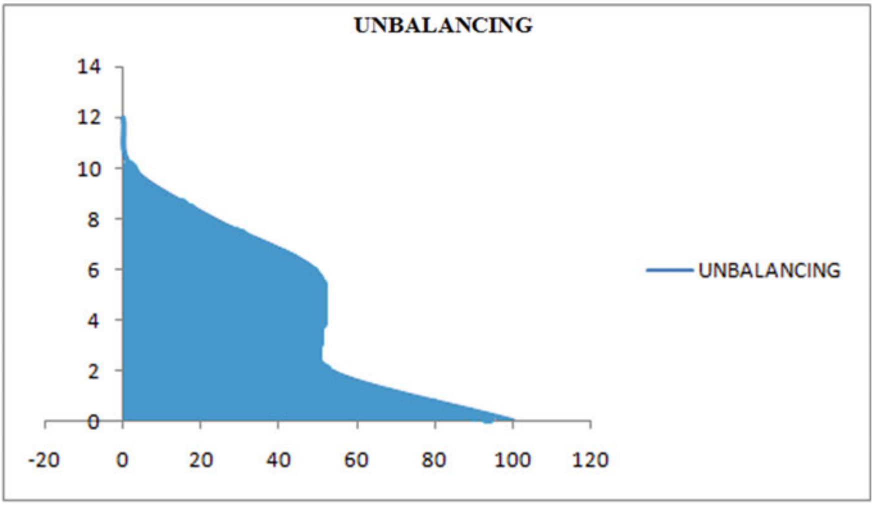


Fig. 11 Unbalancing ratio

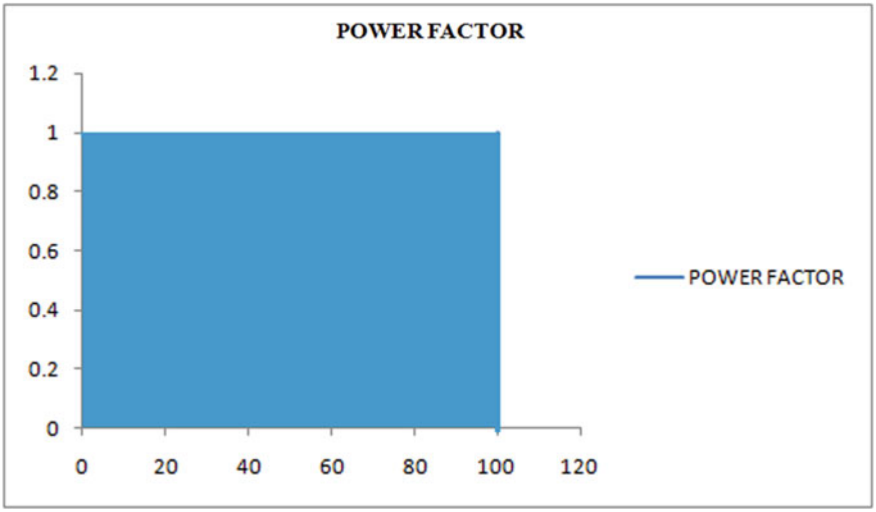


Fig. 12 Power factor versus duration of time

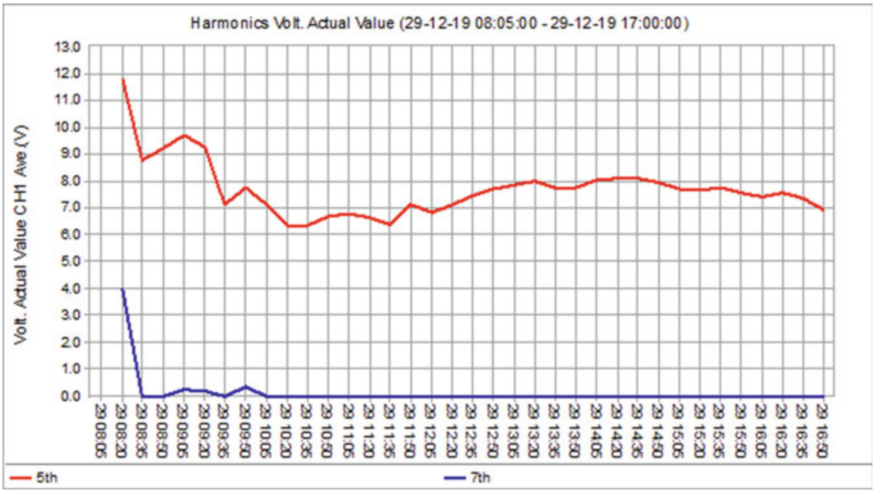


Fig. 13 Voltage harmonic distortions versus time

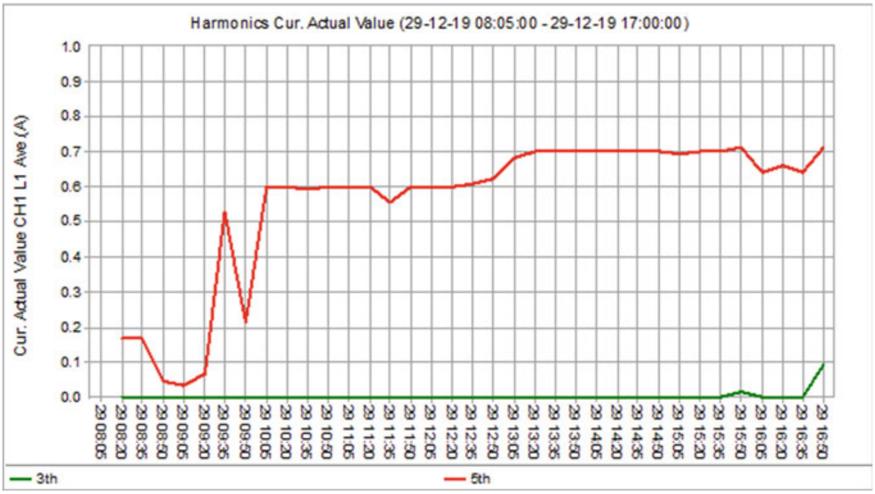


Fig. 14 Current harmonic distortions versus time

Fig. 15 Voltage harmonic spectrum

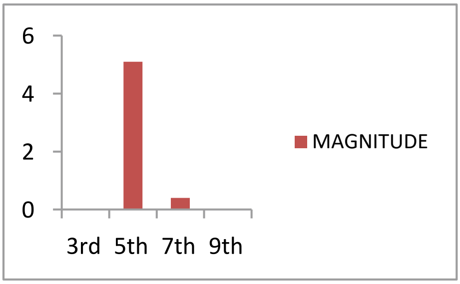
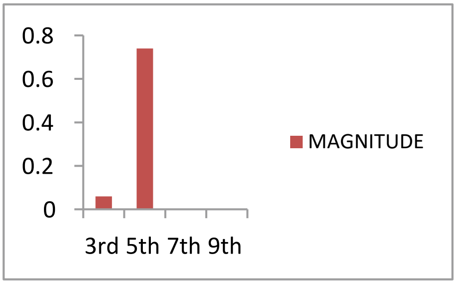


Fig. 16 Current harmonic spectrum



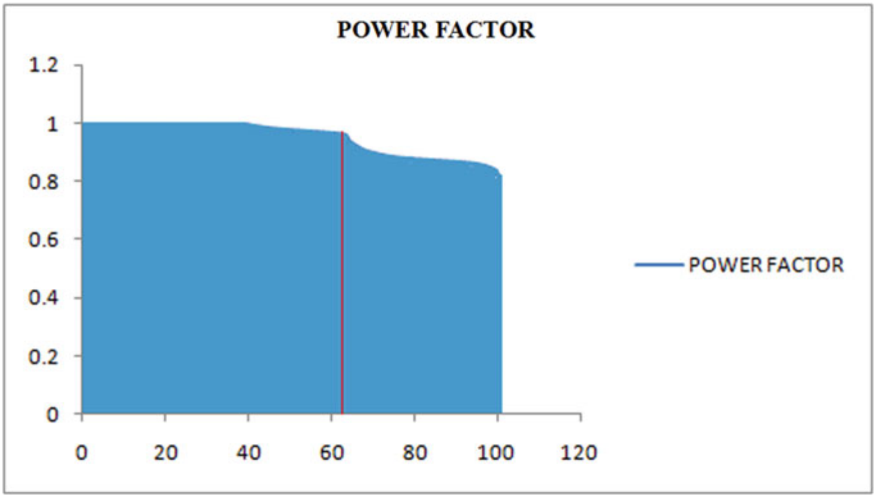


Fig. 17 Power factor versus duration of time

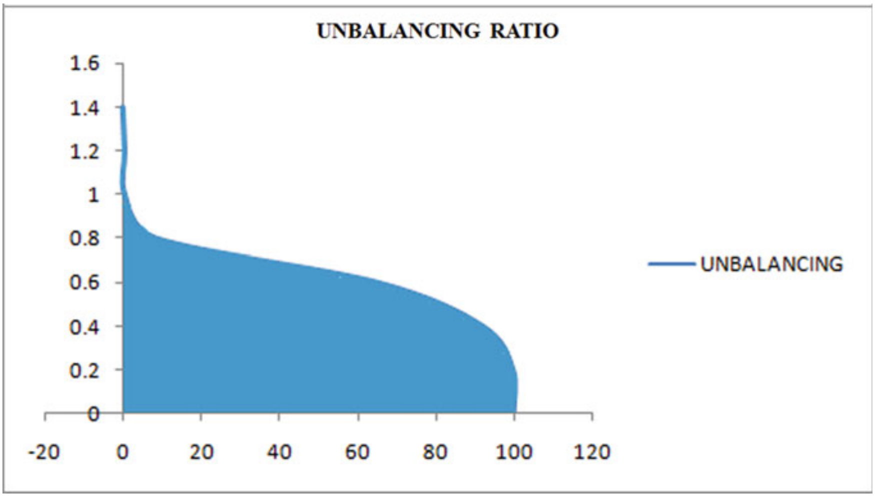


Fig. 18 Unbalancing ratio

3.4 Commercial Loads

The name of the commercial complex which is located in Visakhapatnam. This load consists of lighting load, air conditioners and fans.

The voltage and current harmonics in this load are shown in Figs. 19 and 20.

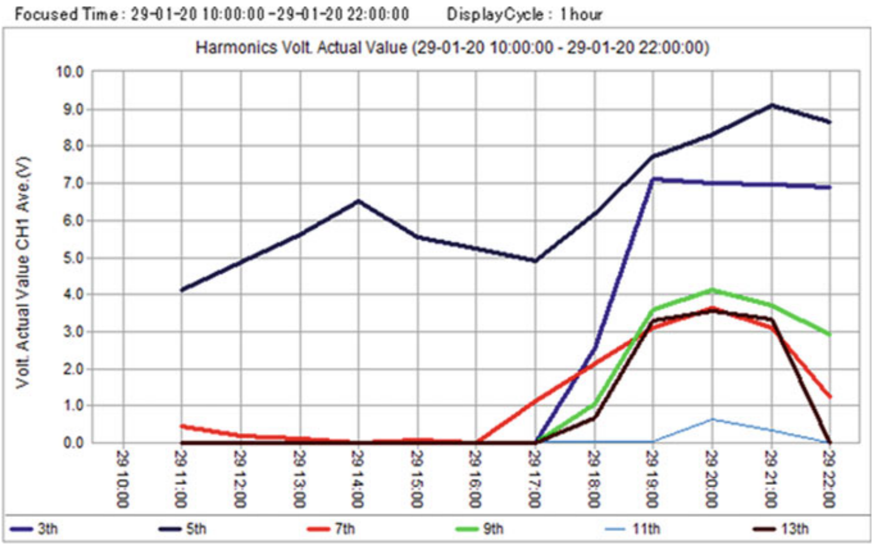


Fig. 19 Voltage harmonic distortions versus time

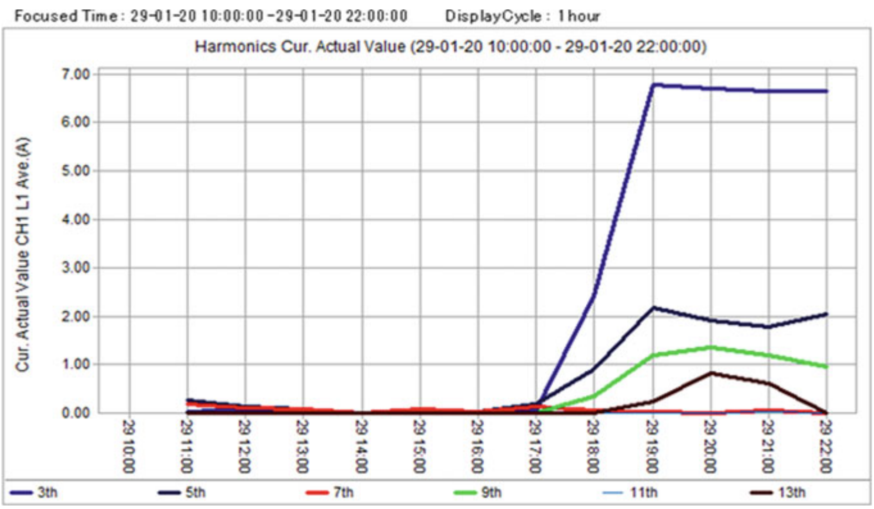


Fig. 20 Current harmonic distortions versus time

From this, 5th order harmonics are more in voltage and 3rd order harmonics are more in current. These harmonics are more during nighttime due to lighting. Here the voltage harmonics are within the limits but current harmonics are highly violating its limits.

The voltage and current harmonic spectrums are shown in Figs. 21 and 22.

From the harmonic analysis data in current harmonics, 3rd order harmonic is dominant one. In commercial load, there are significant current distortions.

The comparison of various power quality parameters are given in Table 1.

The total harmonic distortion in voltage and current for different loads is shown in Figs. 23 and 24.

3.5 *Some of the Individual Equipment*

(a) *One bulb (fluorescent)*

See Figs. 25 and 26.

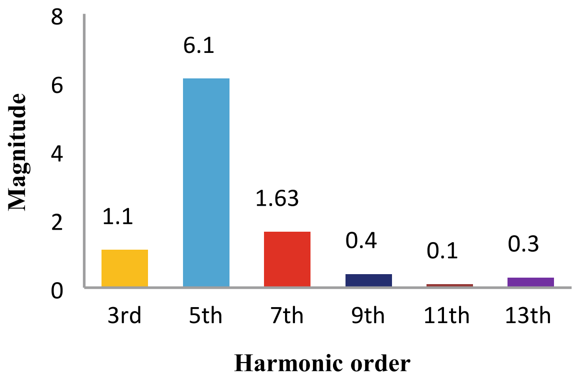


Fig. 21 Voltage harmonic spectrum

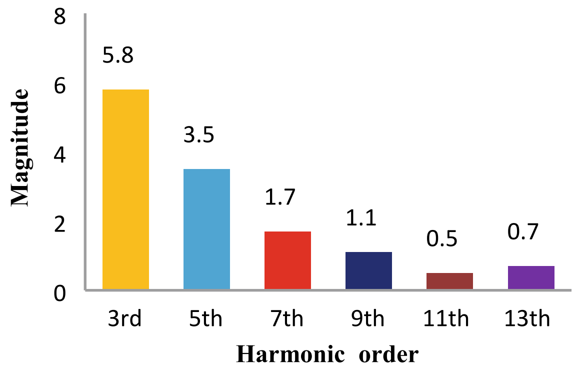


Fig. 22 Current harmonic spectrum

Table 1 Comparison of various power quality parameters

	Interruption	Sag	Swell	Over voltage	Under voltage	% of unbalancing	THD-V	THD-I	PF
AGL-1	0	8	10	0	0	8.35	5.14	6.41	0.77
AGL-2	4	4	9	0	0	1.36	1.58	2.25	0.94
RL-1	0	1	23	20	0	3.75	1.73	6.88	0.99
RL-2	1	1	18	0	0	1.56	1.88	0.51	1
RL-3	2	2	6	10	0	1.31	1.89	9.35	0.98
RL-4	0	1	0	14	0	3.47	2.28	7.06	0.99
RL-5	0	0	5	43	0	1.49	2.5	11.47	1
IND-1	0	0	7	21	0	0.6	5	5.4	0.7
IND-2	3	47	0	0	0	12.29	6.1	47.3	1
IND-3	0	1	16	29	0	0.37	3.7	13	0.9
IND-4	0	0	19	22	0	0.54	0.79	2	0.84
COM-1	0	0	21	11	0	1.78	2.4	60.2	0.72

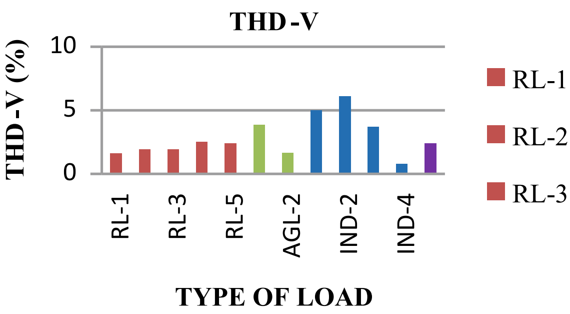


Fig. 23 Total harmonic distortion in voltage

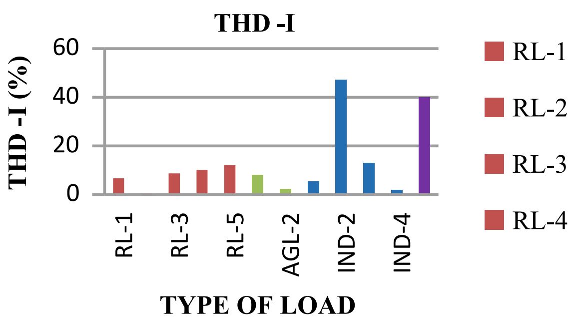


Fig. 24 Total harmonic distortion in current

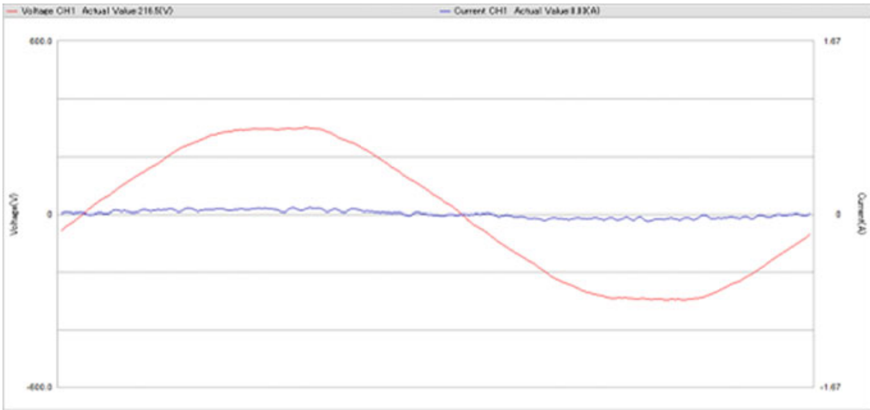


Fig. 25 Voltage and current waveforms

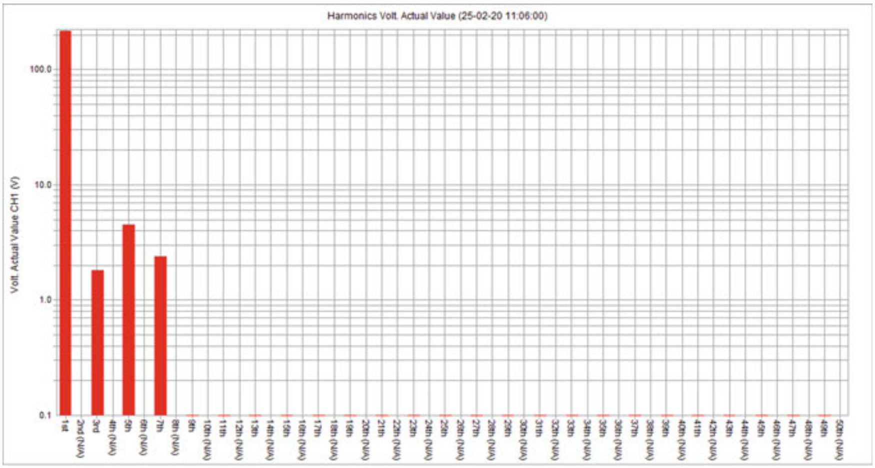


Fig. 26 Voltage harmonic spectrum for 1 bulb

Total harmonic distortion in voltage (%)—2.5
Total harmonic distortion in current (%)—0.

(b) *Two bulbs (fluorescent and LED)*

See Figs. 27 and 28.
Total harmonic distortion in voltage (%)—2.4
Total harmonic distortion in current (%)—0.

(c) *Three bulbs (fluorescent and LED)*

See Figs. 29 and 30.
Total harmonic distortion in voltage (%)—2.5

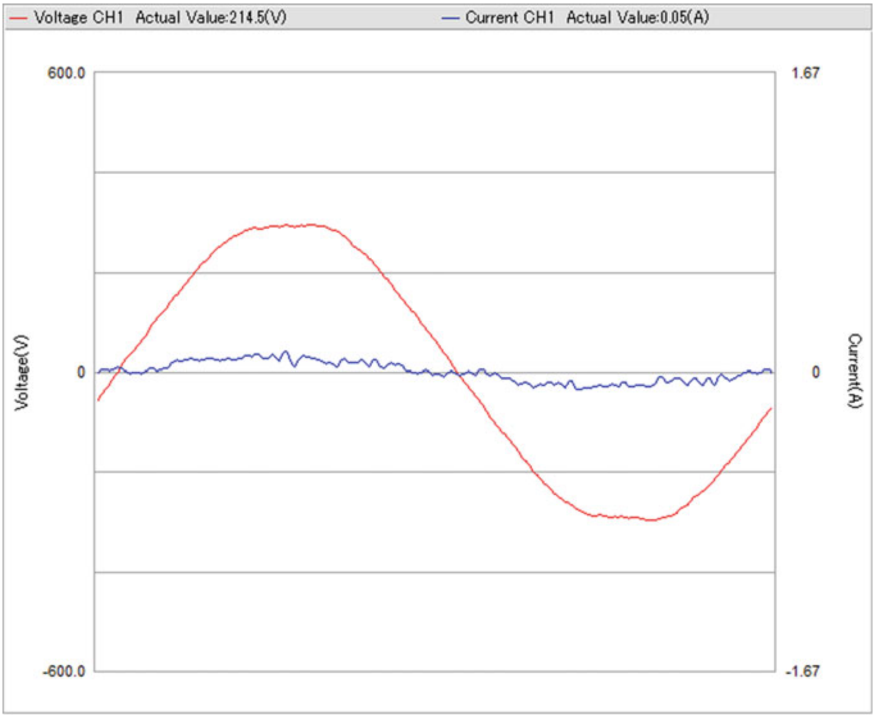


Fig. 27 Voltage and current waveforms

Total harmonic distortion in current (%)—0.

(d) *Exhaust fan*

See Figs. 31 and 32.
Total harmonic distortion in voltage (%)—2.6
Total harmonic distortion in current (%)—0.

(e) *Laptop*

See Figs. 33 and 34.
Total harmonic distortion in voltage (%)—2.4
Total harmonic distortion in current (%)—188.

(f) *Mobile charger*

See Figs. 35 and 36.
Total harmonic distortion in voltage (%)—2.3
Total harmonic distortion in current (%)—132.2 (Table 2).

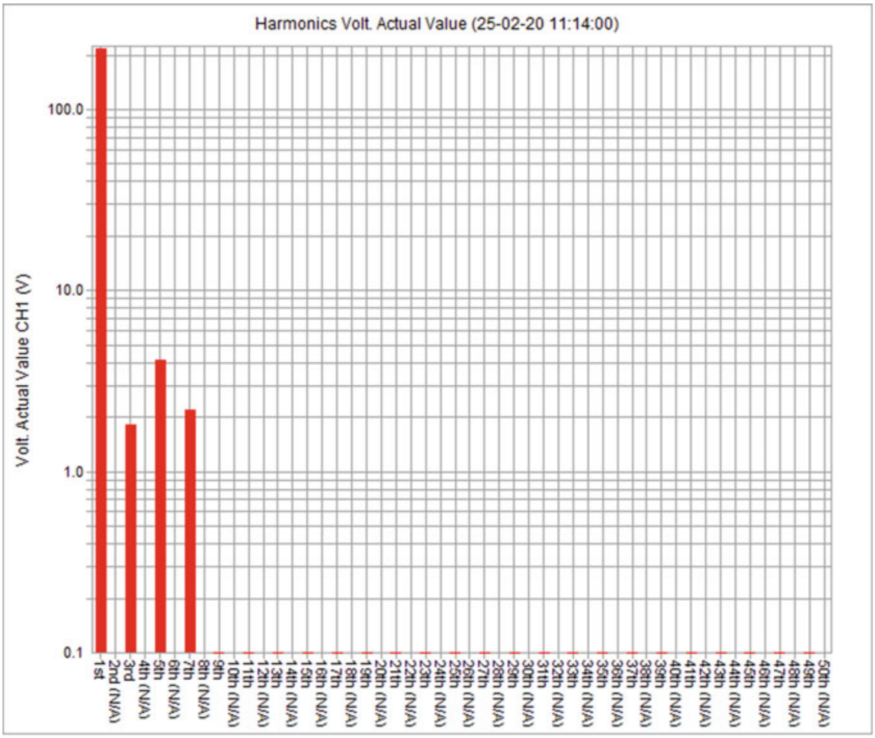


Fig. 28 Voltage harmonic spectrum for 2 bulbs

From all loads, laptop is having more THD in current comparing with other. Welding machine and mobile charger are also violating the limits. Here 3rd order harmonics are more in current.

4 Conclusions

Real-time measurement of power quality parameters in an LT distribution system under different load categories is presented in this work. From the analysis of the data presented, the number of voltage quality events is high for residential loads. Also in residential loads, the THD-I levels are more during daytime than the nighttime. In the case of industrial and commercial loads, the power factor is less than 0.9 which is of serious concern. In the case of agriculture loads, a special case where availability of supply is only for 8 h of duration per day, the harmonics are high. One of the major limitations of this work is the duration of the measurement which is only 24 h and measurement for one week might give a better picture. In the future, it is proposed

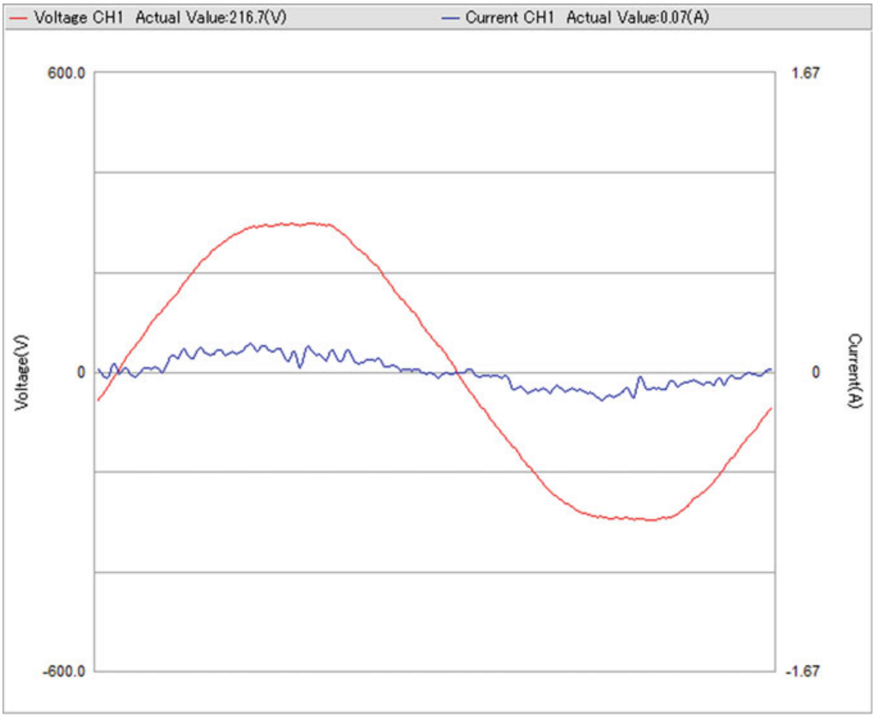


Fig. 29 Voltage and current waveforms

to measure the power quality parameters for at least one week continuously in each category and with more number of the sample under each category.

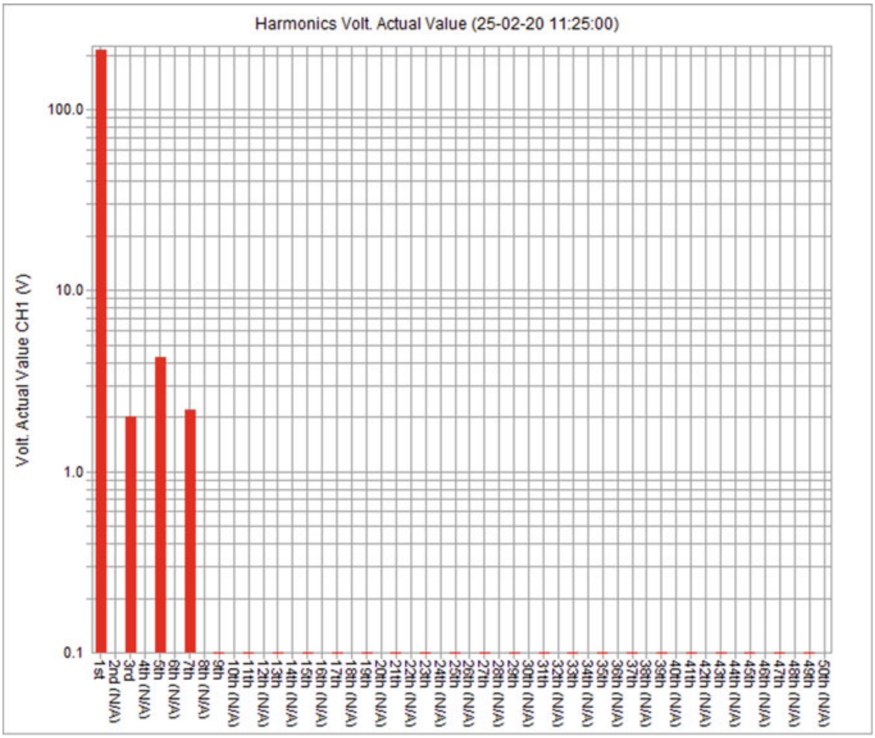


Fig. 30 Voltage harmonic spectrum for 3 bulbs

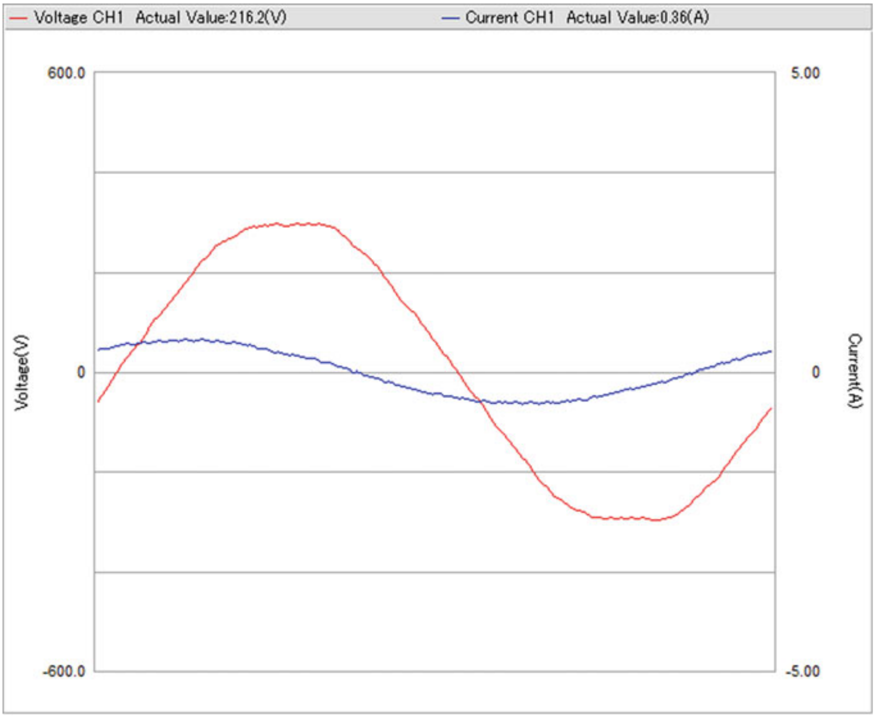


Fig. 31 Voltage and current waveforms

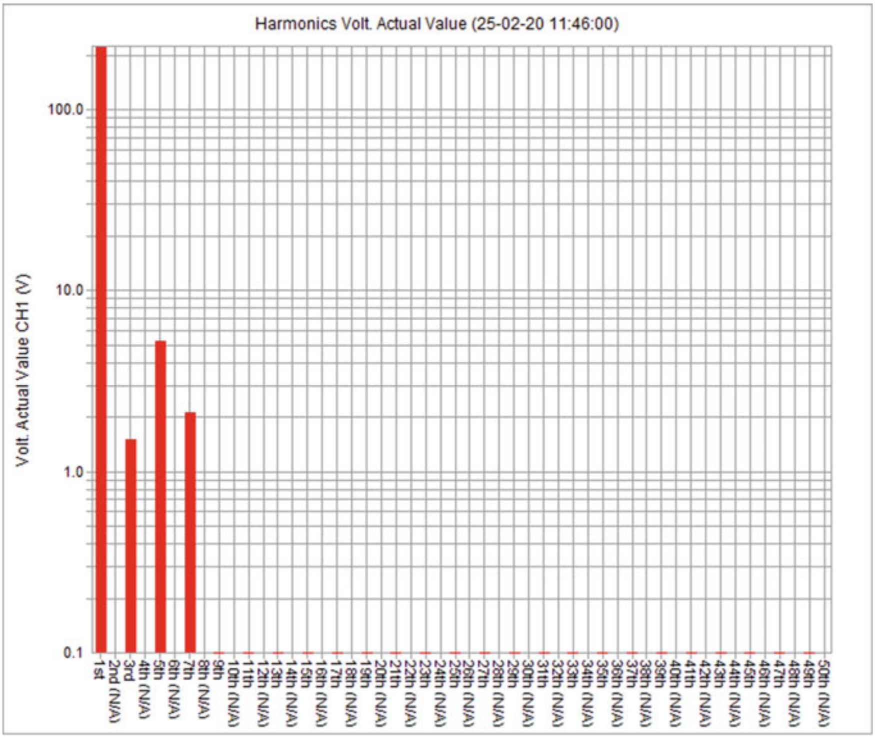


Fig. 32 Voltage harmonic spectrum for exhaust fan

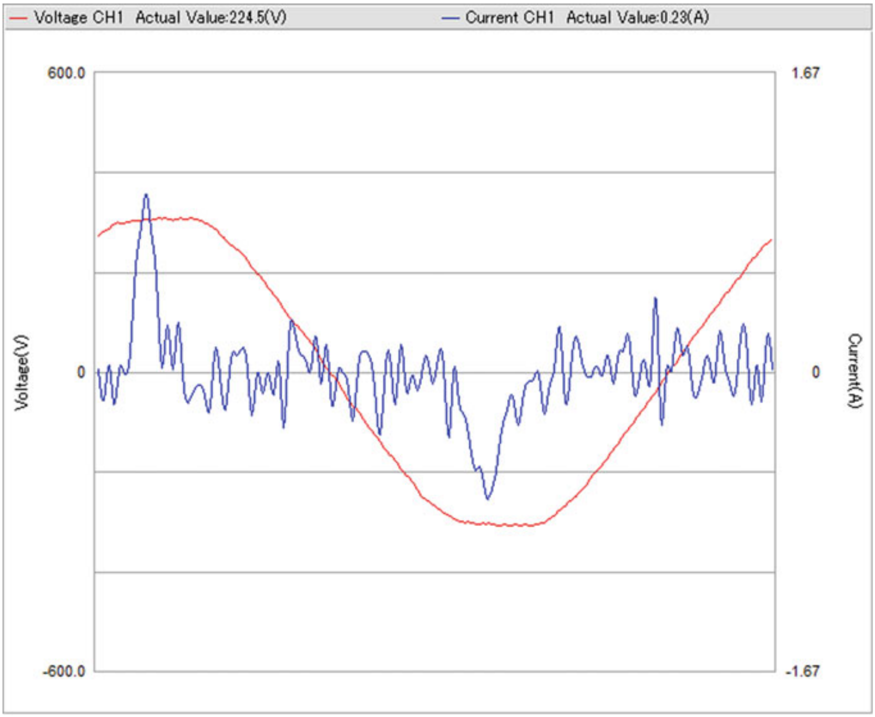


Fig. 33 Voltage and current waveforms

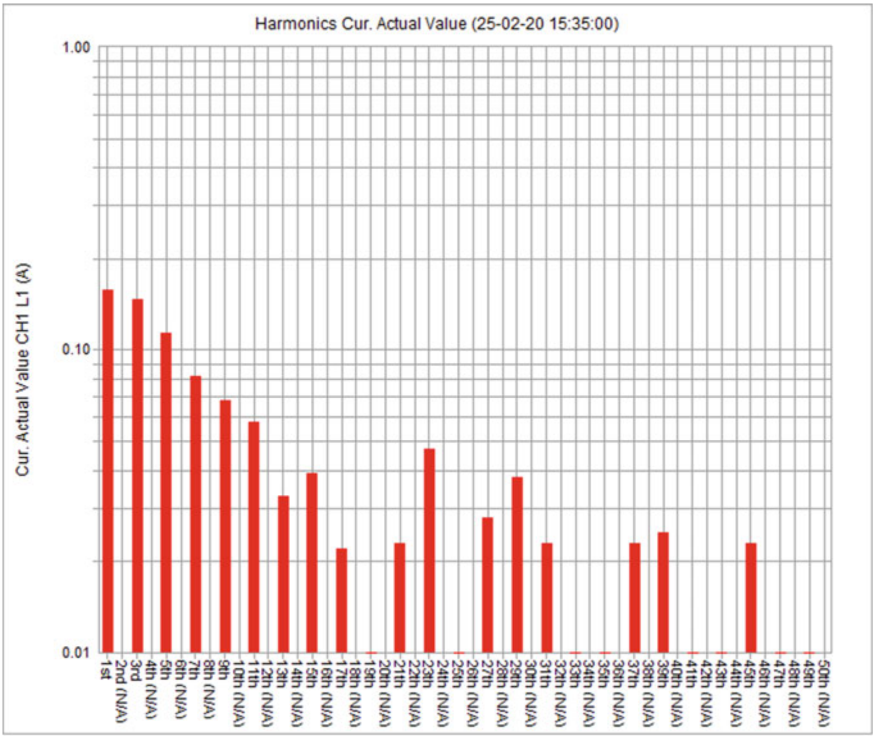


Fig. 34 Voltage harmonic spectrum for laptop

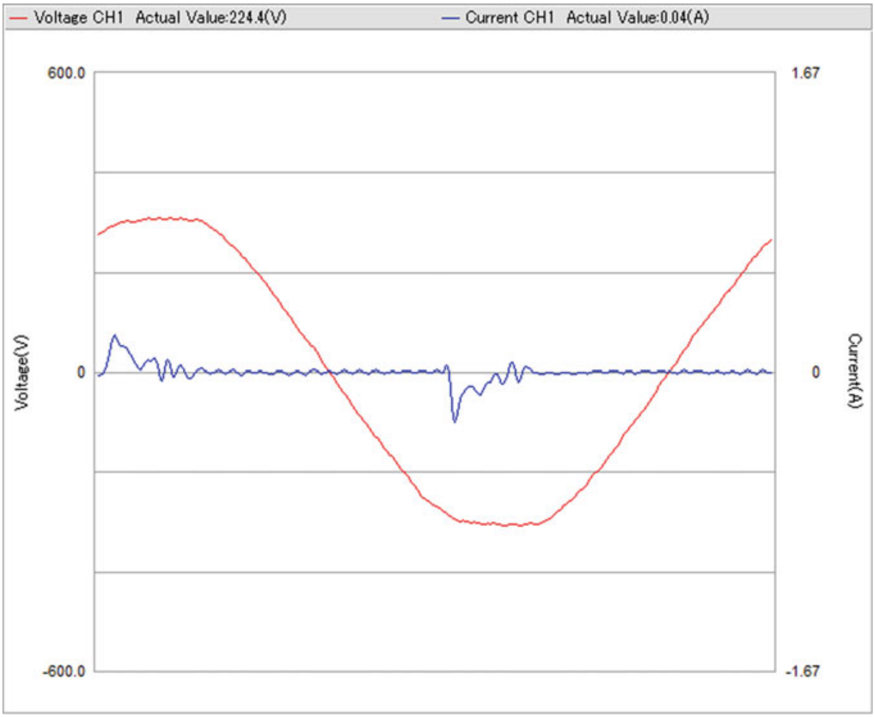


Fig. 35 Voltage and current waveforms

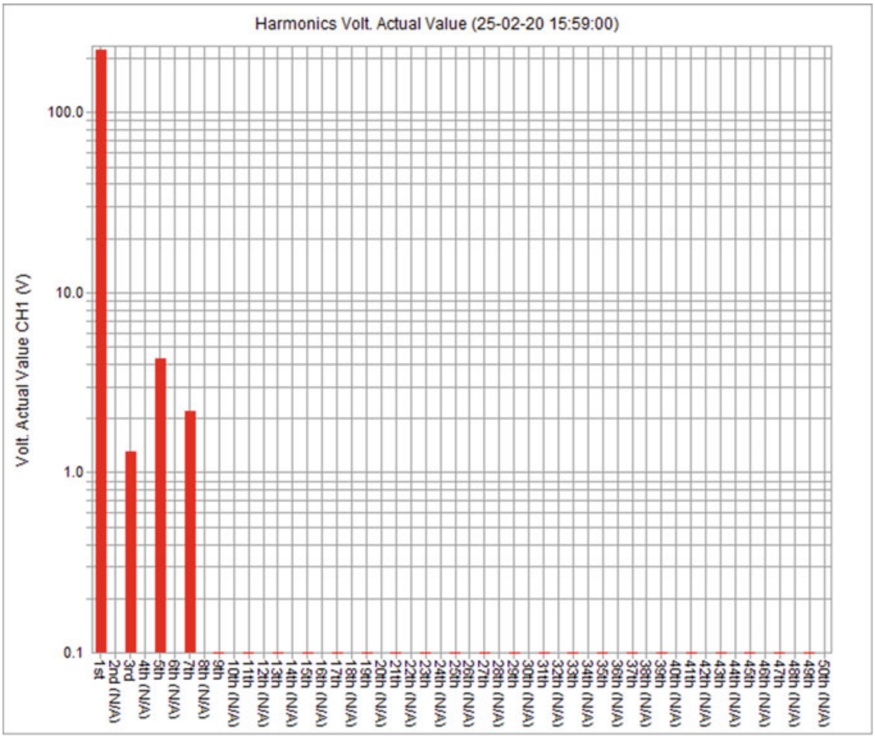


Fig. 36 Voltage harmonic spectrum for mobile charger

Table 2 Power quality parameters for some of the individual equipment

Device	Current THD (%)	Most dominant harmonic order	Other harmonics	PF
Fluorescent lamp	–	–	–	1
Laptop	188	3	5, 7, 9, 11	0.4 (lead)
Mobile charger	132.2	–	–	0.5 (lead)
Welding machine	40.1	3	3, 7, 9, 13	0.41
Woodland (small commercial load)	60.2	3	5, 7, 9, 11, 13	0.72

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