POWER QUALITY EVALUATION AT MATO GROSSO DO SUL FEDERAL UNIVERSITY HOSPITAL

João Cesar Okumoto[1], Paulo Irineu Koltermann[1], Valmir Machado Pereira[1], Gervásio Saraiva Lara[1], Amâncio Rodrigues da Silva Jr.[1]
[1]Universidade Federal de Mato Grosso do Sul, Departamento de Engenharia Elétrica, Cidade Universitária, Campo Grande, MS, BRASIL – CEP: 79070-900 – Caixa Postal: 549
jokumoto@del.ufms.br, koltermann@del.ufms.br, valmir@del.ufms.br, gervasio@del.ufms.br, amancio@del.ufms.br

***Abstract* – The aim of this paper is to determine some power quality problems and their correlation with the medical equipments operation at Mato Grosso do Sul Federal University Hospital, in Campo Grande. This paper describes the stages of the conducted power quality evaluation that is two fold: 1) an on-site inspection of surgery center's electrical system; 2) power monitoring at the panel boards and at utilization of the equipments in some hospital sectors. Voltage and current measurements are utilized to identify voltages disturbances (e.g. sags and swells), neutral currents and harmonic distortions. Recommendations will be made on the results and a report will be given as a guide for new equipment installations and future expansions at hospital.**

***Keywords* – power quality, harmonic distortions, hospital, medical equipment, power quality analyzer, voltage disturbances.**

I. INTRODUCTION

Since 1970, Mato Grosso do Sul Federal University Hospital, in Campo Grande, has been seen the local patients and has given support to the university medical courses as Nursing, Medicine, Dentistry and Pharmacy. The entrance service (13,8 kV feeder) is maintained by ENERSUL – Mato Grosso do Sul Energy Company. The peak load at hospital is 1 MW and its energy consumption is 265 MWh per month. The load is distributed among 12 substations. It has an alternate power supply consisting of 4 diesel generators. They can supply emergency power in some sectors.

In the last years, the hospital has been experienced expansions in its infrastructure to improve patient treatment and to provide employees with suitable work conditions. The facility has undergone many renovations; some changes in the electrical system likely have been performed without taking into consideration some regulations like harmonic distortions directives. Besides, the widespread use of sensitive equipment has required a high quality power. In medical facility, an electrical system and the devices attached have to work safely because any problem may cause human life losses. Common sources of power quality problems found in hospital include: inadequate wiring and grounding, high-wattage equipment and physical plant renovations. The objective of the assessment is to evaluate the quality of service received from the utility, the condition of the hospital's electrical system and to identify areas within the hospital where power quality problems currently exist or may develop. This information will be used for better planning when installing sensitive equipments and in future expansions.

II. THEORETICAL FUNDAMENTALS

Total Harmonic Distortion (THD) is an important tool used to quantify the level of harmonics in voltage or current waveform. According to [1] two different definitions for THD may be found in the literature. In the first definition, the harmonic content of a waveform is compared to its fundamental. In the second definition, the harmonic content of a waveform is compared to the waveform's rms value, as shown in equations (1) and (2).

$$THDI_F = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \qquad (1)$$

$$THDI_R = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{\sqrt{\sum_{n=1}^{\infty} I_n^2}} \qquad (2)$$

Where:

$THDI_F$ - Current Total Harmonic Distortion compared to its fundamental (%).
$THDI_R$ - Current Total Harmonic Distortion compared to the rms value (%).
I_1 - Fundamental value of the current (A).
In – rms values of the harmonics (A).
n - Harmonic order.

Equations (1) and (2) can also be used to show Voltage Total Harmonic Distortion (THDV) by replacing the current values by voltage values in the expression.

It has been shown [1] that THD_F is a much better measure of harmonics content. Utilization of THD_R may yield significant huge errors in quantities, such as, power factor and distortion factor, derived from THD measurement. In the hospital evaluation both measures have been used in order to compare them.

Other definitions regard the Power Factor. Conventional Power Factor is now called Displacement Power Factor (DPF) to relate it to the displacement between fundamental current and fundamental voltage of the system. Distortion Power Factor, on the other hand, takes into account the harmonic currents that do not contribute to the real work produced by the load. The Total Power Factor is thus a

combination of both Displacement and Distortion Power Factors.

III. HARMONICS SOURCES AND THEIR EFFECTS

At the medical facilities many non linear loads can be considered as harmonics sources. Surgical luminaries, monitoring devices, portable x-ray machines and electrosurgical units are found in the surgery rooms. Some office equipment, like fluorescent luminaries, personal computers and printers can also be found. Such non linearity tends to cause several undesirable effects such as [2]:
- Thermal overstresses, that reduces equipments lifetime due to the overload in buses, feeders, cables and transformers;
- Isolation overstress;
- Unusable or undesirable operation of several devices. In this case, the disturbances may cause distortions of displays and readings, providing incorrect diagnostic results;
- Additional losses;
- Power factor reduction.

IV. VOLTAGE DISTURBANCES

Other Power Quality problems are voltage disturbances, that can be any change in the sinusoidal 60 Hz voltage waveform, during more than 0,5 cycle. Such events can be transient voltages, impulsive transients, oscillatory transients, notching, voltage sags, voltage swells and long duration voltage variation, according to the duration and frequency of the waveform [3].

V. METHODOLOGY

In order to identify some possible power quality problems, on-site inspections of the electrical system and power monitoring have been done. The process included: reviewing the hospital electrical system one-line diagrams, interviewing with maintenance and technical personnel and employees (end-users) and identifying the types of sensitive equipments [4].

Due to some devices are installed frequently at the hospital, there is not updated one-line diagram of the electrical system. Thereby, actual updating of one-line diagrams has been performed on the on-site visits, as shown in Figure 1.

To monitor the voltages and currents at the substation principal panel the *Embrasul* Power Analyzer RE 2000 has been used. Analyzer RE 2000 is a three-phases analyzer and captures 18360 samples/second. To study the impact of portable medical equipment upon other sensitive devices a *Fluke* 41B Power Harmonics Analyzer has been used. Single-phase records at the output of each circuit breaker at surgery center corridors panels and devices have been done with the *Fluke* 41B. Measurements have been taken from the substation, then going all the way up to the individual loads. Those measurements have been performed during a week at the chosen points in the simplified one-line diagram of electrical supply. The computer gathers both records from the analyzers.

Temperature readings have been taken by using a *Raytek* MX Infrared Thermometer to study the effects of the harmonics and other power quality disturbances in the system.

The interaction between loads has to be studied to evaluate their contribution with power quality disturbances. Office equipment, like computers, and medical devices with high distortions can affect the operation of other devices.

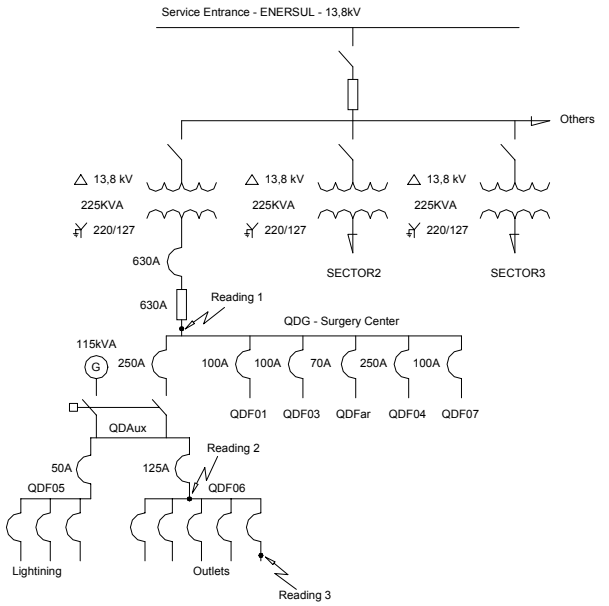


Fig. 1. Simplified one-line diagram of electrical supply.

VI. DISCUSSION AND RESULTS

A. Subestation and Panel Boards

During the on-site inspections of the electrical system and power monitoring at the hospital the following situation has been found.

A 225 kVA transformer feeds the surgery center load; the surgery center power demand is around 60kW. There is an alternate power supply consisting of a 115 kVA diesel generator and it can supply emergency power within 5 seconds of an outage, as required by healthcare standards. No Uninterruptible Power Supply (UPS) is used to run the surgery center loads. There is no surge protection for the circuits and residual-current circuit breakers in the panel board. The protection is performed only by using circuit breakers and fuses.

1) Principal panel board - Figure 2 shows the phase A voltage and its harmonic spectrum. The records were taken from the principal panel board, as can be seen in Figure 1- Reading 1, which feeds the other distribution panels inside the surgery center. The voltage THD is less than 3%, recommended value [5]. The phase B and C voltage THD (not shown here) are according to the limits too. The 5th harmonic voltage was evident in all the readings, 1,99%, 1,73% (not shown here) and 1,89% (not shown here), to each phase, respectively. In order to study these values a long period record (about one month) is recommended. No voltage disturbance was read in the measurements period, only a short distortion was noticed on the voltage waveform. Figure 3 shows the phase C current waveform and its

harmonic spectrum. The measurement shows a 13.02% total harmonic distortion (THD). The 3rd harmonic (7,99A – 8,90%) is the highest component found. The other THD readings are 8.51% in phase A and 8.55% in the phase B (not shown here). According to [6], the values are on the suitable limits.

An infrared study was performed in the main circuits. This study did not reveal any severe hot points in the circuits that could give evidence of deterioration of the contacts and cables. The neutral wire transversal section is in agreement with its current.

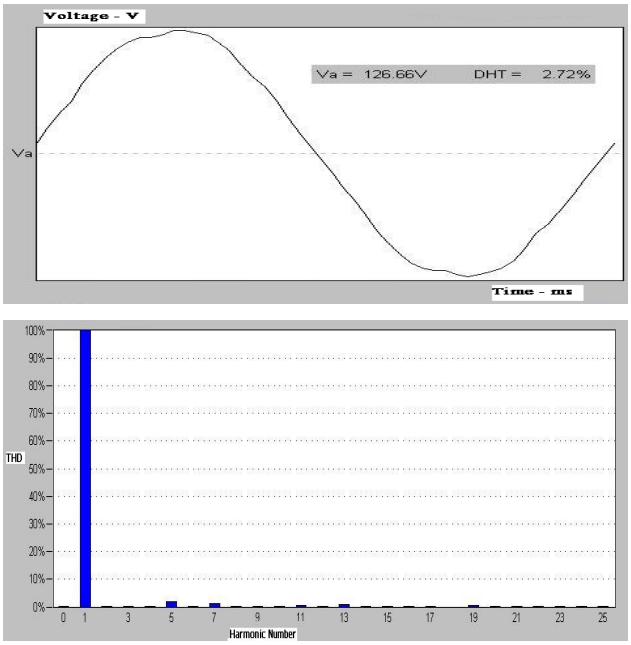


Fig. 2. QDG - Phase A. (a) Voltage waveform. (b) Voltage harmonic spectrum.

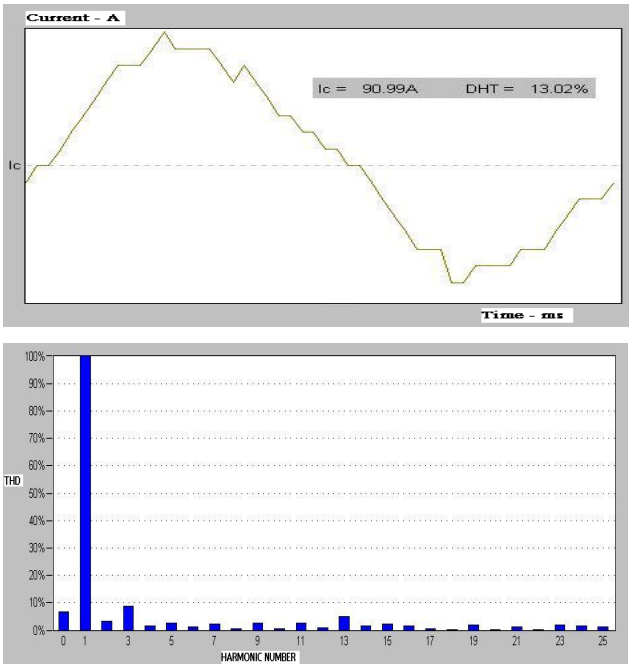


Fig. 3. QDG – Phase C. (a) Current waveform. (b) Current harmonic spectrum.

2) Panel Board QDF06 - Figure 4 shows the measurement took from the panel board QDF06, as shown in Figure 1- Reading 2, the phase B current waveform and its harmonic spectrum. Outlets circuits are attached to this distribution panel. Table I presents the values in which there is an evident waveform distortion and the 5th current harmonic is the highest one (12%). The neutral wire was supporting its current values and no hot point was found in the panel and cables.

Monitoring of panel boards must be done in a long period (about one month) and all the other panels attached to QDG must be evaluated.

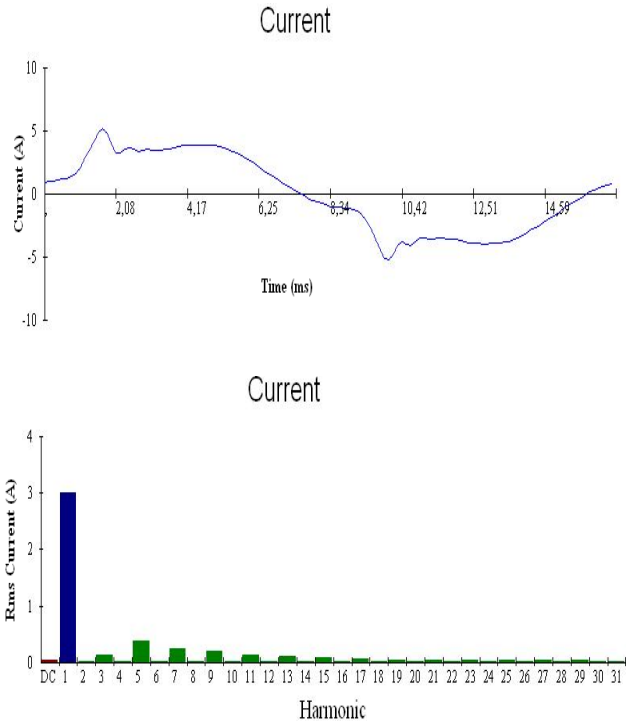


Fig. 4. QDF6 - Phase B. (a) Current waveform. (b) Current harmonic spectrum.

TABLE I
Measurements – *Fluke* 41B Power Harmonics Analyzer

QDF6 – Phase B - Outlets				
Frequency (Hz)	59,98		**Voltage (V)**	**Current (A)**
Power		**RMS**	126,09	3,06
kWatts	0,37	**Peak**	178,32	5,32
kVA	0,39	**THD Rms**	2,33	18,56
kVars	0,10	**THD Fund**	2,33	18,89
Total PF	0,95	**Harmonic Number**		
DPF	0,97	**1**	126,06	3,00
		3	0,77	0,14
		5	2,17	0,38
		7	1,41	0,25
		9	0,43	0,19
		11	0,63	0,14
		13	0,80	0,11

B. Medical Equipment

Eight surgery rooms compound the surgery center; however, there have been activities in only four rooms. In the past the rooms had one or two medical devices, and now they have complex medical systems and/or numerous portable devices.

By interviewing the employees, the following events of power disturbances were identified:

- During some surgeries when the image processing equipment by fluoroscopy works, some surgical luminaries were burnout frequently.
- When the electrosurgical units work, there was interference in patient care monitors displays, stopping the activities in the rooms.
- There were problems due to electrical shock next to some devices, but they will be studied in another evaluation.

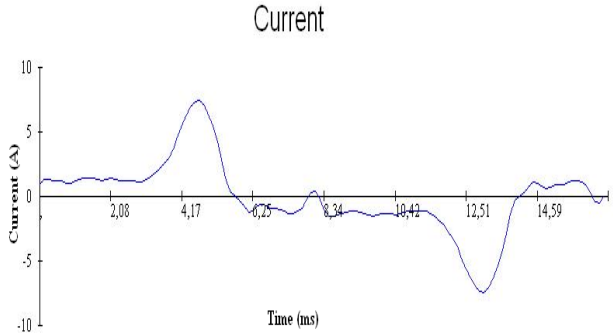
Inside the rooms records were taken from the equipments, as indicated in Figure 1- Reading 3.

1) Image Processing Equipment: The equipment is used for fluoroscopy studies in patients. This study is similar in concept to an x-ray process in which the image is projected continuously in a monitor. It operates on two modes: screening and snapshots

This machine is operated in different location at any hour of the day. It is attached to the circuits of the other outlets. Due to this situation the effect is dependent on the actual location of the equipment. It can be identified as a potential source of power quality concerns, especially when operating these loads close to sensitive devices. In surgery center there are two machines but one is damaged waiting for maintenance. Figures 5 and 6 show the image processing equipment measurements. The 3rd and 5th harmonic currents are evident on two operation modes, as Table II and III show, but they are not violating the harmonics limits [7].

In order to mitigate the interference of this device in another one, designing of dedicated power lines is recommended.

It is worth to notice the difference between the Total PF and DPF. The harmonic power is considered in DPF, increasing the apparent power, whose values must be used to calculate cable and transformers capacity.



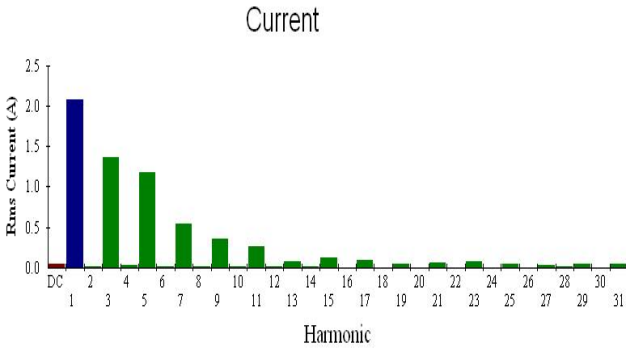


Fig. 5. Image processing equipment - Screening mode. (a) Current waveform. (b) Current harmonic spectrum.

TABLE II
Measurements – *Fluke* 41B Power Harmonics Analyzer

Image processing equipment – screening mode				
Frequency (Hz)	59,98		**Voltage (V)**	**Current (A)**
Power		**RMS**	126,20	2,85
KWatts	0,25	**Peak**	174,66	7,60
KVA	0,36	**THD Rms**	2,75	68,17
KVars	0,08	**THD Fund**	2,75	93,19
Total PF	0,69	**Harmonic Number**		
DPF	0,96	**1**	126,16	2,08
		3	1,13	1,36
		5	2,47	1,17
		7	1,70	0,55
		9	0,20	0,36
		11	0,95	0,26
		13	0,81	0,07
		15	0,25	0,12

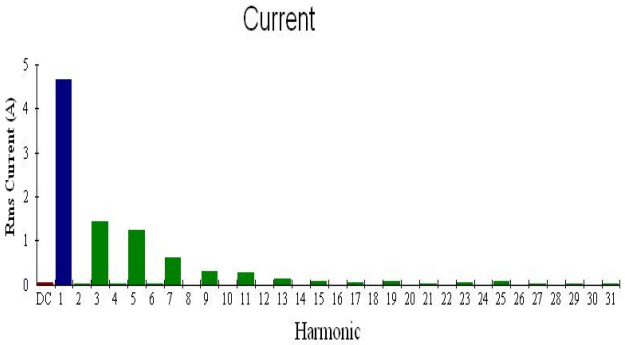


Fig. 6. Image processing equipment - Snapshot mode - Current harmonic spectrum.

TABLE III
Measurements – *Fluke* 41B Power Harmonics Analyzer

Image processing equipment – snapshot mode.				
Frequency (Hz)	59,98		**Voltage (V)**	**Current (A)**
Power		**RMS**	124,54	5,07
kWatts	0,55	**Peak**	172,02	11,05
kVA	0,63	**THD Rms**	2,82	40,36
kVars	0,16	**THD Fund**	2,82	44,12
Total PF	0,88	**Harmonic Number**		
DPF	0,96	**1**	124,5	4,64
		3	1,05	1,42
		5	2,61	1,25
		7	1,60	0,63
		9	0,14	0,30
		11	0,97	0,29
		13	0,82	0,14
		15	0,27	0,09

2) Electrosurgical units - in each room are used for cutting and coagulation in surgeries. They are loads that work on high frequency and the interference on the other devices are frequent. Figures 7 and 8 show the current measurements performed on two modes: idle and working. The THDI is the highest found among the surgery center devices, as shown in Table IV.

In the surgery center the displays distortions are frequently caused by the electrosurgical unit working. To mitigate the disturbances it is necessary to improve the surgery center grounding because since its conception no updating has been made. This subject has been studied in another assessment at hospital evaluating Electromagnetic Compatibility (EMC) problems.

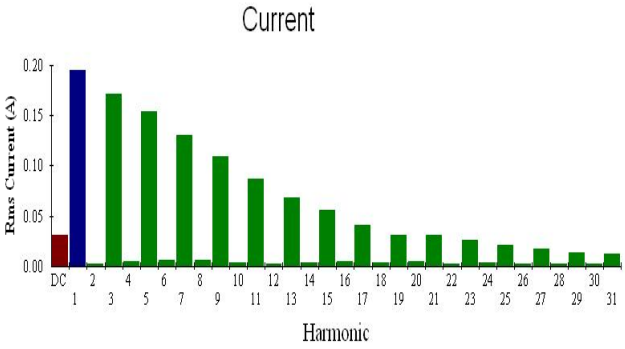


Fig. 7. Electrosurgical unit - Idle mode - Current spectrum.

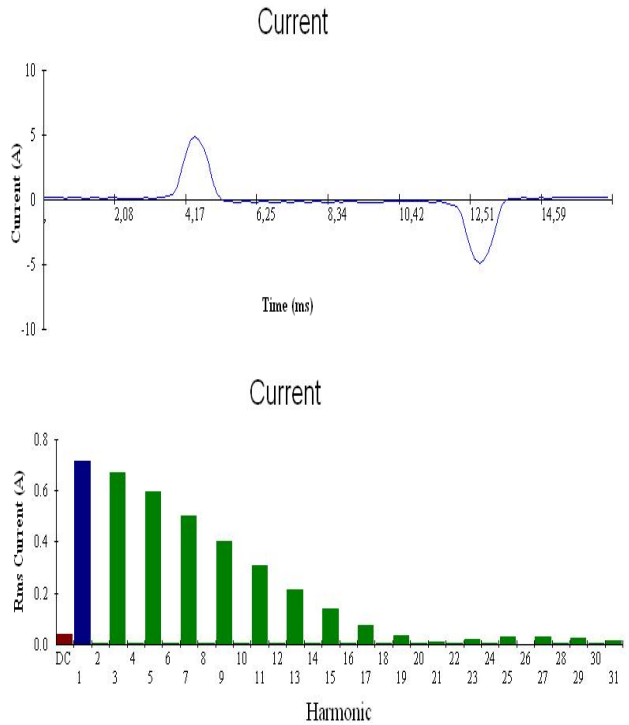


Fig. 8. Electrosurgical unit working. (a) Current waveform. (b) Current harmonic spectrum.

TABLE IV
Measurements – *Fluke* 41B Power Harmonics Analyzer

Electrosurgical unit working				
Frequency (Hz)	59,98		**Voltage (V)**	**Current (A)**
Power		**RMS**	128,44	1,38
KWatts	0,09	**Peak**	178,01	4,98
KVA	0,18	**THD Rms**	2,89	85,43
KVars	0,01	**THD Fund**	2,89	164,38
Total PF	0,51		**Harmonic Number**	
DPF	0,99	**1**	128,41	0,71
		3	0,62	0,67
		5	2,95	0,59
		7	1,89	0,50
		9	0,59	0,40
		11	0,48	0,31
		13	0,56	0,21
		15	0,32	0,14

3) Surgery luminary - Figure 9 shows the surgery luminary current harmonic spectrum, on idle mode. Ten incandescent lamps – 12Vdc – 25W, compound a surgery luminary. Even though the luminary equipment is supplied by batteries, which are recharging on idle mode, the brief blinking of lights can adversely affect surgical procedures.

In terms of voltage sags, imaging processor systems cause sags that may generate some of the problems. During its operation, some surgical luminaries have been experiencing frequent burnout or they have been blinking. Its circuit is attached to panel board QDF06 – Outlets, and not to panel board QDF05 – Lightning, so, one of the cause of disturbances is this interaction between the loads. It advises to separate the power lines. Another recommendation is to replace the lamps in the operating rooms by their energy storage type counterparts, to work in emergency situations. The Table V shows equipment measurements on idle mode.

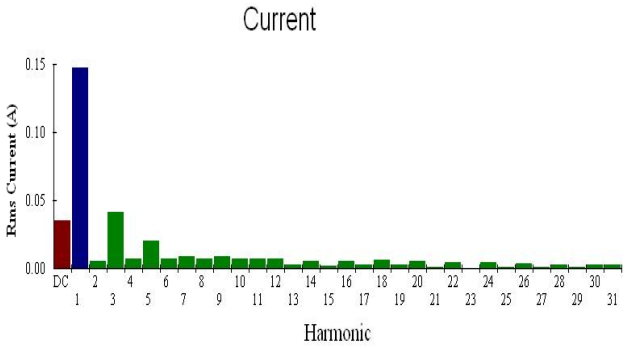


Fig. 9. Surgery luminary - Idle mode – Current harmonic spectrum.

TABLE V
Measurements – *Fluke* 41B Power Harmonics Analyzer

Surgery luminary – idle mode.				
Frequency (Hz)	59,98		**Voltage (V)**	**Current (A)**
Power		**RMS**	128,9	0,16
Watts	15,28	**Peak**	180,73	0,19
VA	20,28	**THD Rms**	2,6	34,12
Vars	10,02	**THD Fund**	2,6	36,30
Total PF	0,76		**Harmonic Number**	
DPF	0,82	**1**	128,88	0,15
		3	0,18	0,04
		5	2,63	0,02
		7	1,77	0,01
		9	0,33	0,01
		11	0,6	0,01

4) Patient Monitor - The patient monitor is an extremely practical way to show information about the patient vital signs. It is possible to record the readings using a floppy disk drive. They are equipped with switch-mode power supplies and are as sensitive to disturbances as computers.

Monitors and computers are 3rd harmonic current source. High neutral currents have been observed even when the phase currents are balanced in system with this 3rd harmonic current [8]. Figure 10 and Table VI shows the high THD of this equipment as its evident harmonic components. There are patient monitors in almost all the hospital sectors. An audit in the entire hospital is recommended to study the effects of the monitors working.

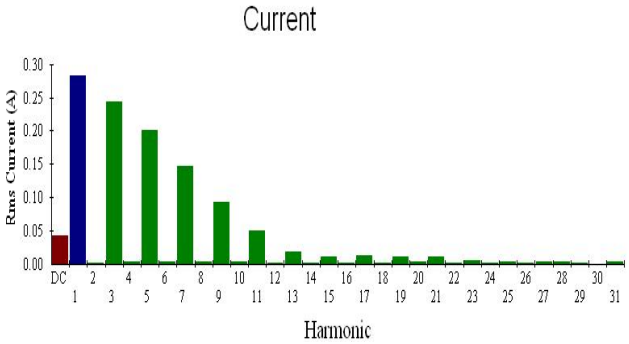


Fig.10. Patient monitor working - Current harmonic spectrum.

TABLE VI
Measurements – *Fluke* 41B Power Harmonics Analyzer

Patient monitor.				
Frequency (Hz)	60,04		**Voltage (V)**	**Current (A)**
Power		**RMS**	128,35	0,43
Watts	32,00	**Peak**	178,99	1,27
VA	55,00	**THD Rms**	2,61	78,53
Vars	9,00	**THD Fund**	2,62	126,84
Total PF	0,59	**Harmonic Number**		
DPF	0,96	**1**	128,30	0,27
		3	0,44	0,22
		5	2,69	0,18
		7	1,67	0,14
		9	0,32	0,09
		11	0,59	0,04
		13	0,66	0,01

VII. CONCLUSION

The physical facilities range from 30 to 35 years old. The neutral and phase wires, transformers and panels were not designed to support nonlinear loads and harmonic flow. Therefore, to improve the electrical system efficiency it is necessary to establish a periodic power quality assessment at hospital, mainly in other sectors, not only in the surgical center.

The records performed from the panels and equipments did not present any evident disturbance, values out of the standard limits.

Frequently, new loads are attached to the hospital electrical system, therefore, their specifications will have to be implemented according to available codes and regulations and the interaction among harmonic producing loads will have to be studied.

A study to use Uninterruptible Power Supplies (UPS) in surgery center is recommended, mainly for emergency lighting, operating rooms, patient monitoring and other equipment that is important to the patients safety.

The evaluation has been an important educational tool because of the involvement of hospital employees and students, giving them ability to identify and prevent power quality events, considering its relationship to the security of people and equipments.

VIII. ACKNOWLEDGEMENT

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