

A CONTRIBUTION TO THE HEALTH AREA BY MEANS OF AN ASSESSMENT OF THE IMPACT OF QUALITY OF POWER AND OF ELECTRICAL INSTALLATIONS UPON ELECTROMEDICAL EQUIPMENT

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ABSTRACT

Through all segments of our society, the use of electronic equipment with computerized resources increases every day. In the health-medical area, designated electromedical equipment, they provide support to sectors in charge of diagnosis, treatment or surgical procedures, improving the quality of services and the manner patients are cared for.

However, the global success of this process must take into consideration the quality of electrical installations at these facilities, as well as the electrical power supplied to the equipment at these same facilities.

Through laboratory research, one attests the risk of medical diagnoses based on information provided by electro-medical equipment powered through electrical networks which do not meet the standards in effect, or which are completely disturbed by other equipment typical of electro-medical environments.

The methodology applied consisted of measurements of the parameters referring to the quality of electrical power in health care facilities. Special attention was given to the voltage harmonic content and to momentary voltage variations, especially to sags caused by X-ray, computerized tomography and magnetic resonance equipment or by induction motors. Later, these disturbances were reproduced in power supplies that are specific for this objective, installed at the Laboratório do Centro Tecnológico de Qualidade de Energia da Escola Politécnica da Universidade de São Paulo- Energy Quality Technological Center of the Technical School of the University of Sao Paulo, known as Enerq-ct. Portable electromedical equipment, kindly supplied by national manufacturers, were subjected to these signals for assessment of their performance.

KEYWORDS: Electronic equipment, health-medical area, electromedical, diagnosis, health care facilities, X-ray, tomography, magnetic resonance.

INTRODUCTION

Advance in technology and development of Medicine at the present day have been promoting great benefits to human health all around the world. More and more frequently, new medical diagnostic processes and modern surgical techniques make use of state of the art equipment, designed and built with advanced electronic technologies and completely computerized.

In Brazil, in order to have its rights of commercialization granted, this equipment must be registered at the Sanitary Agency of the Ministry of Health, after attestation of complying with applicable national and international specifications of technical standards. Another factor that must be considered to guarantee the safety of patients and the reliability of the results is the technical qualification of users of electro-medical equipment, as well as the qualification of the staff in charge of the technical assistance of this

equipment. The global success of the process, however, must include the quality of the electrical installations within health-medical environments, as well as the quality of the electrical power supplied to such equipment.

This article has the objective of attesting, through laboratory research, the risk of medical diagnoses based on information provided by electro-medical equipment fed in electrical networks which do not comply with the standards in effect or are completely disturbed by other pieces of equipment typical of health-medical environments. It is, therefore, a contribution to the health area, since the results of this work will allow manufacturers to improve their electromedical equipment. Likewise, designers and people in charge of the maintenance of electrical installations within health care facilities will be aware of the obligation of complying with the applicable standards, avoiding improvisations which cause risks to patients undergoing treatment or surgical intervention.

The electrical power can have its quality determined in function of four basic electrical disturbances in a current tension signal, found in an electrical installation: tension amplitude, signal frequency, voltage and current unbalances in three-phase systems, and distortions on the signal waveform [1]. Concerning the quality standards of electrical power supplied by the concessionary system, the relative absence of tension variations is of great importance, especially the absence of power outages [2]. On the other hand, for the customer, the term quality of electrical power concerns, mostly, the relative absence of voltage variations as measured in an energy-delivery point.

On most cases, the disturbances are generated by the customers themselves, or by their neighbors, through the use of "modern technology" equipment implemented with non-linear technology. Starting in the 1990s, the increasing use of this equipment through all segments of our society has made the situation worse under the aspect of the quality of electrical energy. In general, those pieces of equipment require a high-quality power supply for their perfect operation, but since they are the main generators of disturbances, they end up becoming their own victims [3].

TECHNICAL STANDARDS

As far as electromedical equipment is concerned, we can find the series of international standards IEC 60601 [4], which were the base for the elaboration of the national standards

NBR IEC 60601 [5]. This set of standards has the main purpose of establishing the minimum safety conditions and the performance of electromedical equipment. With regard to electrical installations, in a worldwide basis, one can find the standard IEC 60364-Electrical Installations of Buildings, as a general standard which, in its part 7-710, deals with the requirements for electrical installations in medical facilities and associated areas [6]. In Brazil, in the same way, there are the standards NBR 5410-Low-Voltage Electrical Installations [7] and NBR 13534-Electrical Installations in Health Care Facilities [8]. The latter became effective on December 29, 1995, with the purpose of establishing a set of minimum safety requirements for the electrical installations in health care facilities, such as hospitals, ambulatory care centers, medical and odontological clinics, veterinary clinics, etc. Nowadays, NBR 13534 is being updated. The fourth issue of the standard NBR 5410 became effective on March 31, 2005.

The standard NBR 13534 considers the electrical installation of a health care facility as the set of components and equipment accordingly interconnected and appropriately located in areas and places that are specific for this purpose, observing the supply, transformation, storage, distribution and use of electrical energy. In each case, power must be supplied on such a way that it is compatible with the demands and the safety that are specific to each medical-purpose site, either diagnostic or therapeutic ones. The electromedical equipment is excluded from the mentioned standard, and its safety is ruled by NBR IEC 60601-1 [5]. Yet, NBR 13534 classifies environments located in health care facilities, into Groups and Classes. The first criterion, referring to Group, deals with the kind of electromedical equipment found on the location during the medical procedures. Thus, three groups are expected, based on whether they have parts applied to the human body or not. Table I presents this classification:

PLACE	TYPE OF ELECTROMEDICAL EQUIPMENT
Group 0	No parts applied
Group 1	a) part applied, externally b) part applied to bodily fluids, but not to the heart
Group 2	Part applied to heart. Additionally, electromedical equipment essential to life support

TABLE I: CLASSIFICATION OF PLACE REGARDING TYPE OF ELECTROMEDICAL EQUIPMENT [8].

Hospitals and similar environments must have a safety source for the case of failure of the regular power supply, capable of supplying their needs for a specified time, considering, in addition, the time necessary for the transfer. Safety installations have the purpose of guaranteeing the continuity of the essential services to the preservation of life

and safety, or are designed to operate in emergency situations.

The second criterion, referring to class, corresponds to the characteristics of the safety system, as shown on Table II:

CLASS	TIME LIMIT FOR SWITCHOVER (s)
5	80,5 (1)
15	80,5 (1)
> 15	> 15 (2)

Notes: (1) - automatic;
(2) - manually or automatic.

TABLE II: CLASSES FOR THE SAFETY SUPPLY SYSTEM [8].

Class 0,5 refers to a power source capable of automatically assuming the power supply and reestablishing it in 0,5s at the most, maintaining it for no less than 1 h. This class is destined exclusively to power surgical lights. Equipment which cannot have its power supply interrupted, especially if controlled by microprocessors, must be integrated to UPS (Uninterruptible Power Supply).

Class 15 comprises equipment used in surgical procedures, assigned to life support, as mechanical ventilation, and connected to the supply of gases. The switchover should occur automatically, reestablishing power in no more than 15s. It must function in case of power outage or voltage dip

greater than 10% of nominal value for a period longer than 3s. In addition, class >15 refers to electro- electronic equipment not directly connected to patients, such as those present in laundry-rooms, equipment for sterilization of materials and systems for disposal of remains. In this case, switchover could be either manual or automatic, being able to actuate in a time superior to 15s, and should guarantee power supply for at least 24h. With regard to electromedical equipment, there are no studies concerning their interaction with electrical installations in health care facilities and the quality of the electrical energy supplied to these facilities [9]. Many of these facilities have electrical installations that are completely adapted and in disagreement

with NBR 13534 [8]. On the other hand, the same standard does not specify maximum figures for disturbances in those facilities, raising doubts on the information provided by the electromedical equipment, either for diagnostic or medical treatment purposes. In Brazil, ANVISA - Agência Nacional de Vigilância Sanitária (National Sanitary Agency) is the agency within the Ministry of Health responsible for coordinating the enforcement of this norm. Through its state-departments, it gives official approval to electrical installation projects for health care facilities. Many of the problems related to quality of electrical power are generated within customers' installations, due to commutation of high-power loads or to the extensive use of speed variators for induction motors. Several international organizations have standards on this issue, but a consensus among them is yet to be achieved. Therefore, there is the need of development of research on sensitive equipment and its interaction with systems of electrical power supply [9]. Although, rules on this subject or an appropriate legislation are not available in Brazil yet. Some limitations for harmonic distortion, flicker severity and voltage unbalance can be found in the report "Critérios e Procedimentos para Atendimento a Consumidores com Cargas Especiais - Criteria and Procedures for Supplying Special-Loads Customers", developed by the Coordinating Group of Eletrobras Electrical Systems Planning, first issued in March 1993. In the international field, the limitations for harmonic distortions are mentioned in standards ANSI/IEEE Std 519/92 [10] and IEC 61000-3-2/01 [11]. The first one can be more appropriately applied to great consumers of electrical power, either commercial or industrial, making them responsible for the control of generation of harmonic currents, while concessionaries should be responsible for the control of levels of voltage distortion on their systems, especially at the common coupling point with the customer. The second norm lays the requirements on injection of harmonic currents by low-voltage equipment and with a current phase of up to 16A [12].

QUALITY OF ELECTRICAL POWER IN HEALTH CARE FACILITIES.

Health care facilities have been constantly increasing the use of electromedical equipment, which performs important functions, such as patient information systems, diagnostic and treatment equipment, among others. Therefore, it is to be realized that electricity in the hospital environment is a source of life, capable of interfering with the patient's ability to survive or not, through the employment of pulmonary ventilation equipment, medicine infusion pumps, lights for surgical illumination, emergency power, compressed air, oxygen, among others [9].

Other equipment, in spite of not being linked to the patient's survival abilities, makes use of electrical power to provide important information concerning the therapeutic treatment, such as laboratory equipment, imaging and physiotherapy equipment, or others, which may compromise patient's health. Moreover, a great deal of information is stored in computerized systems, frequently interconnected through networks, on such a way that aspects related to the quality of the electrical power become extremely important.

ELECTRICAL INSTALLATIONS IN HEALTH CARE FACILITIES

Although the Brazilian standard NBR 13534 [8] issued in 1995 specifies the required conditions for electrical installations in health care facilities as means of guaranteeing personal safety, especially the patient's, what actually happens in most cases is exactly the opposite.

In Brazil, the health issue has been constantly deteriorating, especially due to lack of investments, showing the complete disregard towards the human being. Taxes imposed on citizens, at first aimed to the medical area, are redirected to other purposes, as is the case with the CPMF-Contribuição Provisória sobre Movimentação Financeira - Provisional Taxation of Financial Transactions, CPMF.

Often, state of the art pieces of equipment installed in hospitals and similar facilities can provide incorrect data because they are powered by electrical installations which are inefficient and that lack maintenance. The patient is the one who most suffers because of this situation, as his life may depend on these data.

Within the health-medical environment, the failure of one piece of equipment - due to the quality of the power supply, inefficient electrical installations, or absence of maintenance of equipment and installations - can lead to the loss of a human life. Unfortunately, there are no statistical data regarding those situations, but it could be asked what the acceptable rate of failure would be when one is dealing with human lives [13]. It can be realized, therefore, the criticality of the problem, once safety is usually linked to high investments. The objective of this technical article is not to teach how to design electrical installations or how to maintain them within acceptable standards, but to present factors which may contribute to their deterioration, by presenting real cases witnessed by the author himself, during his field research. In our country, general regulations for low-voltage electrical installations are found in NBR 5410 [7], whose latest issue became effective in March of 2005. NBR 13534 [8] complements the previous standard in case of electrical installations in Health care facilities.

With regard to work safety, the issue on April 7, 2005 of the new NR-10 - Safety in Installations and Services on Electricity [14] has put Brazil on the level of international standards for work safety. The standard is objective and is aimed at the worker, who plays the most important role in the production processes within companies, regulating clearly the employment of the correct techniques in installations and in services with electricity so as to preserve life and assure that the working environments can become safer. Particular attention must be paid to the ground connection system, as a way of guaranteeing the continuity of electrical power supply on a steady manner, assuring the proper performance of the protection devices and preserving personal safety with regard to electrical accidents [13].

Most electrical installations in health care facilities are treated with the same disregard which can be observed

in other activities, either industrial, commercial or service-like. The lack of updated electrical diagrams, of identification of command and control devices in panels, identification of grounding points, among others, are also some of the factors which compromise the good performance

of installations and cause accidents, frequently severe ones. Next, we present some photographs of electrical installations in health care facilities in the city of São Paulo. Comments on the risks and non-conformities are presented for each case.



Picture 1

NBR 5410 [7] determines that insulated conductors (without cover) only can be installed in enclosed ducts, since they are deprived of protection against mechanical shock which could damage insulation. Mends and insulation repositionment don't comply with the standard either. Conductors with different colors have been mended, making identification difficult and placing maintenance personnel under risk. Therefore, pictures 1 and 2 present examples of

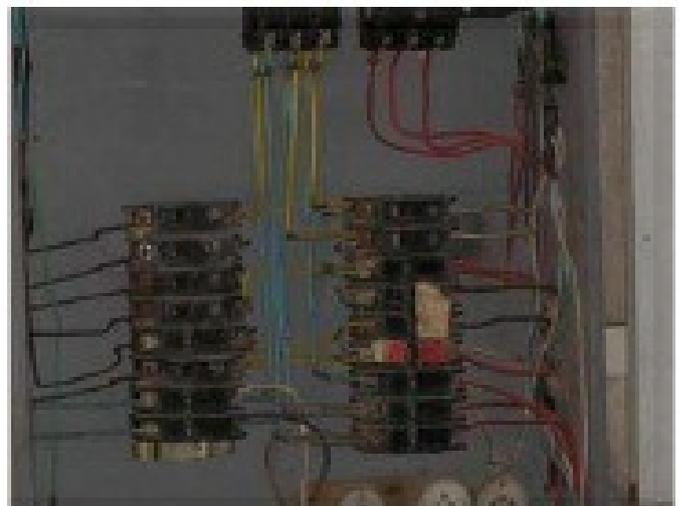


Picture 2

non-conformity to the rule. Within the same building, electric distribution panels completely open and without protection against direct contacts were observed. Circuit-breakers are assembled on a wooden surface, connected by means of conductors. The absence of bus-bars causes current unbalances, compromising the proper performance of the equipment switched to these panels.



Picture 3



Picture 4

In the administrative dressing rooms, showers were installed disobeying all safety concepts, as shown in picture 5. Moisture penetration into electrical ducts caused by the absence of a terminal box may lead to severe electric accidents. Since showers lack a shielded resistance, the circuit does not incorporate a residual differential



Picture 5

current, ignoring standard NBR 5410 [7]. Many of the installations of the atmospheric discharge protection system have been performed without respecting the standard NBR 5419 [15], showing sharp bends and loose braces. Picture 6 presents one of those cases.



Picture 6

In many places of the hospital facility, derivation boxes can be found without lids, with a great number of exposed conductors, as shown in picture 7. The presence of a parallel cord installed in an electroduct can be noticed, not complying to norm NBR 5410 [7].



Picture 7

METHODOLOGY

The methodology applied consisted of taking measurements of parameters regarding quality of electrical power in health care facilities. Particular attention was paid to the voltage harmonic content and to momentary voltage variations,

especially sags. Next, typical disturbances to those environments were reproduced in voltage supplies that are specific to this purpose, located in the Energy Quality Technological Center of the Technical School of the University of Sao Paulo, known as Enerq-ct. Portable electromedical equipment, kindly provided by several national manufacturers were subjected to these signals to have their performance verified. Some trials, as those related to voltage sags, were complemented by the recommendations in standard IEC 61000-4-11 [16]. The main equipment responsible for generating voltage signals identical to the ones measured in the field is a power source manufactured by Pacific Power Source, model 390AMX with an output power of 9kVA. It is, perhaps, the only of such power sources available in this country, equipped with a UMC-31 three-phase controller, capable of generating frequencies between 45 and 500Hz. Once the magnitude is fixed, it has a steady operation, with a precision of 0,5% within predetermined values. In-the-field measurements were performed with an Energy Quality Analyzer Fluke 43B, purchased especially for this purpose. Other precision instruments have also been used, such as a Tektronix TD 1002 oscilloscope, among others.

POLLUTING LOADS IN HEALTH CARE FACILITIES

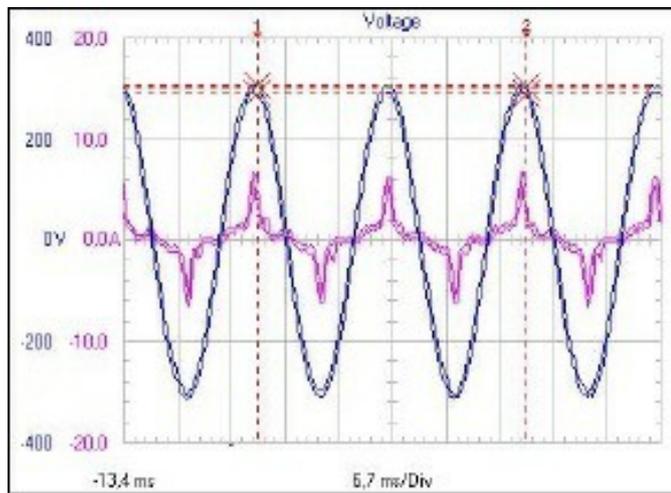
Technological advance is implying a greater use of sensitive equipment in all segments of society, but unfortunately, detrimental regarding aspects related to quality of electrical power. As far as electromedical equipment is concerned, either connected to a patient or providing data on his conditions, the result can be compromising. In the latter case, due to incorrect

information, inadequate medical procedures can be applied, compromising the patient's life. As previously mentioned, most disturbances are generated within the health care facility, by commutation of high-power loads, speed variators for induction motors and mainly by pieces of equipment specific to those environments.

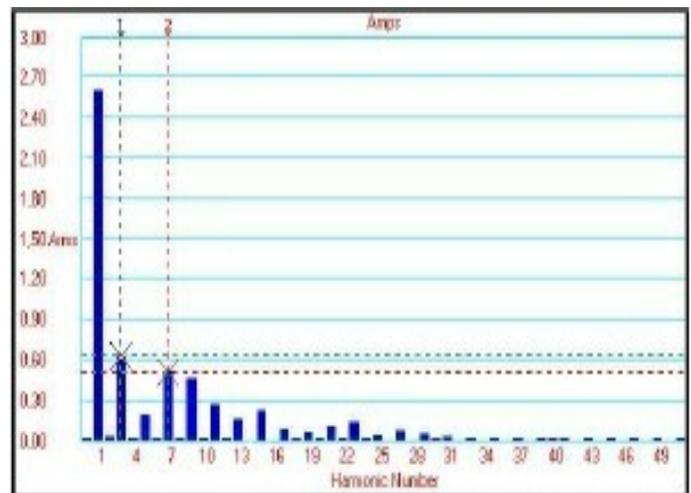
A. X Rays

In 1995 the world commemorated 100 years of the discovery of X rays by the German physicist Wilhelm Konrad Roentgen (1845-1923). Its use was a major breakthrough for diagnostic techniques, thanks to one of its features: high penetration, which permits the observation of internal organs without the need of surgery, either in Medicine or Biology. In

mechanical or metallurgic industries, it allows the identification of internal cracks in metallic structures, and in food industry the extension of the conservation period of perishable products. X rays belong to the spectrum of electromagnetic radiation which differ among themselves by the frequency and length of wave. The production of X rays is accomplished through a source that provides electrons, which are accelerated in a free trajectory until they collide with the atoms in a shield, promoting the displacement of electrons and consequent energy emission. X rays equipment has two operating modes: continuous and momentary [9]. Picture 8 presents tension and current curves, measured in continuous mode. Although the figures for the current in continuous mode have a low value, their harmonic content is high, as shown in picture 9.



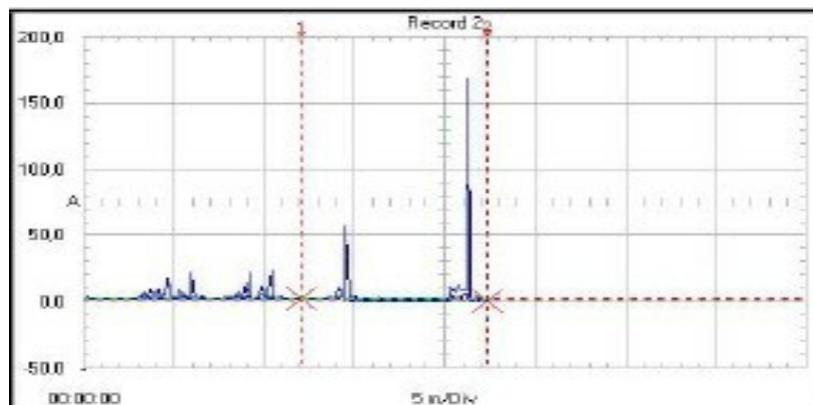
Picture 8: Current waveform



Picture 9: Current harmonic content

During operation in momentary mode at the instant of a radiography, there is a high demand for electrical power, and temporary voltage sags can occur, compromising the

performance of sensitive equipment connected to the supply network. Picture 10 shows the figures for the current during the process of making radiographs.

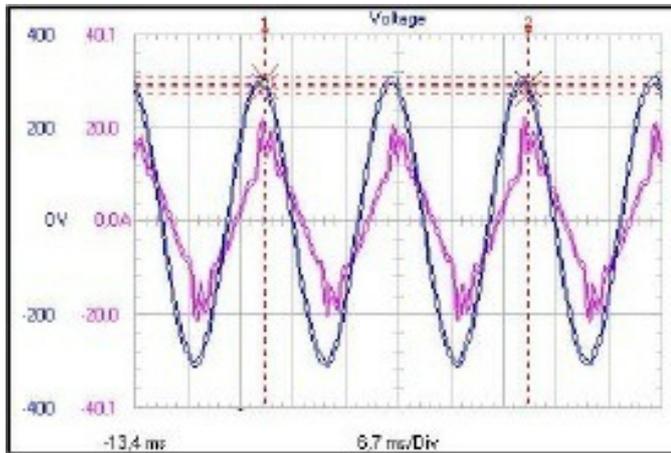


Picture 10: Current peaks generated by X rays equipment

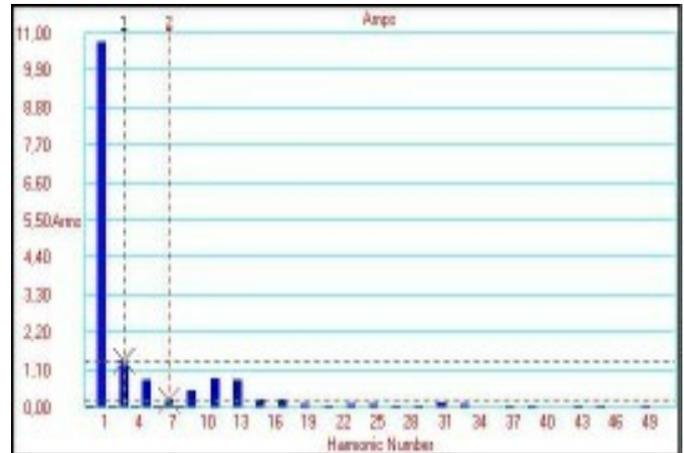
B. Computerized axial tomography - cat

It is one of the most reliable and safe methods of examination in modern Medicine. It consists of an X rays equipment which turns around the patient's body, making transverse radiographs. Next, these radiographs are converted into tomographic cuts by a computer, that is,

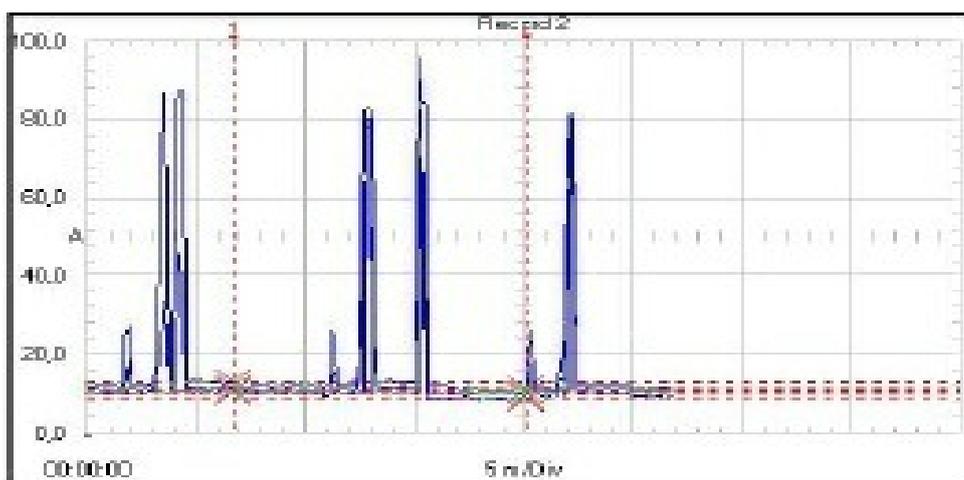
a series of sections which will later be assembled to form a complete image. Thus, it behaves similarly to the X rays equipment, demanding a completely distorted current, as shown in picture 11. The harmonic content and current peaks during its employment are shown in pictures 12 and 13.



Picture 11: Current waveform



Picture 12: Current harmonic content

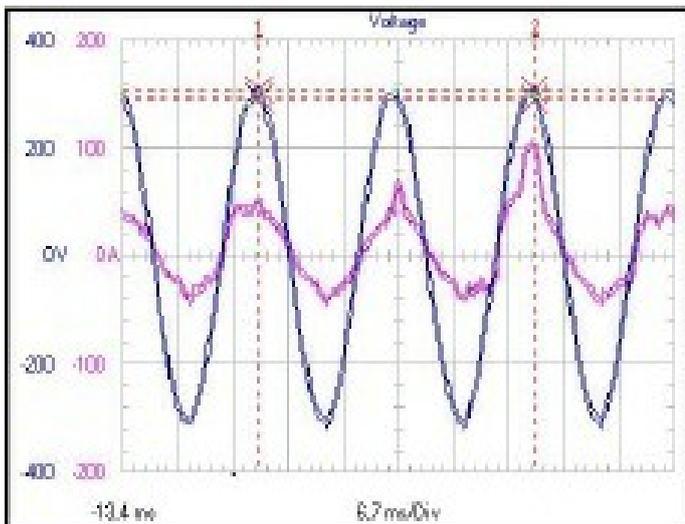


Picture 13: Current peaks generated by computerized tomography equipment

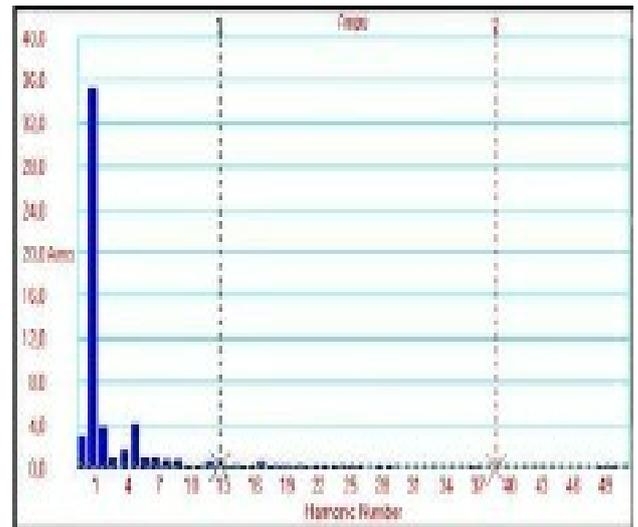
C. Magnetic resonance imaging - mri

Nowadays, Medicine can employ a precise and modern tool, with the purpose of obtaining a sectional image of the internal structure of the body. The image, obtained through magnetic properties, provides doctors with detailed data on location, size and composition of corporal tissue examined, allowing for a quick and precise diagnosis. Magnetic resonance does not make use of X rays; it uses the magnetic properties of atoms that constitute all substances, including obviously the human body. Through a powerful magnetic field generated by the equipment scanner, electrical signals are emitted by the atomic nuclei of body tissues. These signs are intercepted by a circular antenna surrounding the patient. The intensity of the signal varies according to the kind of tissue. A computer assigns each signal to a point corresponding to the body area being

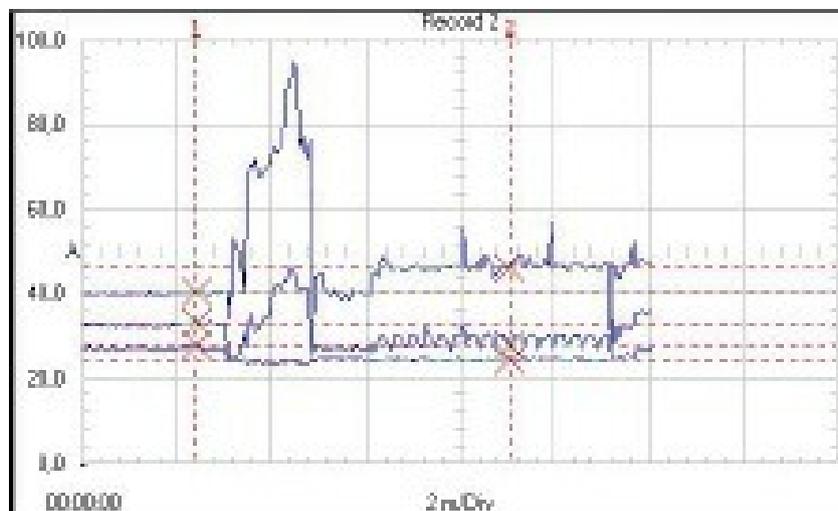
examined and turns them into an image on the screen. Contrary to several X rays examinations, there is no necessity of removing the patient's clothes, however all metallic objects which could interfere with the imaging process should be removed. In the same way, dental plates, pacemakers or vascular prostheses, which may not be removed, should be informed by the patient to the person responsible for the examination. Once magnetic resonance does not involve the use of X rays, there is no need of taking the same precautions. According to present scientific knowledge, the value of magnetic induction necessary to obtain precise results is 2T (20000 times Earth's magnetic field), and does not have any harmful effects on living organisms. In recent years, millions of magnetic resonance procedures have been performed and reports of collateral effects are still unknown.



Picture 14: current waveform



Picture 15: harmonic content of current



Picture 16: current peaks generated by magnetic resonance imaging

D. Electric induction motors

Due to qualities such as: ease of transportation; absence of pollution - preserving man as well as the environment; ease of command and control; non-requirement of storage and the low cost in face of the mentioned advantages, electricity is the preferred form of energy to be transformed into other forms, such as thermal, luminous, mechanical, etc. To transform electrical power into mechanical energy, the electric motor is used, which at present is, certainly, the principal equipment for the final use of the electrical energy. It would be completely impossible for mankind to be able to live without this equipment [17]. In industrial activities, an estimate 75% of the electrical power consumed is transformed into mechanical energy through electric motors [18].

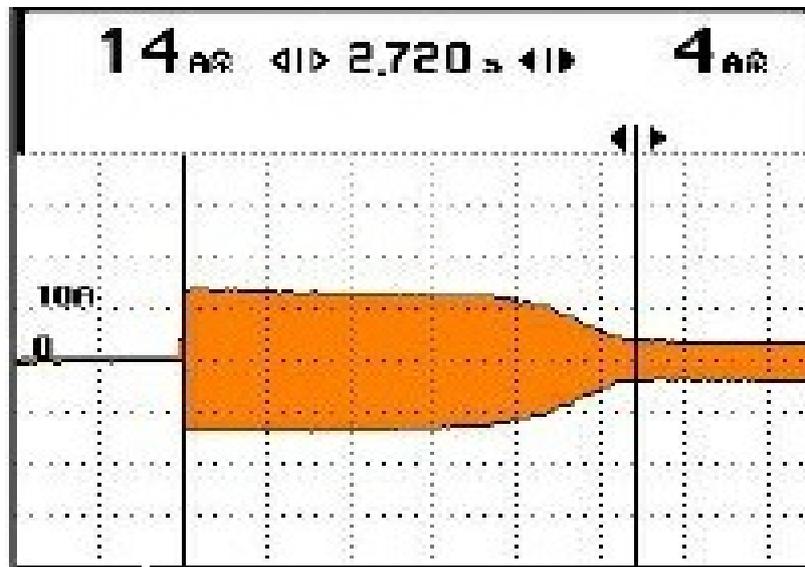
Thus, we can state that technological progress is directly connected to the existence of the electric motor at men's service, always associated to its simple and robust construction, at a low cost and with a high flexibility to be adapted to actuate machines and industrial equipment.

In addition, the electric motor performs energy transformation on a relatively simple manner, requiring low-cost installation and maintenance. It operates silently, occupies little space, has a long life and a high efficiency. However, to allow all those advantages to come true, it is important that the engine is powered by an electrical network that is adequate and of good quality, that it is appropriate to the place in which it is installed and that it has power compatible with the load it will act upon.

Besides tension and frequency, the feed network imposes certain limitations to the motor, with regard to the currents during start-up, once these are the main disturbances caused by the motor to the network, under normal conditions. The start-up currents, which assumes values far superior to the nominal current, must be taken into consideration when dimensioning the terminal circuit to avoid detrimental voltage sags. The current absorbed by motors with squirrel-cage rotor, during start-up, reaches values much higher than its nominal one, requiring it to be able to withstand thermal and dynamic efforts in its coils.

The maximum values of current absorbed with the blocked-rotor to the normal tension are specified in the standard NBR 7094 [19], in kVA/cv or kVA/kW. The referred norm also requires the specification of the ratio of the blocked-rotor current to the nominal current in the identification plate. Picture 17 shows the current during

start-up of an induction motor which actuates upon a vacuum aspirator for medical use. The blocked-rotor current of 14 A drops to the values of the nominal current in 2.72s, enough to generate a voltage sag detrimental to other equipment connected to the same circuit.



Picture 17: current during start-up (direct start)

When the supply network characteristics or the characteristics of other customers connected to the supply network cannot stand the start-up transitoriness, one can use start-up devices designed to reduce transitorily the voltage on the motor terminals. The usual low-voltage start methods are: star-triangle start, compensator switch and soft-starters. In hospital facilities, induction motors are used in several pieces of equipment, on such a way that the most powerful ones are often located in laundry sections, in washing machines, clothes driers, centrifuges and calenders [20].

TESTED EQUIPMENT

Due to ease of transport, portable electromedical equipment was tested, frequently used in Intensive Care Units or Surgical Centers. The trials were performed at the Laboratório do Centro Tecnológico de Qualidade de Energia da Escola Politécnica da Universidade de São Paulo- Energy Quality Technological Center of the Technical School of the University of Sao Paulo. Up to the present moment, three types of electromedical equipment were subjected to tests: heart monitor, pulmonary ventilator and pulse oxymeter. It was verified the behavior of such equipment when subjected to a voltage supply with a high harmonic content and when under influence of voltage sags.

A. Heart monitor

It is used for continual monitoring of the electrocardiogram, in surgical centers and intensive care units, as well as for monitoring temperature, breathing and other information. In addition to the waveform in the electrocardiogram, it can indicate the heart rate, and also provide important information like oxygen saturation levels in arterial

blood (SpO₂) and arterial pressure. The equipment used in the trials that will be presented performs those measurements in a non-invasive manner.

The human heart is an organ that performs the function of an electrohydraulic pump, pumping blood throughout the body, with the purpose of promoting the perfect irrigation of cells [20]. Cells are spread all through the body, thus blood must supply them nutrients and oxygen, and at the same time, collect carbon dioxide. One can observe that the adequate and healthy cell function will in turn depend on the perfect function of the heart. This organ is constituted by a purplish muscle with a conical shape, and a vertex supported by the diaphragm. In the human body, the heart is located between the two lungs, slightly offset to the left side of the chest [22].

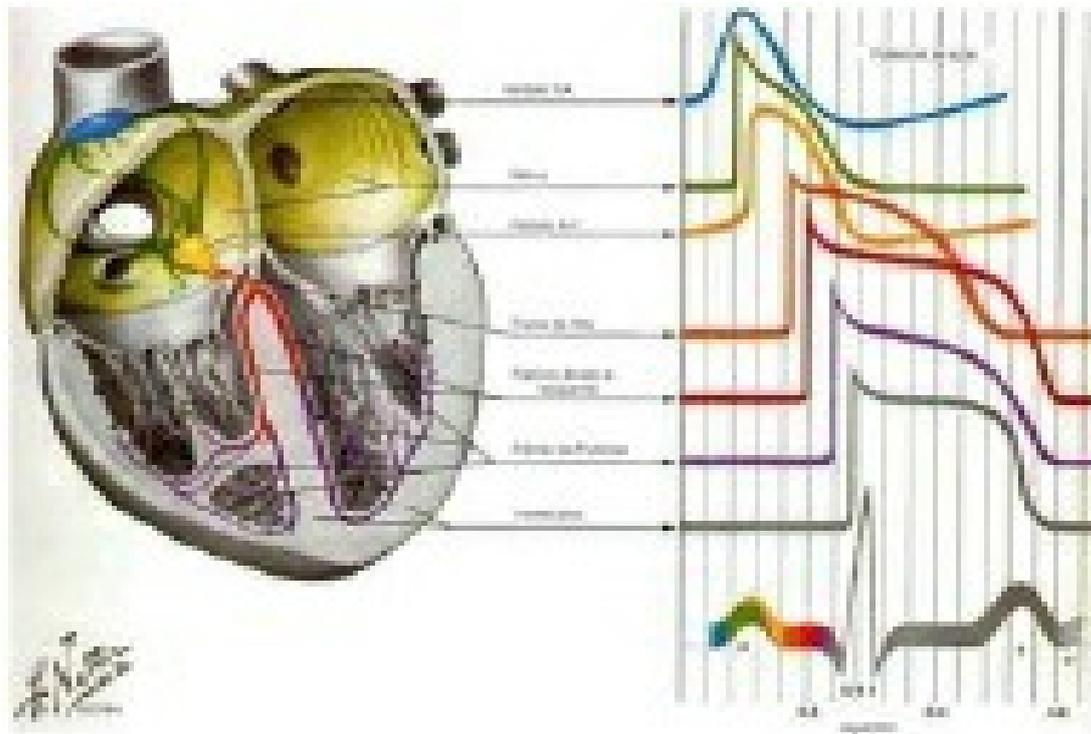
When at rest, blood flow in the adult human being is approximately 5 l/min, equivalent to 60-80 heartbeats per minute. During exercise, the flow rises to 15-25 l/min and the heartbeat rate is between 120 and 160 [20].

Due to this fact, muscular fibers which cover the walls inside the ventricles are the most irrigated in the human body to assure a high oxygenation rate and a good amount of nutrients.

Since the ventricles' muscles are responsible for the pumping of blood to the lungs through the pulmonary artery, and for the pumping of blood to the whole body via the Aorta, these muscles have a high energy consumption. It is on these muscles that serious problems as infarct (blockage of arteries) and ventricular fibrillation (flow of electric current through the heart) take place.

The electrical activity generated within the heart can be detected on the body surface by means of appropriate electrodes placed on predetermined positions. This methodology, called electrocardiogram, which is used

in Medicine for verifying of heart function, presents the potential differences generated in each place of the heart. Picture 18 presents potentials of several places and the final result [23].



Picture 18: Potentials in different parts of the heart

Different waveforms, intervals and segments can be observed in the electrocardiogram, and they translate the electrical activities belonging to different parts of the heart in separate stages of its function. Through analysis of morphology, amplitude, duration and polarity of different results, among other aspects, it is possible to determine a condition of normality or among several pathological conditions of the heart.

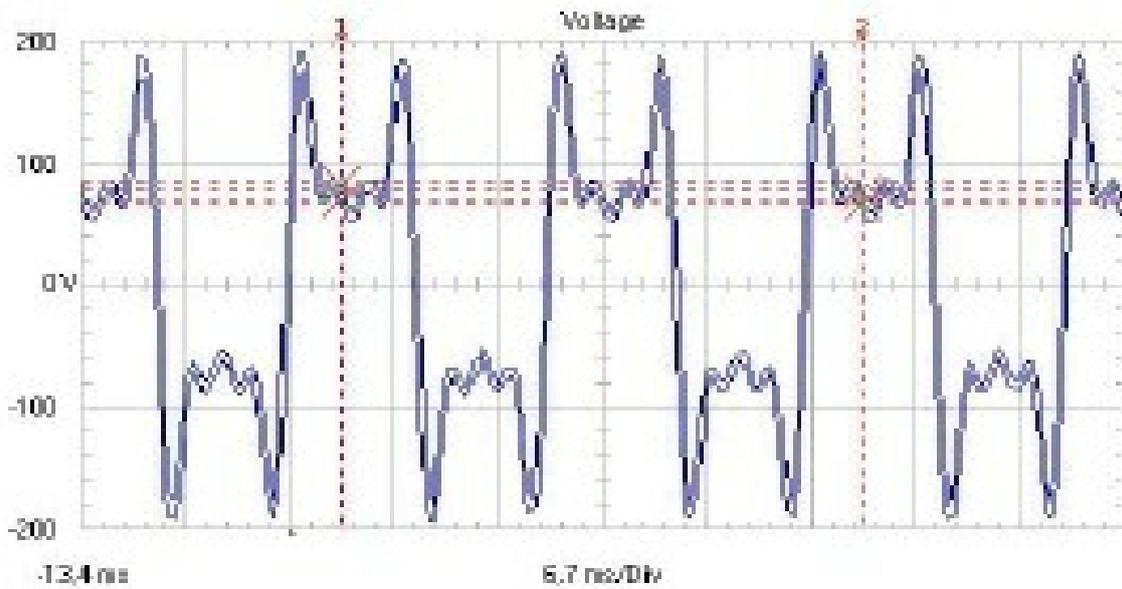
The first set of trials had the purpose of verifying the operation of the heart monitor when fed in a power supply containing voltage harmonics, as shown on Table III. To prevent the instrument from being connected to a human being during tests, we used a patient simulator, which generates voltage pulses on a steady and regular basis, similar to those generated by the heart. The equipment tested has an internal battery for operation in cases of energy outages. In all tests, it was powered by a voltage of 110V.

Test n.	Fundamental (%)	rd harmonic (%)	th harmonic (%)	Th 'harmonic (%)	THD _r (%)
1	100	3	0	0	3
2	100	10	0	0	10
3	100	20	0	0	20
4	100	50	0	0	50
5	0	100	0	0	100
6	100	50	30	20	61.8
7	100	70	50	30	91.5

TABLE III: TEST WITH VOLTAGE HARMONICS

The maximum value obtained for the third voltage harmonic during measurements in several hospitals was 2%, thus the values for tests were far superior, exactly to verify

the behavior of the equipment under conditions that can be far more critical. Picture 19 presents the voltage curve resulting from test number 7.



Picture 19: voltage waveform distorted due to the presence of harmonics

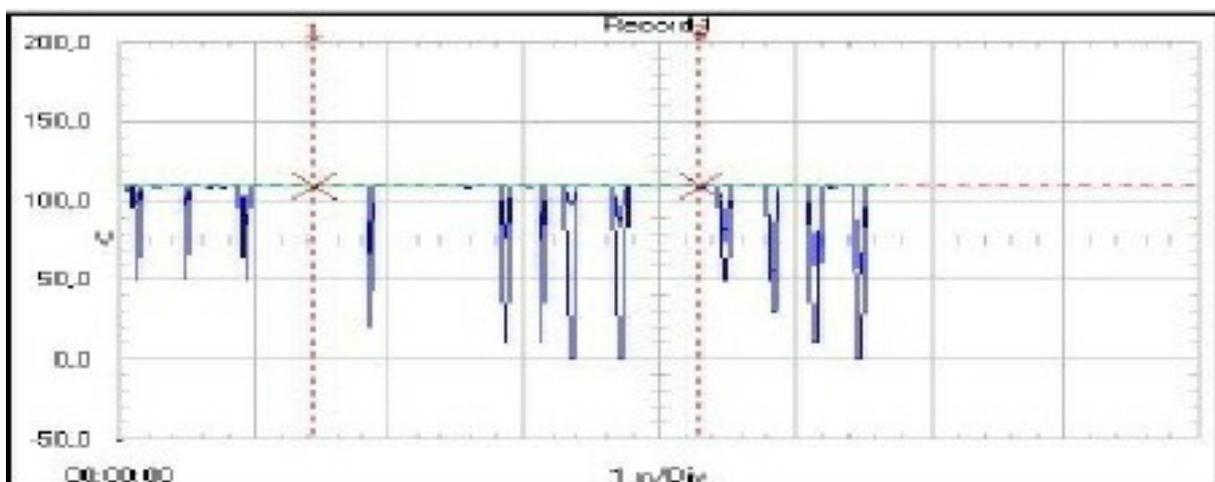
For all the tests, the heart monitor did not present interferences in the electrocardiogram waveform, what testifies the quality of the equipment with regard to this type of power supply disturbance.

The second set of trials referred to momentary voltage sags, similar to those generated by X rays, magnetic resonance and other equipment, and the values are showed on Table IV:

Sag n.	Voltage Sag (V)	Remaining Voltage (V)	Time of Duration (s)	Spacing (s)
1, 2 and 3	60	50	5	20
4	90	20	5	0
5 and 6	100	10	5	20
7 and 8	110	0	1	20
9	60	50	1	20
10	80	30	1	20
11	100	10	1	20
12	110	0	1	20

TABLE IV: TESTS WITH VOLTAGE SAGS

Voltage sags generated and applied to equipment can be seen on picture 20:



Picture 20: Voltage sags applied to heart monitor

As on the previous test, the heart monitor did not present interferences on the signal generated on its screen. In the sags to 10V and 0V (outage) with 1 second of duration, battery switchover occurred, but nevertheless,

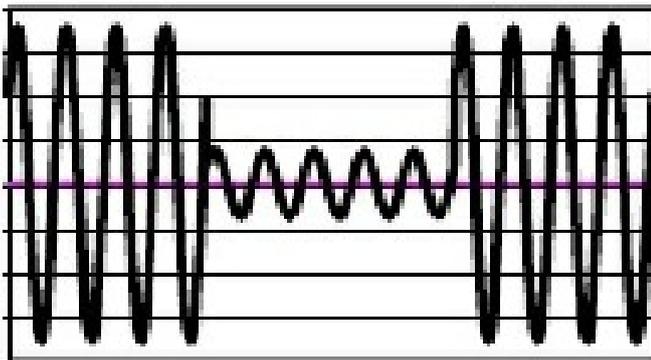
the signal on the screen was constant and steady. In the third set of tests, voltage sags were applied according to item 5.1 of Standard IEC 61000-4-11 [16], whose values are presented on Table V:

Level of remaining voltage -%U _n	Voltage of sag or outage - %U _n	Duration [cycles]
80	20	5
70	30	1
40	60	5
20	80	10
0	100	25
		50
		180

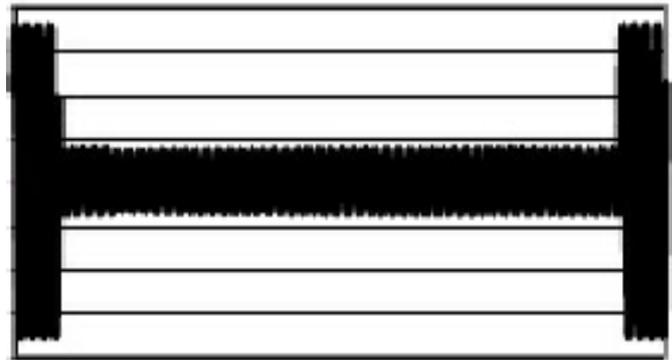
TABLE V: VOLTAGE SAGS RECOMMENDED IN STANDARD IEC 61000-4-11[16]

All the combinations of sags and durations recommended by the referred standard were applied. In all of them, the electrocardiogram signal was steady and without changes in its waveform. In the tests with 20% of remaining voltage, with a duration of 180 cycles and outages with durations of 25, 50

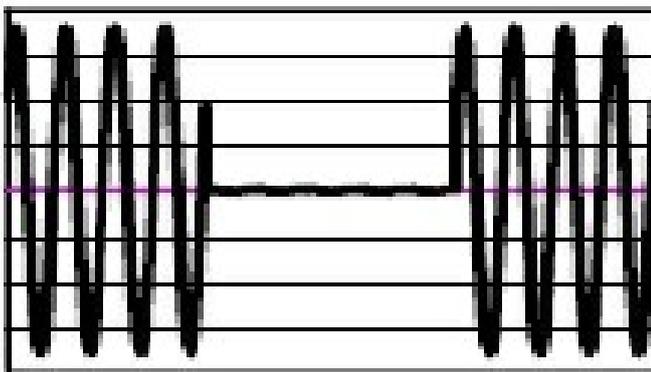
and 180 cycles, switchovers to the internal battery occurred, but no alterations in waveform could be seen on the equipment screen. Pictures 21 to 24 show some sags and more critical outages applied to the equipment:



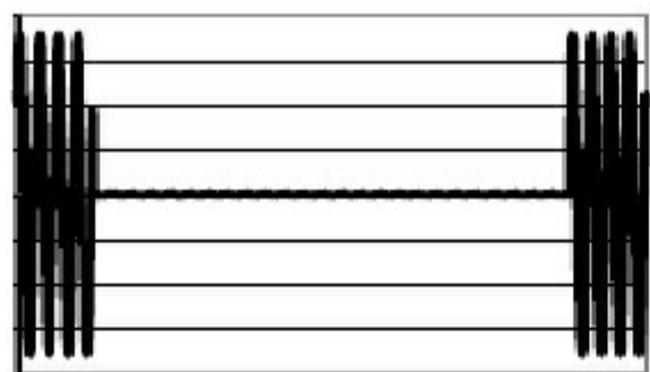
Picture 21: 80% sag - 5 cycles



Picture 22: 80% sag - 50 cycles



Picture 23: Outage - 5 cycles



Picture 24: Outage - 25 cycles

It can be inferred that this piece of equipment keeps a steady operation when subjected to voltages with a high harmonic content and critical momentary voltage sags.

B. Pulmonary ventilator

Natural pulmonary ventilation is accomplished through the spontaneous action of the respiratory musculature, which

when contracting causes a pressure drop between pulmonary cavities and the external environment, allowing the entrance of atmospheric air. This phase is called inhalation. Air is expelled from the lungs through the opposite phenomenon, that is to say, the relaxation of this same musculature induces an increase in pressure within the pulmonary cavities in

relation to the external environment. This phase is called exhalation [20]. The pulmonary ventilator has the objective of providing artificial pulmonary ventilation in patients suffering from respiratory insufficiency caused by diseases, anesthetic effect, etc. It can also be employed to provide a period of relief to the respiratory muscles until the patient's complete recovery and his return to the natural ventilation process.

Respiratory insufficiency can also be induced, and generally associated to surgical procedures for the obtainment of analgesia, muscular relaxation and reduction of metabolic functions.

Most ventilators produce a supply of positive pressure to provide air to the patient's lungs and, soon after, ease the pressure to allow for exhalation. The connection of the equipment to the patient may occur through mouth, nose or through a tracheotomy tube.

The lungs are elastic structures, which contract expelling the air held inside them since there are no forces to keep them inflated. There are no fixative points between our lungs and the thoracic cavity, thus, the lungs are completely free, surrounded only by a thin layer of pleural fluid for lubrication of their movements [24].

Pleural pressure is the pressure of this fluid between the pulmonary pleura and the pleura on the thoracic wall. In the beginning of inhalation, pleural pressure is slightly negative, about 0.5 cm H₂O, only enough to keep lungs opened at their rest level. During normal inhalation, the expansion of the thoracic cavity pulls the lungs, increasing negative pressure to 0.7,5 cm H₂O, resulting in an increase of 0.5 liter in pulmonary volume. Alveolar pressure is the pressure within pulmonary alveoli. If no air enters or exits the lungs, the pressure throughout the respiratory tree up to the alveoli is equal to the atmospheric pressure, and is considered as reference pressure zero. During inhalation, pressure of the alveoli should become slightly inferior to atmospheric pressure. In general, its value drops to 0.1cm H₂O, enough to induce penetration of 0.5 liter of air into lungs. When exhaling, the pressure figures are reversed through the movement of the thoracic cavity. The difference between alveolar pressure and pleural pressure is called transpulmonary pressure. It provides a measurement of the elastic forces which have a tendency of collapsing the lungs at every moment during breathing, called retraction pressure.

The variation on pulmonary volume caused by a given variation of unitary pressure is called complacency, which is of 200 ml/cm H₂O for an average adult.

During normal breathing, at rest, the whole of the muscular contraction occurs only during inhalation, as when exhaling

the process is almost entirely passive, produced by the retraction of the thoracic cavity.

Due to this fact, when breathing, at rest conditions, respiratory muscles only perform one physical effort to incite inhalation, which can be divided in three parts:

- complacency or elastic effort: is required to expand lungs against elastic forces within lungs and thorax.
- tissue resistance effort: is required to overcome viscosity of lungs and of thoracic wall structures.
- resistance of air passages effort: is required to overcome resistance of air passages.

In the presence of pulmonary diseases, all three types of effort are increased, in respect to the cases presented. Pulmonary fibrosis promotes an increase in efforts related to complacency and to tissue resistance, while disorders which cause obstruction of air passages can generate an increase in efforts against the resistance caused by these passages.

During normal exhalation, at rest, no significant effort is performed, since it results almost entirely of the elastic retraction of lungs and thorax. However, during intense breathing or when resistance present in air passages and body tissues increase, the effort while exhaling may be greater than while inhaling. In case of asthma, resistance in air passages while exhaling is much greater than in inhalation. During normal exhalation, at rest, only 3 to 5% of the entire energy spent by the human body is used in the process of pulmonary ventilation. On the other hand, during intense exercise, these figures can rise up to 50 times, especially if the individual presents an increase in resistance of air passages or a decrease in pulmonary complacency. What limits an individual's capabilities for performing physical exercise is, thus, the person's ability of providing the muscles involved in the respiratory process with enough energy.

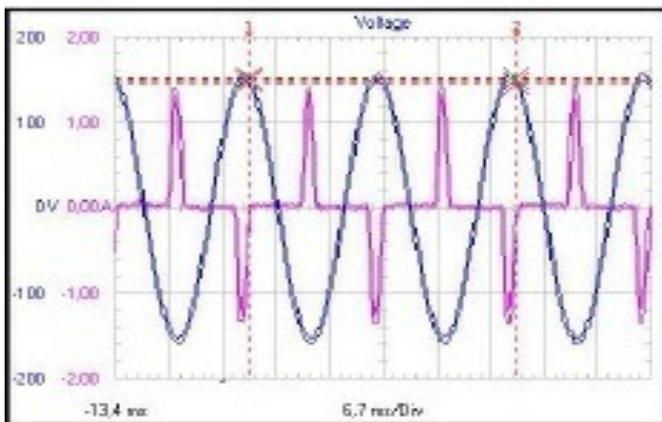
The ventilator tested is of national manufacture, completely microprocessed and designed to be employed in respiratory insufficiency in pediatric and adult patients, with a bodily mass between 6 and 150kg. It's a very practical equipment, with direct digital controls for the main ventilative parameters. The cycle-start is by means of pressure, and since it incorporates a ventilation monitor, it allows for an extensive monitoring of patient's conditions, increasing safety. Besides, a complete system of audiovisual alarms with written messages on the control screen gives a quick identification of the alarm conditions. The presence of lungs was simulated through the use of a rubber balloon, provided by the manufacturer for this purpose. In the first set of tests, the equipment was fed with a nominal voltage of 110V, but containing harmonic contents, as presented on Table VI:

Test n.	Fundamental (%)	rd harmonic (%)	th harmonic (%)	Th ' harmonic (%)	THD _f (%)
1	100	3	0	0	3
2	100	10	0	0	10
3	100	20	0	0	20
4	100	30	0	0	0
5	100	50	0	0	50
6	100	30	10	5	31.9
7	100	50	30	10	59.1
8	100	70	50	30	91.4

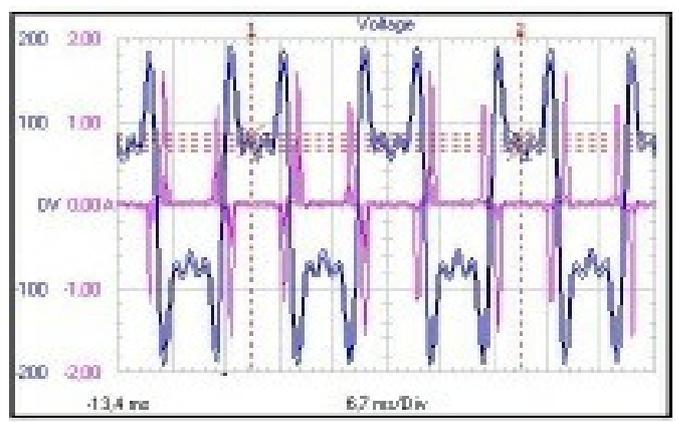
TABLE VI: TESTS WITH VOLTAGE HARMONICS

Picture 25 shows the current curve when the equipment is fed with sine voltage:

For comparison purposes, picture 26 shows voltage waveforms in test 7, and the corresponding current wave:



Picture 25: Current waveform with sine voltage



Picture 26: Current waveform with distorted voltage

Although one can observe an important alteration in current waveform between sine voltage and the supply with completely distorted voltage, no alterations in the regularity of the equipment's ventilation cycles could be noticed. The digital Manometer, installed in the frontal part, indicated the same values in all trials. In this

way, the equipment's immunity to sharply distorted voltages could be attested.

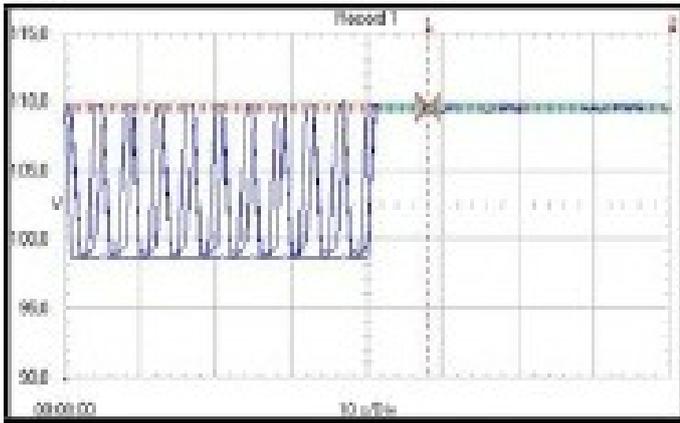
The second set of trials referred to momentary voltage sags, similar to those generated by X-rays equipment, magnetic resonance and others, whose values are shown on Table VII:

Test n.	Quantity of sags	Voltage of sag (V)	Remaining Voltage (V)	Time of Duration (s)	Spacing (s)
1	10	11	99	3	1
2	10	22	88	3	1
3	10	33	77	3	1
4	10	44	66	3	1
5	10	55	55	3	1
6	10	11 to 110	99 to 0	3	60

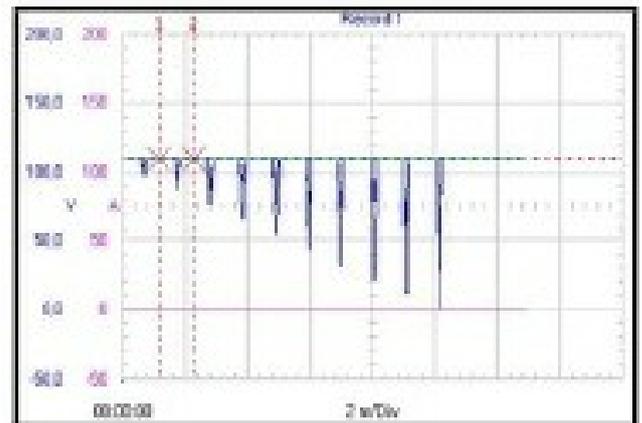
Note: the equipment was supplied a nominal voltage of 110V

TABLE VII: TESTS WITH VOLTAGE SAGS

Pictures 27 and 28 show voltage sags applied to equipment, referring to trials n.5 and n.6:



Picture 27: Voltage sags in test n.5



Picture 28: Voltage sags in test n.6

In trial n.6, the equipment presented irregular operation for sags of 77 V, 88 V, 99 V and outage. Problems showed included stoppage, expiratory valve blockage and in operation of the alarm system.

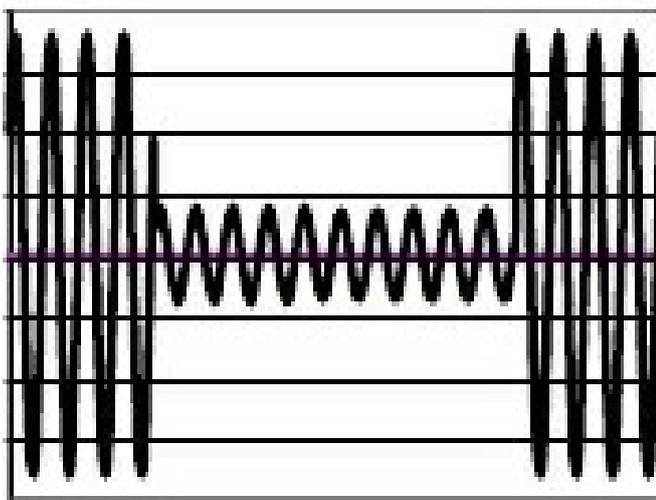
In the third set of trials, we applied voltage sags following recommendations in item 5.1 in the standard IEC 61000-4-11 [16], whose values have been showed on table 5.

Pressure and airflow figures were monitored with a flow meter connected to the equipment's exit duct (inhalation circuit).

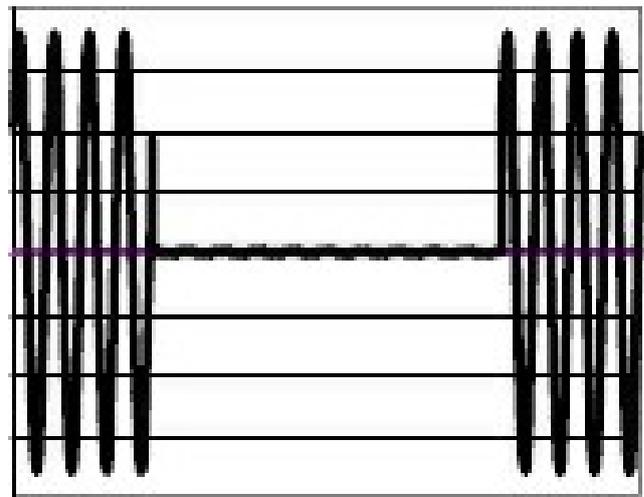
The equipment withstood, without alterations, sags of 20%, 30% and 60% for all the durations, that is to say, from 0,5 to 180 cycles. The same occurred for sags of 80% and outages with durations of 0,5, 1 and 5 cycles. On the other hand, either for sags of 80% or for outages with a duration of or superior to 10 cycles, the equipment presented several problems, which might put at risk the patient connected to it:

1. the operation was interrupted, in spite of the battery being fully charged. Adjusted parameters were not lost, but alarm did not sound;
2. in some tests, depending on the instant when sags or outages were applied, the expiratory valve remained permanently opened, releasing into the environment all air/oxygen injected into the lungs. The alarm system also did not sound, and the equipment had to be disconnected from the power supply and reprogrammed to resume operation;
3. in the same way as in case 2, in some tests, the equipment halted and kept injecting air/oxygen with the expiratory valve completely shut. The alarm did not sound and the equipment also had to be disconnected from the power supply and reprogrammed. The pressure gauge indicated an increase which was far superior to the supportable levels for the lungs of a human being.

Graphs in pictures 29 and 30 present waveforms for sag and outage for duration of 10 cycles. From this duration on, the equipment started to present the irregularities mentioned.



Picture 29: 80% sag with duration of 10 cycles



Picture 30: Outage with duration of 10 cycles

C. Pulse oxy meter

The pulse oxy meter is an equipment designed for determining oxygen saturation levels (S_pO_2) in arterial blood,

being this accomplished in a non-invasive manner, through optical sensors positioned externally to the patient [20]. The employment of the pulse oxy meter is considered standard

procedure for monitoring blood oxygen saturation levels in intensive care units, surgical centers, post surgical recovery, units for patients with severe burns, units for catheterization and in ambulances. Its non-invasive characteristics render blood sampling and laboratory analysis unnecessary. Another favorable feature is the possibility of monitoring blood oxygen levels, continuously and in real time, allowing for the prompt detection of eventual reductions in those levels, which could lead to risks to the patient. Blood color varies in function of oxygenation levels; blood with a high oxygen concentration being bright red. The presence of carbon dioxide alters blood color, tending to a

slightly blueish color. Its operation is based on blood spectrophotometer, which measures light transmitted or reflected by capillaries within the human body, synchronized with the heartbeats.

The equipment tested is of national manufacture, and does not have a battery to guarantee its operation during power outages. It is micro processed and has an alarm system for cases of alterations in pre-established parameters. In the first set of tests, the equipment was supplied with voltages with harmonic content, as shown on Table VIII:

Test n.	Fundamental (%)	2 nd harmonic (%)	3 rd harmonic (%)	4 th harmonic (%)	5 th harmonic (%)	THD _f (%)
1	100	10	0	0	0	10
2	100	20	0	0	0	20
3	100	30	0	0	0	30
4	100	70	0	0	0	70
5	100	30	10	5	5	31.9
6	100	50	30	10	10	59.1
7	100	70	50	30	30	108.2

TABLE VIII: TESTS WITH VOLTAGE HARMONICS

During the trials, the behavior of the equipment changed, experiencing a very critical moment. The great influence of 3rd harmonic fundamental generated interferences on the equipment display. For figures above 70% the equipment resumed normal operation. The 5th and 7th harmonics had

little influence in the final result, predominating the presence of the 3rd harmonic.

The second set of trials referred to momentary voltage sags, similar to those generated by X-rays equipment, magnetic resonance and others, whose values are shown on Table IX:

Test n.	Quantity of sags	Voltage of sag (V)	Remaining voltage (V)	Time of duration (s)	Spacing (s)
1	10	3.3	106.7	1	1
2	10	5.5	104.5	1	1
3	10	8.8	101.2	1	1
4	10	11	109	1	1
5	10	22	88	1	1

Note: Equipment was supplied a nominal voltage of 110V

TABLE IX: TESTS WITH VOLTAGE SAGS

In test n.1 there were no observable abnormalities. In trials numbers 2 and 3, the display was slightly dim, but displayed values were not altered. In trials numbers 4 and 5, the equipment presented a blinking screen, and the values displayed decreased until the alarm actuated. The equipment had to be disconnected from power supply to resume operation.

In the third group of trials, we applied voltage sags in accordance to item 5.1 of standard IEC 61000-4-11 [16], whose values have been shown on table 5.

Since it is an equipment extremely sensitive to voltage sags, the presentation of results on Table X was thought to be convenient:

Level of remaining voltage- % U _n	Voltage of sag or outage- % U _n	Duration-[cycles] / occurrence
80	20	5 cycles / dimmed display, but no data loss occurred
70	30	5 cycles / dimmed display, but no data loss occurred
40	60	10 cycles / equipment halted, and screen displayed random characters. It had to be switched off to resume 25, 50 and 180 cycles / shut down but returned to main screen. Operation. Resumed normal operation.
20	80	10 cycles / equipment halted, and screen displayed random. characters. It had to be switch off to resume operation.
0	100	10 cycles / equipment halted, and screen displayed random. characters. It had to be switch off to resume operation.

TABLE X: TEST OF VOLTAGE SAG ACCORDING TO STANDARD IEC 61000-4-11[16]

CONCLUSIONS

The present study demonstrated the importance of the quality of electrical power within health care facilities. The disturbances to which electromedical equipment were subjected in tests may have origin within the installations in these same facilities, as well as in the distribution systems of concessionaires of electrical power supply. In other circumstances, poor design or maintenance also might contribute to malfunction of electromedical equipment. On the other hand, with the knowledge provided by the tests, manufacturers should concentrate their efforts in improving their equipment, aiming at reducing sensitivity to such disturbances. Similarly, electrical power concessionaires will possess a better knowledge on problems caused by poor quality of electrical power supplied to consumers of health-medical area.

Great difficulties were met while carrying out this study, among which one can name:

- Several manufacturers refused to supply their equipment for testing, fearing that problems subject to legal implications could be found, due to medical errors caused by malfunctions on such equipment;
- Authorization for carrying out measurements in Health Care Facilities aiming at determining polluting loads which deteriorate the quality of electrical energy and,
- Permission for inspections of electrical installations in the facilities, as means of attesting the conformity to applicable standards.

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