

# Discussion Paper



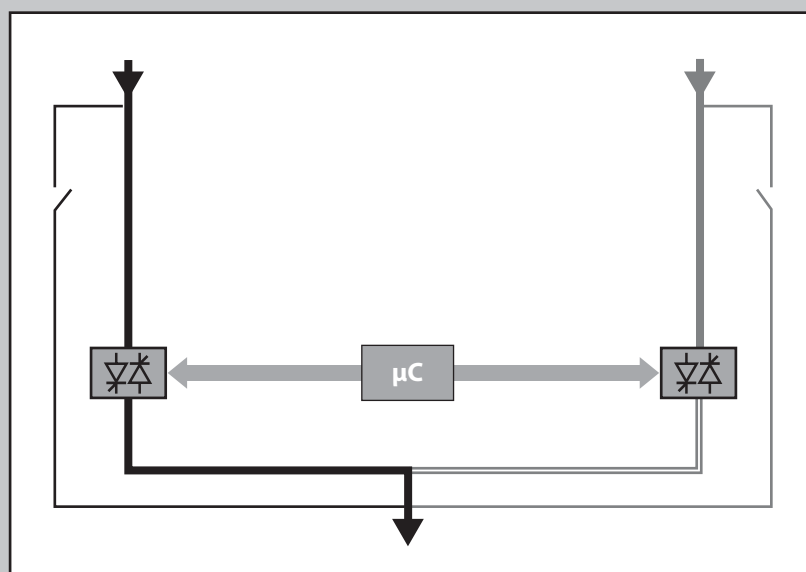
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*Under Review*

### *Classification of electrical installations in healthcare facilities according to reliability and availability of power supply*



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## **1. Executive Summary**

Common electrical disturbances can cause high-tech medical equipment to malfunction. As medical equipment is often connected to vulnerable patients, such a malfunction can easily result in serious problems.

International standards for medical installations focus primarily on safety, in particular on protection against indirect contact. For example, standard IEC 60364-7-710 classifies medical locations into three groups - 0, 1 and 2 - on the basis of the type of contact between the applied parts and the patient.

Currently, the requirements defining the availability of supply, reliability of supply and the power supply's infrastructure's resiliency to disturbances are merely qualitative. There is a need for a universally accepted definition of these three parameters. To guarantee the right performance level of electrical installations in healthcare facilities, both the safety of supply and the quality of supply need to be considered with equal importance.

Patient safety is the prime reason for minimizing equipment malfunction and its consequences. But healthcare facilities administrators also need to consider the economical aspects. Electrical disturbances can result in diagnostic tests needing to be repeated, an increase in medical supply waste and/or expensive service and repair calls. A recent study carried out by Leonardo ENERGY to assess the costs related to power quality problems concluded that inadequate power supplies can vastly increase a hospital's operational costs.

In addition to the costs related to labour and equipment repairs, there is the loss of a patient's quality of life, which is impossible to quantify in monetary terms. Often medical equipment incorporates sensitive electronic power supplies and microprocessors. Apart from safety aspects, malfunctions can result in patient discomfort and misdiagnoses.

Through direct interviews carried out by the authors of this paper it emerges that the current technical standards are considered – almost unanimously – to be inadequate to guarantee the safety, reliability and availability of electricity supplies. After defining the real user needs and analysing the interview results, the IEC classification of medical locations has been extended to include the following aspects:

- Availability, resiliency and reliability of supply (i.e. quality of supply)
- The patient's quality of life

This new approach aims to provide decision makers with an effective tool for the specification of electrical installations in hospitals. Combining safety aspects with requirements for power quality reduces operating costs and improves the patient's quality of life.

## **2. Purpose of this White Paper**

The design of electrical installations for hospitals increases in complexity with the size and the level of care delivered by the facility. Special requirements have to be met since lives are at stake.

For the design of electrical installations in hospitals, the most important factor is the reliability of supply and its resiliency to disturbances. Every effort must be made to reduce the probability of equipment failure due to loss of power from the electricity network and from internal emergency power sources.

Through a statistical approach in combination with field work, we have developed a classification scheme for functionality in medical locations. This approach could provide a basis for future standardization activity in this field.

Current design practice mainly considers the cost and safety aspects. The new classification scheme will stimulate a process based on all the relevant key issues, in particular the quality of supply parameters power quality (PQ), which are often given too little attention and often at too late a stage.

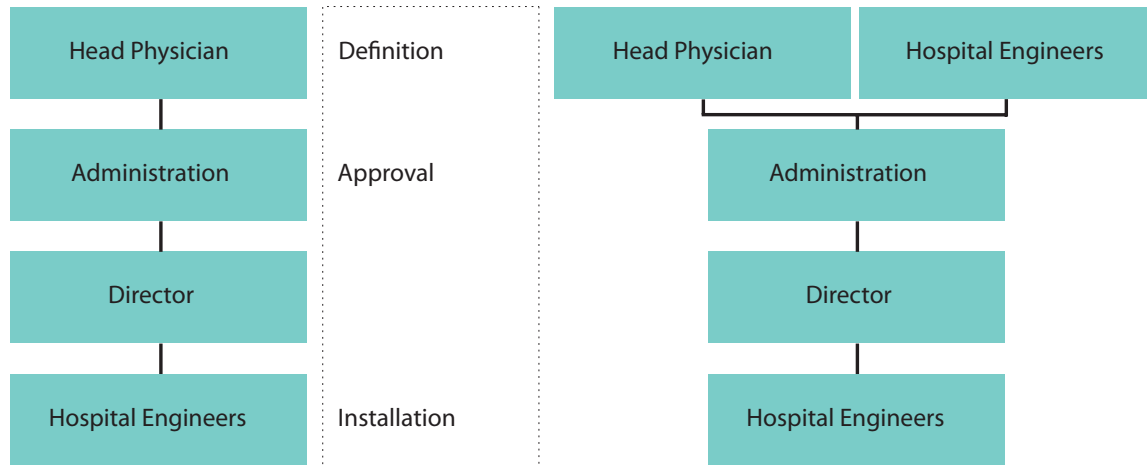


Figure 1 –Design and purchasing process for electrical installations and equipment. Current practice (left), optimal practice (right)

A new and comprehensive approach guarantees that the electrical installation will not only be compliant with standards and consider economical constraints, but will also adopt best practices in terms of:

- Safety
- Lowest cost of ownership
- Higher patient quality of life

This new classification system is therefore relevant to all decision makers in the hospital – not only the facility manager. The scheme creates a common language to improve the communication of needs between facility managers and physicians.

### 3. The Standard approach: IEC 60364-7-710 requirements

#### 3.1. Scope

International standards, in particular IEC60364-7-710 (from which most national standards are derived) focus primarily on safety, in particular the protection against indirect contact.

In terms of availability of supply and overall reliability in medical locations, IEC standards only require the distribution system to facilitate the automatic change-over from the distribution network to the emergency power supply which feeds essential loads.

The standard suggests a classification scheme for medical locations which is based on their intended purpose.

#### 3.2. Classification of medical locations

Medical locations are classified by IEC according to the use of “applied parts”. An applied part is a piece of electrical equipment that is brought into physical contact with the patient, or might come into contact with the patient, or needs to be touched by the patient. The classification is as follows:

- Group 0: medical locations without applied parts
- Group 1: medical locations where applied parts are used
  - o externally
  - o invasively to any part of the body, except for the locations described in group 2
- Group 2: medical locations where applied parts are used in applications such as intracardiac procedures, operating theatres and vital treatments where discontinuity of the supply can cause danger to life

In order to determine the classification of a particular medical location, the medical staff must indicate which medical procedures will take place within that location.

### **3.3. System earthing and safety requirements**

In each medical location of group 1 and group 2, supplementary equipotential bonding conductors must be installed and connected to the equipotential bonding bus bar for the purpose of equalizing potential differences between protective conductors and extraneous conductive parts located in the “patient environment”.

The TN-C system is not allowed in medical locations and medical buildings downstream of the main distribution board.

In group 2 locations, the IT earthing arrangement (hereinafter referred to as “medical IT”) must be used for circuits supplying medical electrical equipment and systems intended for life support, surgical applications and other electrical equipment located in the “patient environment”.

### **3.4. Emergency supply**

Regarding the continuity of supply in medical locations, secure power supplies are classified on the basis of change-over time required by the service they supervise:

- Power supplies with a changeover period less than or equal to 0.5 s  
Secure power supply which is capable of maintaining operating theatre table lights and other essential luminaires, e.g. endoscopes, for a minimum period of 3 hours and with a changeover period not exceeding 0.5 s.
- Power supplies with a changeover period less than or equal to 15 s  
Secure power supply for equipment which must be connected within 15 s for a minimum period of 24 hours, when the voltage of one or more line conductors at the main distribution board for the critical services has decreased by more than 10% of the nominal value of supply voltage for a duration greater than 3 s.
- Power supplies with a changeover period greater than 15 s  
Used for equipment required for the maintenance of hospital services, which may be connected either automatically or manually for a minimum period of 24 hours. This includes, for example, sterilization equipment, air conditioning, heating and ventilation systems.

### **3.5. Equipment requirements**

IEC requires that in the event of a mains power failure, a minimum illuminance level must be provided from a secure supply within a changeover period not exceeding 15 s in the following locations:

- Escape routes
- Rooms in which essential services are provided
- Rooms of group 1 and 2 medical locations

Services other than lighting which require a secure supply within a changeover period not exceeding 15 s include fire protection systems and medical electrical equipment used in group 2 medical locations. Such equipment needs to be identified by responsible staff.

The standard also provides a table listing the secure power supply requirements for different medical locations.

It's important to note that a definitive list of medical locations showing their assigned groups is impracticable, as the use of locations differs between countries and even within a country.

### **3.6. Verification**

IEC 60364-7-710 defines the following tests to be carried out for locations belonging to group 1 and 2:

- Functional test of insulation on monitoring devices of medical IT systems
- Verification of equipotential bonding
- Verification of secure power service
- Measurement of leakage current of medical IT transformers in no-load condition

# Power Quality

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These tests are in addition to the requirements of IEC 60364-6-61 (a standard which defines tests and verifications to be performed on installations prior to commissioning or to re-commissioning after a modification or repair).

Periodic checks on secure power services are recommended at the following intervals:

- Services with batteries: monthly / 15 min capacity test
- Services with combustion engines: monthly / until rated running temperature is achieved; 12 months for “endurance run”

Medical location		Group			Class	
		0	1	2	$\leq 0,5 \text{ s}$	$>0,5 \text{ s} \leq 15$
1	Massage room	X	X			X
2	Bedrooms		X			
3	Delivery room		X		X <sup>a</sup>	X
4	ECG, EEG, EHG room		X			X
5	Endoscopic room		X <sup>b</sup>			X <sup>b</sup>
6	Examination or treatment room		X			X
7	Urology room		X <sup>b</sup>			X <sup>b</sup>
8	Radiological diagnostic and therapy room, other than mentioned under 21		X			X
9	Hydrotherapy room		X			X
10	Physiotherapy room		X			X
11	Anaesthetic room			X	X <sup>a</sup>	X
12	Operating theatre			X	X <sup>a</sup>	X
13	Operating preparation room		X	X	X <sup>a</sup>	X
14	Operating plaster room		X	X	X <sup>a</sup>	X
15	Operating recovery room		X	X	X <sup>a</sup>	X
16	Heart catheterization room			X	X <sup>a</sup>	X
17	Intensive care room			X	X <sup>a</sup>	X
18	Angiographic examination room			X	X <sup>a</sup>	X
19	Haemodialysis room		X			X
20	Magnetic resonance imaging (MRI) room		X			X
21	Nuclear medicine		X			X
22	Premature baby room			X	X <sup>a</sup>	X
<sup>a</sup> Luminaires and life-support medical electrical equipment which needs power supply within 0.5 s or less						
<sup>b</sup> Not being an operating theatre						

Table 1 - Examples for allocation of group numbers and classification for safety services of medical locations (IEC 60364-6-61).

## 4. Assessing the Existing situation

### 4.1. Description of the study / research methodology

This paper is based on the authors' work experience as well as interviews with electrical installation managers working in healthcare facilities with bed totals ranging from a few dozen to thousands and electrical installations with rated power ranging from 50 kW to 10 MW.

The interviews were based on a series of questions aimed at identifying:

- Current practice in the definition of the main features of electrical installations (scheme, redundancy level, adopted equipment, etc.)
- Approach to requirements defined in technical standards
- Decision making process
- Needs

The needs and problems identified were common to all facilities.

## **4.2. Overview of main problems and needs identified during interviews**

### **4.2.1. Proper UPS sizing**

UPS units are designed to supply energy to linear or non-linear loads having a crest factor of 3:1.

A UPS modifies the characteristics of the electrical installation, such as:

- Short circuit power and current
- Impedance
- Protection coordination criteria
- Neutral system
- Electromagnetic emissions and immunity

The UPS is an autonomous power source inside the facility and it must be installed following the requirements defined in the IEC standard.

Considering the electricity needs of medical facilities usually exceed typical UPS supply capacity and their requirements are very often more restrictive than elsewhere, the choice of UPS size must be made by applying accurate and specific criteria.

### **4.2.2. Periodic tests**

The periodic tests required by the IEC standard are satisfactory in terms of the nature of the test, but not good enough in terms of the frequency of the tests (i.e. how often they are carried out).

### **4.2.3. Mutual influences between medical devices**

The proper operation of medical devices depends on several factors, including the quality of the electrical supply. X-Ray based machines, magnetic resonance imaging (MRI) and nuclear medicine devices are sensitive to voltage and frequency variations. But X-Ray machines are also the most important source of electrical pollution because of their intense and distorted high currents.

Medical equipment representing a dynamic load to the electrical system can cause power quality problems for the entire facility.

Electrical disturbances can enter healthcare equipment through any electrical port: not only via the AC power input, but also through communication ports.

### **4.2.4. Patients' quality of life**

The correct functioning of electrical equipment is linked to a patient's quality of life, since it can:

- Minimise the repetition of examinations and the associated stress
- Prevent accidents caused by the improper use of medical devices

Moreover, the patients quality of life can be improved by providing them clear instructions on what to do in case of abnormal electrical supply.

### **4.2.5. Doctors' and nurses' training**

Hospital personnel generally lack knowledge on both electrical safety and power quality phenomena. This may cause risky behaviour in the operating theatre or improper use of medical devices such as electro-surgery equipment.

## **4.3. Overall requirements for delivering medical services**

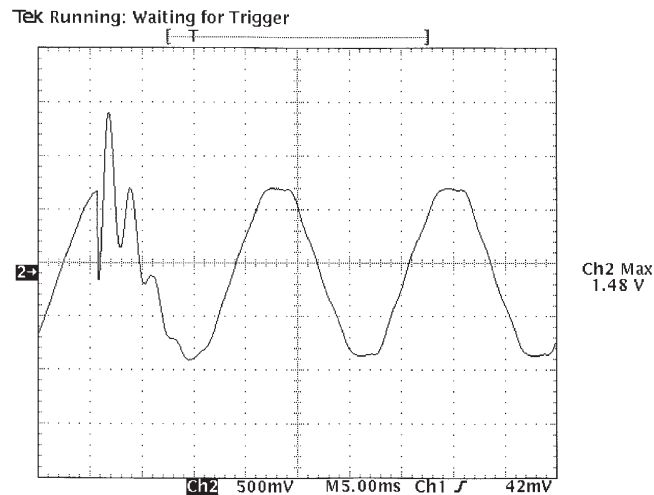
### **4.3.1. Power quality requirements for medical devices**

X-Ray based devices, MRI systems, CT scanners and linear accelerators typically absorb currents with high crest factor and very steep wave fronts (see Figure 2).

This behaviour can cause voltage sags and other electrical disturbances in the installation. In particular X-Ray based devices are a major source of electrical pollution as well as being sensitive to voltage variation.

The problem of sensitivity to electrical disturbances is common to almost every electronic medical device. In addition, the immunity to power quality issues of most of these devices is generally low, and is very often unknown.

Many power quality problems could be avoided if (1) the quality of power at the point of use is known, (2) the equipment immunity is known, and (3) the immunity is sufficiently high.



*Figure 2 - Oscilloscope screenshot of the electrical behaviour of the mains during angiography (sinusoidal voltage and distorted currents)*

Nowadays manufacturers are introducing new devices with input capacitor filters to mitigate the problem, but this causes a leading power factor which must be considered when choosing a UPS.

A large variety of other solutions are now available on the market and some power quality problems can be solved with the appropriate choice of power-conditioning devices such as isolation transformers, surge-protective devices, voltage regulators and UPS systems. However, these do not always provide the best answer for solving power quality problems.

#### 4.3.2. Power quality requirements for other loads

Loads in hospitals are not limited to medical devices.

##### 4.3.2.1. HVAC

Direct on line (DOL) starters used for fan and compressor motors can cause voltage drops on the distribution line because of their high inrush currents. On the other hand, if the motors are fed by inverter drives, the starting current is equal to the rated current, but high frequency harmonics could be injected into the local network by the inverter.

While HVAC systems are not sensitive to electrical disturbances, they should be operated in a mode allowing only short interruptions for the sake of air disinfection and patients' comfort.

##### 4.3.2.2. Ordinary and emergency lighting

Lights that have no function as emergency lights do not need special requirements. Emergency lights need continuity of power supply via the central power supply system (CPSS) or via a self supply.

##### 4.3.2.3. Sterilisation equipment

Depending on the material they have to sterilise, some sterilisation equipment should be protected by generators to avoid long interruptions.



## 4.3.2.4. Telecommunication equipment

Telecom equipment is typically supplied by DC voltage. Therefore, this paper also considers DC power supplies.

Nowadays power supplies for telecommunication applications generate a very limited amount of harmonics and can withstand high levels of electrical pollution.

Continuity of power supply is ensured by batteries on the DC bus.

## 4.3.2.5. ICT equipment

This paragraph refers to ICT devices used for administrative and other office activities. ITIC (Information Technology Industry Council) – previously named CBEMA (Computer Business Equipment Manufacturers Association) – defined the curve shown in Figure 3. It represents the acceptable duration of voltage disturbances for ICT equipment as a function of amplitude.

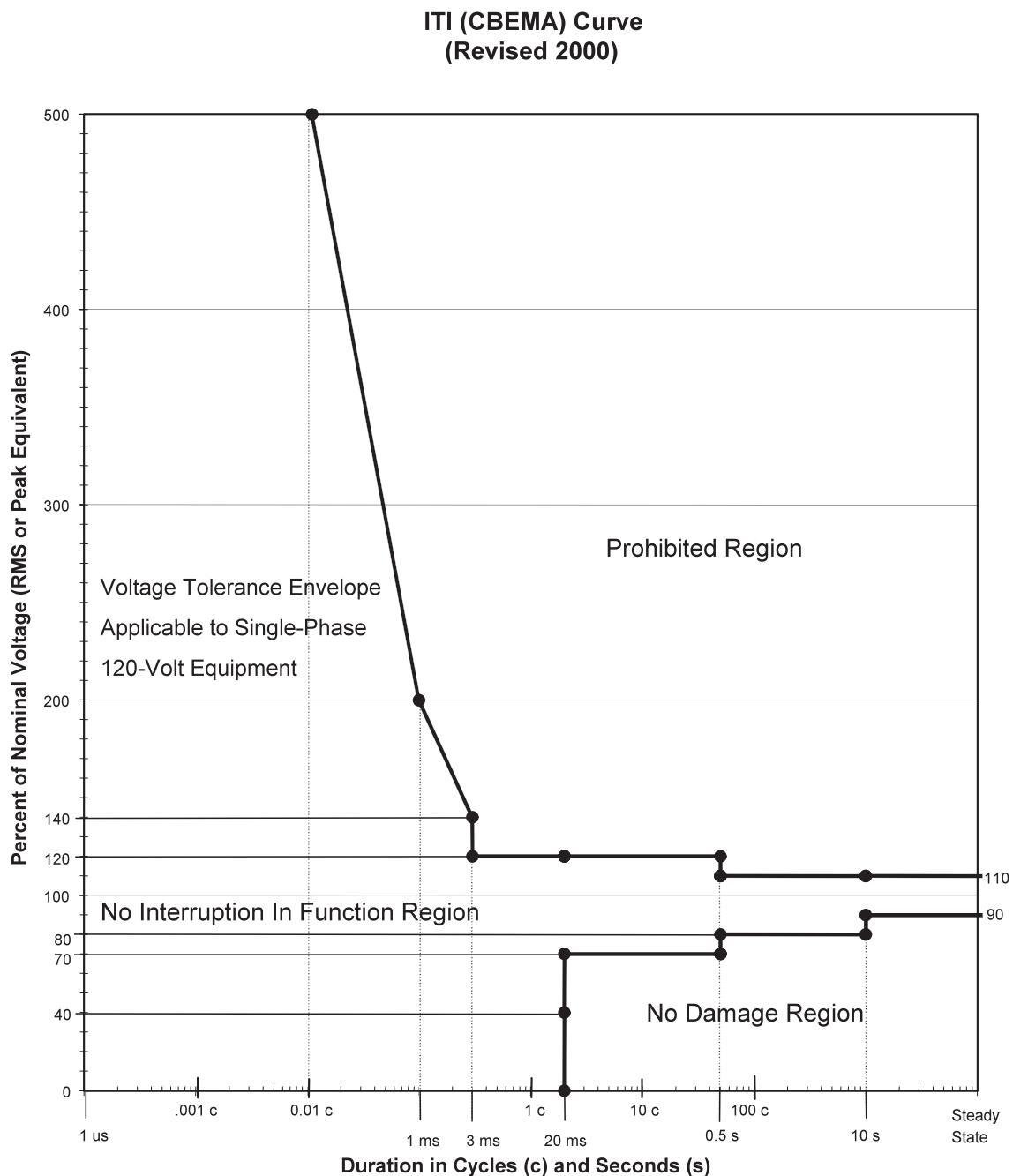


Figure 3 - ITI Curve (2000 issue)

#### 4.3.2.6. Fire alarms and smoke extractors

For proper operation, fire alarms and smoke extractors need power continuity via the CPSS.

#### 4.3.2.7. Distribution systems for medical gases

Gases are delivered under pressure. The supervision system needs continuity of power supply. An on-line double conversion UPS is required.

#### 4.3.2.8. Kitchens

For safety of operators, only short interruptions are acceptable. Generator supply is required.

#### 4.3.3. Requirements for Patients' quality of life

The European "Report on the open consultation on Patient Safety in the European Union" (ISBN 978-92-79-09670-9) states: "[...] 25% of respondents indicated that they had experienced an adverse event in their home country and 3% in another Member State [...]".

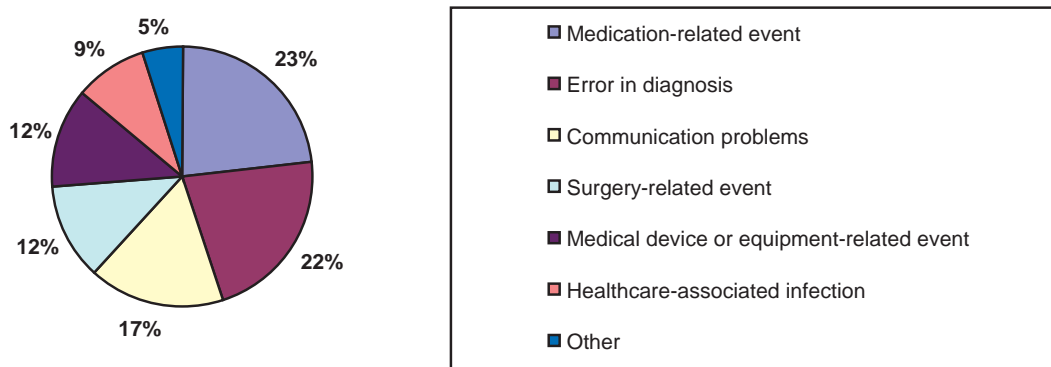


Figure 4 – Origin of adverse events in Home Countries  
"Report on the open consultation on Patient Safety in the European Union" (ISBN 978-92-79-09670-9).

No specific analysis has been performed to evaluate the number of adverse events related to power supply outages, but they are perceived as being important by the interviewees. Often backup power is needed to finish an examination to avoid:

- Loss of time or repetition of the examination
- Excessive exposure to X-Rays or radiation
- Stressful situations

To prepare for possible outages, periodic tests of backup devices (Gensets, UPS, Emergency lights) can help patients and personnel to cope with an actual abnormal situation without stress and avoiding panic.

## 5. Building a Resiliency classification for medical facilities

### 5.1. Patient's quality of life categories

In the medical environment, levels of safety and continuity of supply need to be higher than standard levels used in most other facilities. It is easy to understand how stressful it would be for a patient to wait inside a CT unit or with a probe in a vein.

All processes have been classified into three levels according to the continuity of supply required to ensure the patient's quality of life. Such levels are named LQ (Life Quality) and are defined as:

- LQ 0 – Processes that can be immediately interrupted without or with only limited stress to the patient (e.g. EEG)
- LQ 1 – Processes that can be interrupted after a series of operations that require a limited amount of power (e.g. nuclear medicine, CT for saving data)
- LQ 2 – Processes that must be completed by using the rated power (e.g. angiography or dialysis)

# Classification of electrical installations in healthcare facilities according to reliability and availability of power supply

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In the above mentioned examples, the LQ level may vary depending on the level of service that the hospital or clinic wants to provide.

It is important to highlight that the LQ levels are related only to the quality of life and not to the risk of death.

The quality of life of the patient is also linked to the knowledge level of nurses and doctors on how to properly use the medical devices.

For example, some minor incidents have occurred due to improper use of monopolar electro-surgery devices where there has been incorrect sizing of the passive plate or a lack of consideration of the capacitive coupling between the patient's body and the cold mattress. Both cases could have been avoided by a proper training of the operators.

The LQ concept can be also applied to those devices not directly linked to the quality of life of the patients. For example, ICT devices used for scheduling examinations could also be classified as LQ 2.

## 5.2. Leonardo ENERGY Healthcare facilities resiliency level identification

With today's continuous and rapid advancements in medical technology, hospitals, clinics and medical laboratories increasingly rely on sophisticated electronic devices for the diagnosis, treatment and monitoring of patients. This reliance, in turn, demands a high level of power quality and reliability. To prevent disruption of mission-critical services, equipment should have a low sensitivity to power quality disturbances and should itself generate the minimum amount of power quality disturbance.

The main problem is a universally accepted definition of power quality. In this case, it's possible to formulate a general one:

"Electrical energy is a product and therefore should meet certain quality requirements. To operate correctly, electrical equipment, requires electrical energy to be supplied at a voltage within a specified range around a rated value. The user is entitled to receive an acceptable quality of power from the supplier."

This definition cannot, unfortunately, be used in practical terms. Therefore, we need to define power quality benchmarks.

The EN 50160 standard helps by defining the voltage parameters of the mains supply and the permissible deviation range at the customer's point of common coupling in both public low voltage (LV) and medium voltage (MV) electricity distribution systems, under normal operating conditions. However, no special requirements are defined for specific locations such as medical facilities, and the parameter levels are principally informative.

The problem is that consumer's needs are not always the same. Even fulfilling the requirements of EN 50160 does not assure a satisfactory level of power quality (PQ), as this level depends on the application. The level of PQ that is required must be defined in a different way.

For this reason, a classification in terms of the level of resilience of equipment (REL) is introduced:

- REL 0: The equipment (or system) is sensitive to supply voltage disturbances and could be damaged; every disturbance exceeding EN 50160 levels will affect equipment operation. Equipment is damaged by the disturbance and must be replaced or repaired. Downtime period could be very long.
- REL 1: The equipment (or system) is sensitive to supply voltage disturbances with no damage risk. Every disturbance exceeding EN 50160 levels will affect equipment operation. Equipment is not damaged by the disturbance and downtime is just related to the emergency supply changeover time.
- REL 2: The equipment (or system) is highly resilient. Disturbances exceeding EN 50160 levels will not necessarily affect equipment operation. Equipment is not damaged by the disturbance and downtime is just related to the emergency supply changeover time.
- Table 2 shows the quality of life (LQ) relative to 3 medical location groups as classified by IEC 60364-7-710. The relationship between the desired LQ level and IEC groups is provided by the resiliency level (REL).

		Group (IEC 60364-7-710)		
		0	1	2
LQ	0	REL 0	REL 1	REL 2
	1	REL 1	REL 1	REL 2
	2	REL 2	REL 2	REL 2

Table 2 – LE Healthcare facilities Resiliency requirements

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Devices that cannot reach the requested REL level by themselves, must be protected by a UPS, filter or design solution to achieve the minimum requirement. In this context, REL levels refer to the system, not only to individual devices.

Table 3 provides REL levels which can be obtained through the adoption of different technical or managerial solutions that improve a system's resilience to PQ issues. The adoption of a particular solution to a particular PQ phenomenon will guarantee the related REL level.

The REL level of the whole system will be the minimum level related to each phenomenon, i.e.:

- A system is REL 2 if every phenomenon is addressed by a REL 2 solution
- A system is REL 1 if every phenomenon is addressed by a REL 1 solution (at least) and cannot be considered as REL 2
- A system is REL 0 if every phenomenon is addressed by a REL 0 solution

Table 4 provides the minimum REL level that is required for the medical locations listed in Table 1, and the related technical or managerial PQ solutions to ensure this level is met.

Area	Technical solution	Interruptions	Frequency variation	Voltage changes	Voltage fluctuation/flicker	Voltage dips and swells	Harmonics and interharmonics	Unbalance	Overvoltages and transients	EMC and High frequency disturbances
Equipment	Backup generator	1	1	1	1	1	1	1	1	1
	Dynamic voltage restorers	2			2		2		2	2
	Passive harmonic filters	1					1		1	
	Isolation transformers	1	1	1		1	1	1	1	
	Active filters						2		2	
	UPS	2	2	2	2	2	2	2	2	2
	Voltage stabilizers	2	2	2	2	2	2	2	2	2
	Static transfer switches						2		2	2
	Static var compensator	1		1	1				1	
	Surge protection								1	
System	Multiple independent feeder	2								
	Emergency supply redundancy	2								
	Simple radial scheme	0								
	Double radial scheme	2								
	Ring scheme	2								
	Meshed scheme	2								
Design	Equipment oversizing						2			
	Horizontal selectivity	1								
	Vertical selectivity	1								
	Neutral conductor oversizing						1			
Management	Standard test frequency increasing	1				1				
	Staff training	1								
	System planning	1	1	1	1	1	1	1	1	1
	Involvement of technical staff in decision making	1	1	1	1	1	1	1	1	1

Table 3 – REL levels for systems provided by different technical or management solutions

# Classification of electrical installations in healthcare facilities according to reliability and availability of power supply

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Medical locations		Massage room	Bedrooms	Delivery room	ECG, EEG, EHG room	Endoscopic room	Examination or treatment room	Urology room	Radiological diagnostic and therapy room	Hydrotherapy room	Physiotherapy room	Anaesthetic room	Operating theatre	Operating preparation room	Operating plaster room	Operating recovery room	Heart catheterization room	Intensive care room	Angiographic examination room	Haemodialysis room	Magnetic resonance imaging (MRI) room	Nuclear medicine	Premature baby room
Minimum REL		0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	1	1	1	2
Equipment	Backup generator																						
	Dynamic voltage restorers																						
	Passive harmonic filters																						
	Isolation transformers																						
	Active filters																						
	UPS																						
	Voltage stabilizers																						
	Static transfer switches																						
	Static var compensator																						
	Surge protection																						
System	Multiple independent feeder																						
	Emergency supply redundancy																						
	Simple radial scheme																						
	Double radial scheme																						
	Ring scheme																						
	Meshed scheme																						
Design	Equipment oversizing																						
	Horizontal selectivity																						
	Vertical selectivity																						
	Neutral conductor oversizing																						
	Standard test frequency increasing																						
	Staff training																						
	System planning																						
	Involvement of technical staff in decision making																						

Table 4 – REL levels for medical locations, with the respective minimum REL level required, and the solutions to attain this level.

## 6. Best practices

### 6.1. Tests, when standards are not enough

The nature of the EN standard tests is satisfactory, but the prescribed testing frequency (how often tests are carried out) is not sufficient to ensure continuity of supply. More frequent testing at full load is advisable to train hospital personnel in coping with an emergency without being overwhelmed by the situation.

All devices connected to the MV/LV transformer must be tested regularly. In particular the following devices require at least one test per month:

- Circuit Breakers
- Generator set (full load)
- Emergency lights
- CPSS (battery discharge)

## 6.2. Design Criteria

### 6.2.1. Neutral conductor systems

In all countries, LV networks and loads are earthed for safety reasons, to avoid the risk of electrocution.

The objectives of earthing are:

- Setting a fixed voltage potential between live conductors and the earth
- In the event of a failing electrical insulation, limiting the voltage potential between the frames of electrical equipment and the earth
- Eliminating the risk of individuals receiving an electric shock or being electrocuted
- Limiting voltage surges caused by MV faults

Three earthing systems are standardised internationally: *TN* (*TN-C* or *TN-S*), *TT*, and *IT* (including *medical IT*).

The hospital's choice of earthing system (how to connect the neutral conductor) depends on the size of the installation and the IEC standard, and can be summarized as follows:

- In large healthcare facilities, the *TN-S* system is generally used (except for patient environments in group 2 locations), since the installations are equipped with their own transformer substation
- In small hospitals, the *TT* system is the most commonly used (except for patient environments in group 2 locations)
- In all hospitals, patient environments in group 2 locations use the *medical IT* system

### 6.2.2. Installation equipment

#### 6.2.2.1. Boards

Boards used in *medical IT* systems must be equipped with an insulation transformer. If group 2 locations are not completely fed by a *medical IT* system and contain ordinary loads, two approaches can be adopted:

- One board feeding both systems (in this case the board must guarantee the separation between the two systems)
- Two separated boards, one for each system

The choice between these two solutions is made by analysing cost versus system reliability.

#### 6.2.2.2. UPS

This paper focuses on the specifics of medical applications. Hence, general requirements are not discussed (emergency power off, cooling, ventilation for batteries, etc.).

EN 62040 defines the standard for uninterruptable power supplies (UPS). Part 1-1 of this standard defines the "General and safety requirements for a UPS used in operator access areas". Part 1-2 defines the "General and safety requirements for a UPS used in restricted access locations". Chapter 1.2 states the following: "Even if this standard does not cover all types of UPS, it may be taken as a guide for such equipment. Requirements additional to those specified in this standard may be necessary for specific applications, for example: [...] electro medical applications with the UPS located within 1.5 m from the patient contact area [...]". This implies the EN 62040-1 standard is sufficient for a UPS installed at a minimum of 1.5 m from the patient.

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## 6.2.2.3. X-Ray based devices

A UPS which is designed to supply X-Ray based devices, MRIs or any device with high inrush currents, can differ on the following requirements:

- The UPS should supply sufficient power to get the patient into a safe condition
- The UPS should supply full load until the operation is completed

As already stated in 4.3.1, devices can be sensitive to electrical disturbances, and/or be the source of such disturbances. Two major solutions are:

- Properly sizing the local distribution network
- Providing an on-line double conversion (VFI-SS-111) UPS

The latter solution avoids voltage drops due to harmonic currents and electrically separates the mains supply from loads.

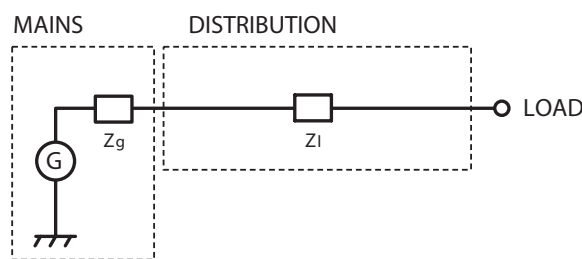


Figure 5 - Impedance model of distribution line

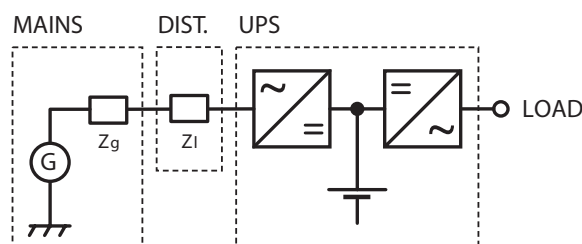


Figure 6 – On-line Double Conversion UPS (principle scheme) and distribution line

In cases where only a limited amount of power is required to get the patient into a safe condition, a UPS with lower power than the rated power of the X-Ray device is typically used to supply the control and measurement systems. It is important to verify that the device allows for a command to switch in low consumption working mode.

The choice gets more complicated when there is a requirement to complete the examination. Just oversizing the UPS is not enough, since sufficient power alone cannot guarantee acceptable dynamic response. The risk of output voltage distortion remains.

When considering the total cost of ownership (TCO) of the system, a UPS with batteries directly connected to the DC BUS, or any high input harmonic distortion device (THD<sub>i</sub>), is not advisable. The reasons are:

- DC voltage ripple reduces battery life
- The upstream plant must be oversized
- It increases the risk of electromagnetic disturbances affecting sensitive medical devices

Contact the UPS producer for a proper choice of system.

## 6.2.2.4. ICT networking devices

Hospitals and clinics include a lot of ICT loads such as servers, workstations and networking switches – to store data, manage bookings and allow information access. Their sensitivity to electrical disturbances is lower than that of medical devices, as shown in Figure 3.

Despite the fact that the ITI curve allows supply interruptions up to 20 ms, it is advisable to foresee an on-line double conversion UPS to protect ICT devices from harmonics and overvoltages.

Especially for computer servers, it is recommended to select a UPS with the following characteristics:

- A unitary input power factor to avoid the need for upstream oversizing
- A leading output power factor of 0.9 to ensure the highest power density
- A high efficiency across a wide range of loads, to ensure energy saving and minimum carbon footprint at low load (typical for data centres)

## 6.2.2.5. Central Power Supply System

A Central Power Supply System (CPSS) is a UPS matching the requirements of both EN 62040 and EN 50171 standards. The main requirements of the latter are:

- Use of long life batteries
- Protection against battery polarity inversion
- Dry contact signalling
- A battery charger protected against short circuits
- 80% of battery recharge in 12 hours
- Fire resistance

Additional requirements can be stipulated by national laws.

A CPSS must be used to feed emergency lights, fire alarms, smoke extractors and all electrical systems related to safety.

## 6.2.2.6. STS

Static Transfer Systems (STS) are intelligent units with two inputs and one output (Figure 7). In the event that the preferred power source does not match the tolerance values permitted by the load, the STS seamlessly transfers the load to an alternative source. This ensures “high availability” of power supply for sensitive or critical installations.

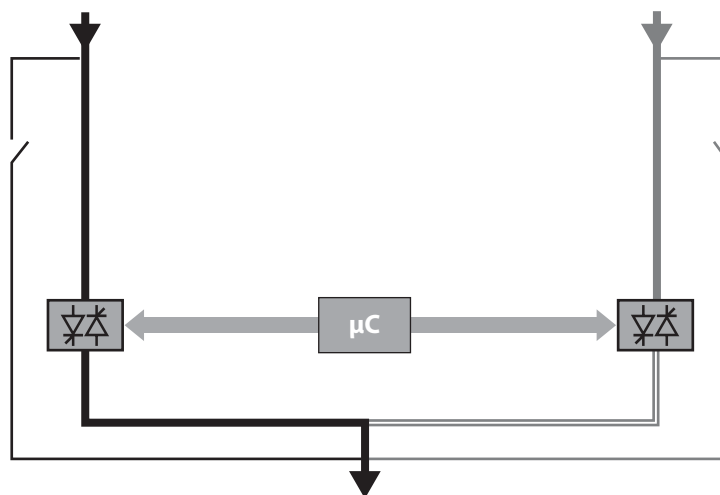


Figure 7 - STS principle scheme

The purpose of STS devices is to:

- Ensure redundancy of power supply to critical installations (two independent power sources)
- Increase power supply reliability for sensitive installations
- Facilitate the design and extension of a high-availability power supply

STS systems incorporate reliable and proven solid-state switching technology (SCR), enabling them to perform fast and safe switching (automatic or manually) without interrupting the power supply to the load.



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IEEE publication Std 493-2007, *Design of Reliable Industrial and Commercial Power System*, analyses the mutual influence of dual-cord loads in a 2N supply architecture in terms of availability. Because it electrically separates loads, the STS can be used to avoid failure propagation, preventing any mutual influences. This again improves availability.

2N architecture	Inherent Availability	Probability of failure (5 years)
12 dual-cord loads	0.9999913	16.61%
24 dual cord loads	0.9999825	31.13%

Table 5 - Mutual influence of loads

## 6.2.2.7. Generator Set

The generator set does not need to fulfil any requirements other than providing a backup for at least 24 hours.

The following elements are worth considering when sizing the generator set:

- Generator sets are usually not suitable for feeding capacitive loads with power factor less than 0.97
- Any total harmonic distortion (THD) generated by loads will be translated into voltage harmonics by the voltage drop on the subtransient reactance ( $X''_d$ ) of the synchronous generator. Those voltage harmonics can be approximated by the following formula:

$$THD_{U\%} = \frac{X''_{d\%}}{100} \sqrt{(2I_{2\%})^2 + (3I_{3\%})^2 + \dots + (nI_{n\%})^2}$$

- The generator set and the MV/LV transformer should have the same neutral system to avoid any unnecessary tripping of the residual current device.

## 6.2.3. Distribution schemes

Defining the distribution scheme is the fundamental task in any electrical project.

The basic analysis must evaluate the real user needs and the level of service that the network has to provide. This service includes:

- The availability and continuity of the correct power supply
- The resilience to various interruptions due to faults or breakdowns (unplanned), or for maintenance or modifications (planned)

Distribution schemes can be classified as follows:

### – Simple Radial Scheme

In a simple radial scheme, the power is drawn from a busbar. Subsequently, it is distributed radially towards the loads (or to secondary busbars when appropriate).

### – Ring Scheme

The ring scheme contains at least one extra branch than necessary to connect the loads to the feeder node. As a result, each load has at least one alternative feeding path. A ring scheme grid can consist of an open ring or a closed ring. The ring scheme can be double or triple redundant and used at all voltage levels.

### – Double Radial Scheme

The double ring scheme consists of a simple radial scheme that is doubled. The benefit of this scheme is that each load has two equal alternative feeding paths. The duplication can run up to a single server node, or – as is more frequently done – to one or more distribution nodes (busbars).

### – Meshed Scheme

In this scheme, there are multiple connections between the grid nodes. This enables alternative supply paths for some of those nodes and the establishment of a reserve connection. It also improves the subdivision of the load in various branches and among different feeder sources.

Table 4 shows a classification of schemes in terms of availability, reliability, cost and other key features.

Features	Scheme			
	Simple Radial	Double Radial	Ring	Meshed
Reliability	min	max	med	max
Availability	min	max	med	max
Voltage level stability	min	Max	med	max
Losses	max	Min	med	max
Investment cost	min	Max	med	max
Operative cost	min	Max	med	max
Flexibility	min	Max	med	max
Complexity	min	Med	med	max

Table 6 – Comparison between various electrical schemes

In healthcare facilities, choosing the appropriate electrical distribution scheme is based on budget constraints as well as the needs surrounding availability and reliability of supply.

While old installations are in most cases still based on a simple radial scheme, today double radial or ring solutions are often preferred.

## 6.2.4. Redundancy

Redundancy is a useful method for increasing availability and optimising the balance between operational excellence and financial effectiveness. Alternative circuits, equipment, and components are installed so, in the event of one or more failures, functionality is preserved. The level and type of redundancy provided determines which functionalities will be retained in the case of a fault, and the number and types of faults that can be handled.

**Standby redundancy** means that an alternative way of performing the function is provided but is inoperative until needed. When the primary mains can no longer provide its service, the alternative source switches on.

The disadvantage of standby redundancy is that there is an inevitable period of disruption between the failure occurring and the redundant unit being brought into use. Such schemes are rarely satisfactory for critical systems such as group 2 medical locations.

In **active or parallel redundancy**, all redundant units are operating simultaneously rather than being switched on when needed. The most obvious approach is to use two components, each capable of carrying the full load so if one should fail the other will take over. This is referred to as 1+1 redundancy.

An alternative approach is to split the total load among a number of units, each capable of carrying only a fraction of the total load, and provide just one additional redundant unit for all of the load. This is referred to as **N+1 redundancy**.

N+1 redundancy can be cheaper to implement than 1+1 redundancy and it is more flexible; e.g. it is easy to add an additional load (a 2+1 system becomes a 3+1 system).

Table 4 shows best practices adopted in hospitals.

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	No redundancy	Gen Set	N	N+Gen Set	N+1	N+1+Gen Set	2N	2N+Gen Set
HVAC	X	X						
Analysis			X	X				
Ordinary lighting	X	X		X				
Emergency lighting	X	X		X				
Sterilisation equipment	X	X						
ECG, EEG, EHG	X	X						X
X-Ray equipment	X	X		X				X
Dialysis equipment				X				X
MRI	X	X		X				X
Equipment for nuclear medicine	X	X						
Angiography			X	X				
Surgeon Theatres			X	X				
Intensive therapy			X	X				
Incubators				X				X
Other endoscopic equipment		X		X				X
Telecom equipment		X		X				
ICT				X				X
Ordinary lifts	X	X						
Firefighters' lifts		X						
Fire alarms, smoke extractors, etc.		X						
Distribution systems for medical gases		X		X				X
Kitchens	X	X						
Others								

Table 7 – Best practices in redundancy adoption for main installation parts

## 6.3. Personnel training

The following topics – with particular attention to electrical aspects – are worth including in personnel training programmes:

- Fire prevention, evacuation, first aid, safety and emergency in hospitals
- Biological risks
- Chemical risks
- Anaesthetic inhalation risks
- Gene-toxic risks
- Hospital rubbish risks
- Manual loads handling
- Electrical risks
  - o Rudiments of electricity
  - o Biological effects of electricity
  - o Macro and micro electric shock situations
  - o Main plant components recognition
    - Electrical risk linked to improper use of medical devices
  - o Risk prevention and protection
- Ionizing radiation risks
- Non-ionizing radiations risks
- Shifts and health
- Psychological risks

- VDU risks
- Personal protection devices
- Safety signals

## 7. Conclusions

The IEC standard for electrical installations in medical locations focus on safety aspects, in particular the protection against indirect contact. Its requirements in terms of availability of supply and overall reliability are qualitative rather than quantitative.

There is a serious need for a universally accepted definition of availability and reliability levels of power supplies. The quality of healthcare applications relies on sufficient availability of the power supply and the adequate performance of the electrical installation. This was the conclusion from several interviews with medical staff and technicians.

The interviews also highlighted another strong need: to introduce more severe directives for the frequency of periodic testing. The current standards are considered (almost unanimously) to be insufficient to guarantee safety, reliability and availability of emergency supply systems. Almost every interviewed technician proposed to increase the frequency of periodic testing to at least twice that currently prescribed by IEC 60364-7-710.

The IEC standard classifies medical locations as group 0, group 1 or group 2 according to the use of applied parts and whether the patient's life is at risk or not.

Two innovative notions were introduced in this paper: the resilience of equipment to power quality disturbances (REL) and the patient's quality of life (LQ). Based on these notions, a new classification scheme for the resilience level of healthcare facilities was built up. This scheme does not merely consider the safety of the patient, but also takes into account:

- The availability, resilience and reliability of the power supply
- The patient's quality of life

It enables decision makers and technical staff of healthcare facilities to properly design the electrical installation for the best quality of life for patients, using the most cost effective technical solution, and do so in accordance with the IEC 60364-7-710 classification scheme.

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