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Recommendations and Standards for Building and testing an Intensive Care Unit (ICU) Electrical installation

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Abstract

The Intensive Care Unit, well known as ICU, is a specialized section of a hospital that provides comprehensive and continuous care (treatment and monitoring) for persons who are critically ill or in an unstable condition and who can benefit from treatment. The importance of this specific area of the hospital can be also understood from the amount and variety of the equipment that is installed inside. Therefore the Intensive Care Unit (ICU) should provide both continuous fault-free equipment operation and enhanced electrical safety for the patients and the medical staff.

The main objective of the thesis is to study and design the electrical installation and the dedicated devices of a sample ICU, according to the latest European regulations and standards.

In the first introductory chapter is described the main ICU medical equipment, patient modules, areas and utilities. The second chapter contains the Main Standards, Directives and Recommendations related to the building installing and testing of the ICU electrical installation and dedicated equipment. Chapter three described general the electrical safety in the ICU and the methods and means of protection against an Electrical shock. The next chapter reviews the methods and means of protection against an Equipment Malfunction and against Mains power failure. The fifth chapter is the design of a sample ICU Area including main power electrical installation and dedicated protection and monitoring devices. The last chapter includes the electrical safety tests of the installed system and dedicated devices and also the value limitations according to the European Standards and Regulations.

Περίληψη

Η Μονάδα Εντατικής Θεραπείας, γνωστή ως ICU, είναι ένα εξειδικευμένο τμήμα του νοσοκομείου που παρέχει πλήρη και συνεχή φροντίδα (θεραπεία και παρακολούθηση) στα πρόσωπα που αντιμετωπίζουν κρίσιμα προβλήματα υγείας ή βρίσκονται σε μια ασταθή κατάσταση. Ο εξειδικευμένος εξοπλισμός της χωρίς καμία αμφιβολία μπορεί να επιφέρει πολύ θετικά αποτελέσματα στον ιατρικό τομέα

Η λειτουργία και η σημασία της μονάδας, αναμφίβολα μπορούν να διαφανούν και από τον άριστο εξοπλισμό που διακατέχει. Είναι βέβαιο ότι μέσα από την συγκεκριμένη μονάδα θεραπείας μπορεί να δοθεί στον ασθενή η κατάλληλη σημασία έτσι ώστε να μπορεί να γιατρευτεί. Ο άρτια εξοπλισμός που υπάρχει μπορεί να επιφέρει άριστα αποτελέσματα. Συνεπώς, η Μονάδα Εντατικής Θεραπείας (ICU) πρέπει να συνεχίσει την απρόσκοπτη λειτουργία της και συνάμα την ενίσχυση του εξοπλισμού της, έτσι ώστε να υπάρχει ενισχυμένη ηλεκτρική ασφάλεια τόσο για τους ασθενείς όσο και για το ιατρικό προσωπικό.

Ο κύριος στόχος της διατριβής είναι η μελέτη και ο σχεδιασμός της ηλεκτρικής εγκατάστασης και δείγμα των αποκλειστικών συσκευών της μονάδα, σύμφωνα με τις τελευταίες ευρωπαϊκές προδιαγραφές.

Στο πρώτο εισαγωγικό κεφάλαιο, περιγράφεται ο βασικός εξοπλισμός της μονάδας και η ιατρική που παρέχεται. Ακολούθως στο δεύτερο κεφάλαιο περιλαμβάνονται οι κύριοι κανόνες, οδηγίες και οι συστάσεις που σχετίζονται με την εγκατάσταση του κτιρίου. Επίσης γίνεται αναφορά στον έλεγχο της ηλεκτρικής εγκατάστασης και του ειδικού εξοπλισμού της μονάδας.
Στο τρίτο κεφάλαιο περιγράφεται η γενική ηλεκτρική ασφάλεια στη μονάδα, με ιδιαίτερη αναφορά στις μεθόδους και στα μέσα προστασίας από ηλεκτροπληξία.
Στη συνέχεια στο επόμενο κεφάλαιο εξετάζεται το κατά πόσο οι μέθοδοι και τα μέσα προστασίας μπορούν να είναι λειτουργικά έναντι των δυσλειτουργιών που μπορεί να προκληθεί από την διακοπή ρεύματος. Για την όσο καλύτερη λειτουργία της μονάδας γίνεται αναφορά στο πέμπτο κεφάλαιο, όπου γίνεται νύξη για τον σχεδιασμό του χώρου της μονάδας, συμπεριλαμβανομένων των κύριων ηλεκτρικών εγκαταστάσεων συσκευών προστασίας και παρακολούθησης.
Μέσα από μια εκτεταμένη ανασκόπηση, έρευνα και πληθώρα πειραμάτων στο τελευταίο κεφάλαιο παρουσιάζονται οι ηλεκτρικές δοκιμές ασφαλείας του εγκατεστημένου συστήματος, οι ειδικές συσκευές, σύμφωνα πάντα με τα Ευρωπαϊκά πρότυπα και κανονισμούς.

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1. Introduction

The intensive care unit, well known as ICU, is a specialized section of a hospital that provides comprehensive and continuous care (treatment and monitoring) for persons who are critically ill or in an unstable condition and who can benefit from treatment. The purpose of the ICU is simple even though the practice is very complex. Patients are generally admitted to an ICU if they are likely to benefit from the level of care provided. Intensive care has been shown to benefit patients who are severely ill and medically unstable. People in ICUs need constant medical support to keep their body functioning. They may not be able to breath on their own and they may have multiple organ failure. Medical equipment takes the place of these functions while the person recovers.

A modern ICU represents the pinnacle of any hospital`s approach to highly technological and sophisticated in-patient care. Over the last two decades, there has been a virtual knowledge explosion in our understanding of critical illness. The past decade has seen the ICU evolve from a rule of thumb experience based practice to an increasingly precise and scientifically based one. The importance of this specific area of the hospital can be also understood from their equipment that is installed inside. ICU equipment includes patient monitoring, respiratory and cardiac support, pain management, emergency resuscitation devices, and other life support equipment designed to care for patients who are seriously injured, have a critical or life-threatening illness, or have undergone a major surgical procedure, thereby requiring 24-hour care and monitoring. There are lots of pre-existing guidelines and standards for building medical locations, electrical installations and testing the medical equipments. The most up-to- date international standard for electrical installations in medical locations is published in IEC 60364-7-710. This standard was developed with full participation of the British Electrotechnical Committee where the IEE and the UK Health Departments had a major input in its final approval. Also IEE Guidance Note 7 (Chapter 10) covers the special requirements for medical locations. It was first published in 1998 and revised in 2003. The latter publication is based on IEC 60364-7-710 for medical locations. The main objectives of the thesis is the design of the ICU area with the whole electrical power system and installations, providing safety, with isolated power supply preventing any accident in the critical care area within the regulations and standards. The investigation of the ICU department is very complicate procedure due to multiple parameters that have to be cover and at the same time safety and quality assurance must be present except from the simplicity and the operation of the whole department linked with the hospital.

1.1. Physiological Monitoring

In the ICU area each patient module should have monitoring capabilities that include the analysis and display of any important data of the each patient. For this reason one or more electrocardiographic leads, at least three fluid pressures and direct or indirect measures of arterial oxygen levels should be monitoring. Bedside monitoring equipment should be located to permit easy access and viewing of the entire needed data. The bedside nurse and the monitor technician must be able to observe the monitored status of each patient at a momentary look. This goal can be achieved either by a central monitoring station, or by bedside monitors that permit the observation of more than one patient simultaneously. It should be assumed that monitoring equipment will increase in volume over time. Therefore, space and electrical facilities should be designed accordingly to serve the area.

1.1.1. Monitoring and Life Support Equipment

Almost all the facilities in the ICU area are working with the electricity to provide any important data, analysis and clues to the medical staff and care to the patients, such as electrocardiographic leads, computerized rate and waveform analysis to recognize and alarm for asystole, ventricular tachycardia and fibrillation, and preset the maximum and the minimum heart rates. Furthermore monitoring equipment should have the capacity for two or more simultaneous pressure displays. Each bedside station must have the capability of providing a continuous measure of arterial oxygen levels. Pulse oximetry and transcutaneous $p0_2$ measurements are presently the preferred modalities of oxygen monitoring. End-tidal $C0_2$ or transcutaneous $pC0_2$ measurements may be used for carbon dioxide monitoring as needed. Respiratory rate monitoring should be available for patients at risk for apnea. The capability for providing all these functions is strongly encouraged and should be made a provision at the begging drawings of the ICU area from professional engineers who are required to design a reliable power system and also make provisions for future equipments.

1.2. ICU Areas

In the hospital environment and especially in this critical area, the needs of the below suggested areas are very important due to the complexity and critical situation that the medical staff and also the patients faced. These areas should be designed by experienced architects and civil engineers. With their experience they will provide building drawings with all the needed areas in the ICU helping the medical staff at first but also patients.

Floor Plan and Design

ICU floor plan and design should be based upon patient admission patterns, staff and visitor traffic patterns, and the need for support facilities such as nursing stations, storage, clerical space, administrative and educational requirements, and services that are unique to the individual institution.

Eight to twelve beds per unit is considered the best combination after evaluation and researches for an ICU department. Each intensive care unit should be a geographically distinct area within the hospital, with controlled access. Supply and professional traffic should be separated from public and visitor traffic. Location should be chosen so that the unit is adjacent to, or within direct elevator travel to, and from, the Emergency Department, Operating Room, intermediate care units, and Radiology Department.

Patient Areas

Patients must be situated so that direct or indirect (e.g. by video monitor) visualization by healthcare providers is possible at all times. This permits the monitoring of patient status under both routine and emergency circumstances. The preferred design is to allow a direct line of vision between the patient and the central nursing station.

Central Station

A central nursing station should provide a comfortable area of sufficient size to accommodate all necessary staff functions. When an ICU is of a modular design, each nursing substation should be capable of providing most if not all functions of a central station. Adequate space for computer terminals and printers is essential when automated systems are in use. Patient records should be readily accessible.

Work Areas and Storage

Work areas and storage for critical supplies should be located within or immediately adjacent to each ICU. Also should provide for the storage and rapid retrieval of crash carts and portable monitor and defibrillators. There should be a separate medication area of at least 50 m^2 containing a refrigerator for pharmaceuticals, a double locking safe for controlled substances, and a sink with hot and cold running water.

Receptionist Area

Each ICU or ICU cluster should have a receptionist area to control visitor access. Ideally, it should be located so that all visitors must pass by this area before entering. The receptionist should be linked with the ICU(s) by telephone or other intercommunication system. It is desirable to have a visitors' entrance separate from that used by healthcare professionals.

There are also other areas and room in the ICU area which are essential to provide the necessary and complete care in the ICU area such as:

1.3. Patient Modules

Patient modules should be designed to support all necessary healthcare functions. The latest notes Health Building Note 27 (HBN 27: IntensiveTherapist Unit), describes that the floor space allocated for each bed should be sufficient to accommodate all equipment and personnel that might be necessary to meet patient care needs. Each State Department of Public Health should be consulted for specific guidelines related to square meters per bed, or space required between beds. Ward-type ICUs should allow at least 21m^2 square meters of clear floor area per bed. ICUs with individual patient modules should allow at least 23m^2 square meters per room (assuming one patient per room), and provide a minimum width of 4.5 meters, excluding ancillary spaces (anteroom, toilet, storage). A cardiac arrest and emergency alarm button must be present at every bedside within the ICU. The alarm should automatically sound in the hospital telecommunications center, central nursing station, ICU conference room, staff lounge, and any on-call rooms. Space and surfaces for computer terminals and patient charting should be incorporated into the design of each patient module as indicated. Every effort should be made to provide an environment that minimizes stress to patients and staff. Therefore, design should consider natural illumination and view. Advice from environmental engineers and designers should be sought to deinstitutionalize patient care areas as much as possible.

1.4. Main Utilities in ICU

Each intensive care unit must have electrical power, water, oxygen, compressed air, vacuum, lighting, and environmental control systems that support the needs of the patients and critical care team under normal and emergency situations, and these must meet or exceed regulatory and accreditation agency codes and standards.

1.4.1. Electrical Power

According to the BS 7671 – IEE Wiring Regulations 16th Edition and to the Health Technical Memorandum 2011 (HTM 2011) the electrical supply to each ICU should be provided by a separate feeder connected to the main circuit breaker panel that serves the branch circuits in the ICU. The main panel should also be connected to an emergency power source that will quickly re-supply power in the event of power interruption. Each outlet or outlet cluster within an ICU should be serviced by its own circuit breaker in the main panel. It is critical that the ICU staff have easy access to the main panel in case power must be interrupted for an electrical emergency.

Grounded 240 volt electrical outlets with 20 amp circuit breakers should be located within a few feet of each patient's bed and the wire must be $4mm^2$. Further to the regulations BS 7671 – IEE Wiring Regulations 16th Edition and to the Health Technical Memorandum 2011 (HTM 2011) in every ICU room twenty four outlets per bed are desirable and also three to six priority outlets should be feet from the UPS. The regulations also suggest that head outlets of each bed should be placed approximately 20cm above the floor to facilitate connection, and to discourage disconnection by pulling the power cord rather than the plug and outlets at the sides and foot of the bed should be placed close to the floor to avoid tripping over electrical cords.

1.4.2. Lighting

General overhead illumination plus light from the surroundings should be adequate for routine nursing tasks, including charting, yet create a soft lighting environment for patient comfort. Total luminance should not exceed 325 lux. It is preferable to place lighting controls on variable-control dimmers located just outside of the room. This permits changes in lighting at night from outside the room, allowing a minimum disruption of sleep during patient observation. Night lighting should not exceed 75 lux for continuous use or 215 lux for short periods. Separate lighting for emergencies and procedures should be located in the ceiling directly above the patient and should fully illuminate the patient with at least 1615 lux shadow-free. A patient reading light is desirable, and should be mounted so that it will not interfere with the operation of the bed or monitoring equipment. The luminance of the reading lamp should not exceed 325 lux.

2. Main Standards, Directives and Recommendations

Investigating the medical locations and especially the ICU area can be found many standards and directives. Through the years they were also published and recommendations for the safe way of

building, installing and testing medical locations. Reading and understanding the standards, the directives and the recommendations help to create an ICU which can provide safety and easy operation.

1. IEC 60364-7-710. Electrical installations of buildings. Requirements for special installations or locations – Medical locations. International Electrotechnical Commission, 2002.
2. BS 7671:2001. Requirements for electrical installations. IEE Wiring Regulations. Sixteenth edition. British Standards Institution, 2001.
3. EN 1838:1999, BS 5266-7:1999. Lighting applications. Emergency lighting, 1999.
4. EN 60601-1, IEC 60601-1. Medical electrical equipment. General requirements for safety.
5. EN 61558-2:1998–2003. Safety of power transformers, power supply units and similar.
6. EN 62040-1-1:2003. Uninterruptible power systems (UPS). General and safety requirements for UPS used in operator access areas.

3. Electrical safety in ICU

Electrical safety in critical areas can be achieved by ensuring the safety of the installation and the safe operation and maintenance both preventive and corrective, of all the medical electrical equipment connected to the area and to the electrical distribution system.

Electricity has big effect when passing through any substance having electrical resistance, heat is produced and the amount of heat depends on the power dissipated, described by the following equations:

$$V = I * R \tag{3.1}$$

$$P = V * I \tag{3.2}$$

$$P = I^2 * R \tag{3.3}$$

The human tissue is capable of carrying electric current quite successfully. Skin normally has a fairly high electrical resistance while the moist tissue underneath the skin has a much lower resistance so an electrical burn often produce their most marked effects near to the skin, although it

is fairly easy for internal electrical burns to be produced which if not fatal can cause long lasting injury. Another effect of the electricity is the muscle contraction, which is shown when an electrical stimulation is applied to a motor nerve or a muscle and then a contraction of the muscle occur. This situation happens when a person holds a live electrical wire (L) and cannot let it go due to the uncontrolled contraction of the muscle. Furthermore can cause respiratory and cardiac arrest, both respiration and heart are working by muscles and when an electricity pass from these muscles due to the contraction may cause tetanus of these muscles and cannot contract with rhythm with resulting probably death. Ventricular fibrillation is also another effect of electricity when it passes through heart, microshock or through hand across the chest in the skin surface, macroshock and the ventricles are not pumping blood with result the death.

Electric Current - (1 second duration)	Physiological Effect
1 mA	Threshold of feeling, tingling sensation
10-20 mA	"Can't let go!" current – onset of sustained muscular contraction.
100-300 mA	Ventricular fibrillation, fatal if continued.

Table 3.1. Effects of Electricity

Further, the use of medical electrical equipment on patients under intensive care has called for enhanced reliability and safety of electrical installations in hospitals so as to improve the safety and also to ensure at every moment the safety of the patients and for the medical staff.

Minimizing electric shock in hospitals is one of the most important goals for safe electrical design. Many guidelines and directives for electrical safety were published since 1963 until today such as Health and Social Security published Hospital Technical Memorandum number 8 called "safety code for electro-medical apparatus", British Standard BS 5724 part 1, a comprehensive specification for safety of medical electrical equipment and at the end the latest were BS 7671 – IEE Wiring Regulations 16th and 17th Edition which include ways to achieved the safety more generally, the Health Technical Memorandum 2011 (HTM 2011), the international standard IEC 60601-1 - medical electrical equipment - General requirements for basic safety and essential performance and the IEC 60364-7-710:2002-11, which is an internationally applied standard specifying the requirements for the electrical installations for medically used rooms.

3.1. Medical Locations

Medical location is considered to be a place used for diagnostic, therapeutical, surgical and rehabilitation purposes as well as for aesthetic treatments, like the infirmary, dentistry, ICU and operating theatre. Since the hazard to people depends on the treatment being administered, medical hospital locations are divided into three groups, based on the type of medical electrical equipment used and also on the medical procedures that are being carried out.

Group 0 :

In this group are all the treatments that the medical staff is not using at all any medical electrical equipment even for diagnosis. In this group are included the consulting room, the rooms that the staff and patients are resting etc.

Group 1:

In group 1 are the locations where medical electrical equipment is in use, but not for treatment of heart (intracardiac) conditions. Equipment with patient-applied parts is used externally or invasively but without entering the cardiac zone like physiotherapy and hydrotherapy, dialysis room etc.

Group 2:

In group 2 are the locations where all kind of medical electrical equipment with patient-applied parts is in use for heart (intracardiac) conditions and surgery, and one of the most well known areas that is included in the Group 2, is the ICU.
There is also one exception for the devices with an internal power source/battery (that cannot be used under charging) should not be taken into account for room classification, unless it is involved in intracardiac procedures, so it can be classified to the Group 2.

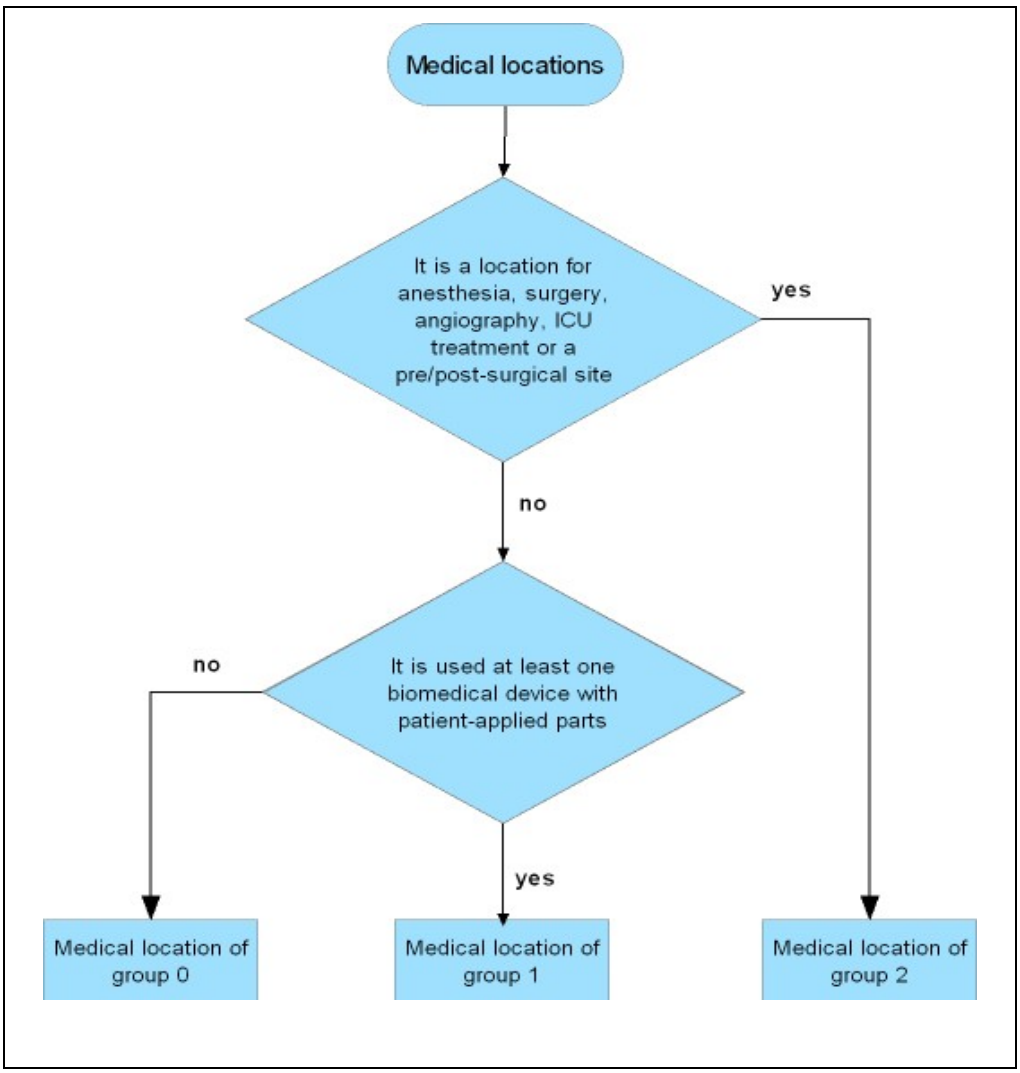


Figure 3.1. Classification of Medical Locations

3.2. Methods and Means of Protection against Electrical Shock

Different protection methods against electrical shock can be found in many directives and publications but the most updated is the IEC 60364-7-710, Electrical installations of buildings. Requirements for special installations or locations – Medical locations and the International Electrotechnical Commission BS 7671 – IEE Wiring Regulations 16th and 17th Edition.

3.2.1. Residual Current Device (RCD)

The Residual Current Device also known as GFCI outside of the European Countries, it is a protective mechanism and it can be used for safety. This device is able to disconnect a circuit whenever it detects that the electric current is not balanced between the energized conductor and the return neutral conductor. Such an imbalance, sometimes can caused by current leakage

through the body of a person who is grounded and accidentally touching the energized part of the circuit. A dangerous shock can result from these conditions. RCDs are designed to disconnect quickly enough to diminish the harm caused by such shocks although they are not intended to provide protection against overload or short-circuit conditions, but for these situations should be used the MCBs which is connected before RCDs.

Due to the regulation BS 7671 – IEE Wiring Regulations 16th Edition, the RCDs must be present in every electrical panel especially for the circuits that are responsible for the sockets even in ring type or radial and in wet locations (swimming pools, bathrooms) for the safety of the user.

In medical locations the installations for protection also follows the above regulation. Should be also mention that the system of the hospital is TN and TT and apply these regulations and requirements because in case of the TNC system is not mentioned anything because is not allowed to use such system in any medical location.

For medical location group 1, RCDs must be used in final circuits rated up to 32A with 2,5mm^2 cable, with maximum residual current of 30mA, so all the outlets should be protected by RCDs.

In medical location group 2 in TN system, RCDs should only be used in circuits for the supply of operating tables just for the movements of the table, circuits for X-ray units, circuits for large equipment with a rated power greater than 5 kVA and also to circuits for non-critical electrical equipment (non life-support).

Another important aspect is the type of the RCD and in the medical locations of group 1 and group 2 only type B or type A should be used.

Figure 3.2. Single Phase RCD Type A

Figure 3.3. Three Phase RCD Type B

Differences between the two types A and B are shown below type AC cannot be used to medical location since lots of equipment uses DC pulsing and with type AC cannot be detected.

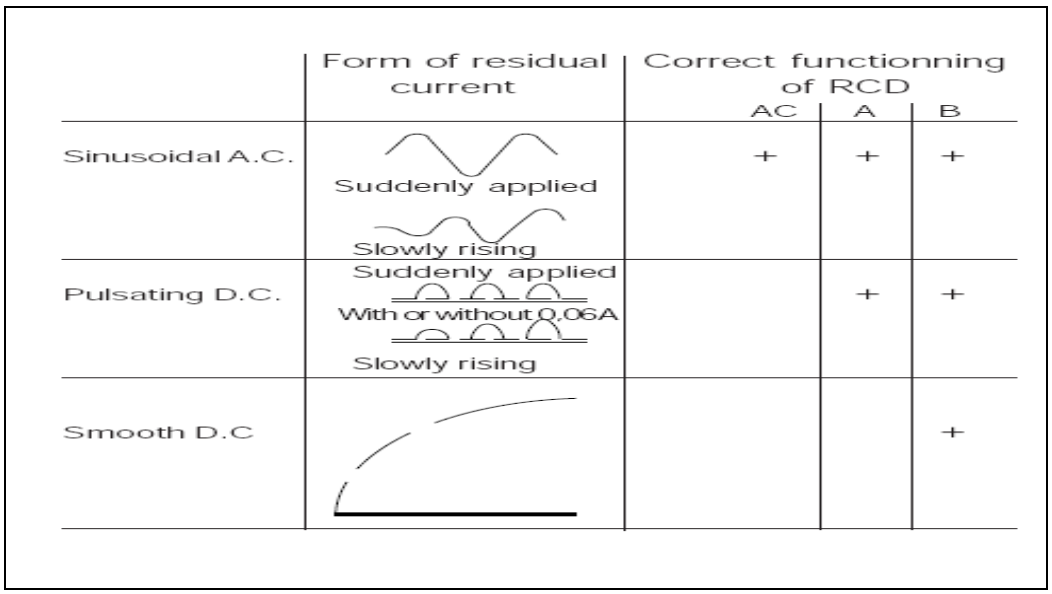


Figure 3.4. Differences between AC,A and B type of RCDs

Hospital RCDs are more sensitive than those fitted in homes. A hospital RCD will trip at 10 milliamperes leakage current. Power outlets supplied through RCD have a 'Supply Available' lamp. The lamp will extinguish when the RCD trips due to excessive leakage current.

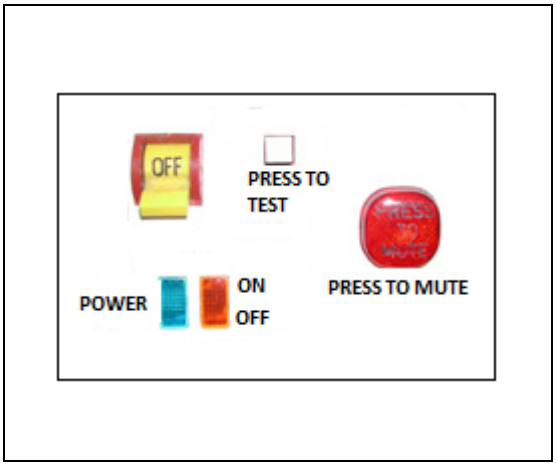


Figure 3.5. Hospital RCD

The hospital RCDs have the same operation as the other, by measuring the current balance between two conductors using a differential current transformer, and opening the device's contacts if there is a balance fault, a difference in current between the phase conductor and the neutral conductor. Generally even if is single phase or three phase, RCDs operate by detecting a nonzero sum of currents, otherwise there is a leakage of current to somewhere else to earth/ground, or to another circuit.

Hospital RCDs are designed to prevent electrocution by detecting the leakage current, which can be far smaller, typically 5–10 mA than the trigger currents needed to operate conventional circuit breakers, which are typically measured in amperes. RCDs are intended to operate within 25–40 milliseconds, before electric shock can drive the heart into ventricular fibrillation, the most common cause of death through electric shock.

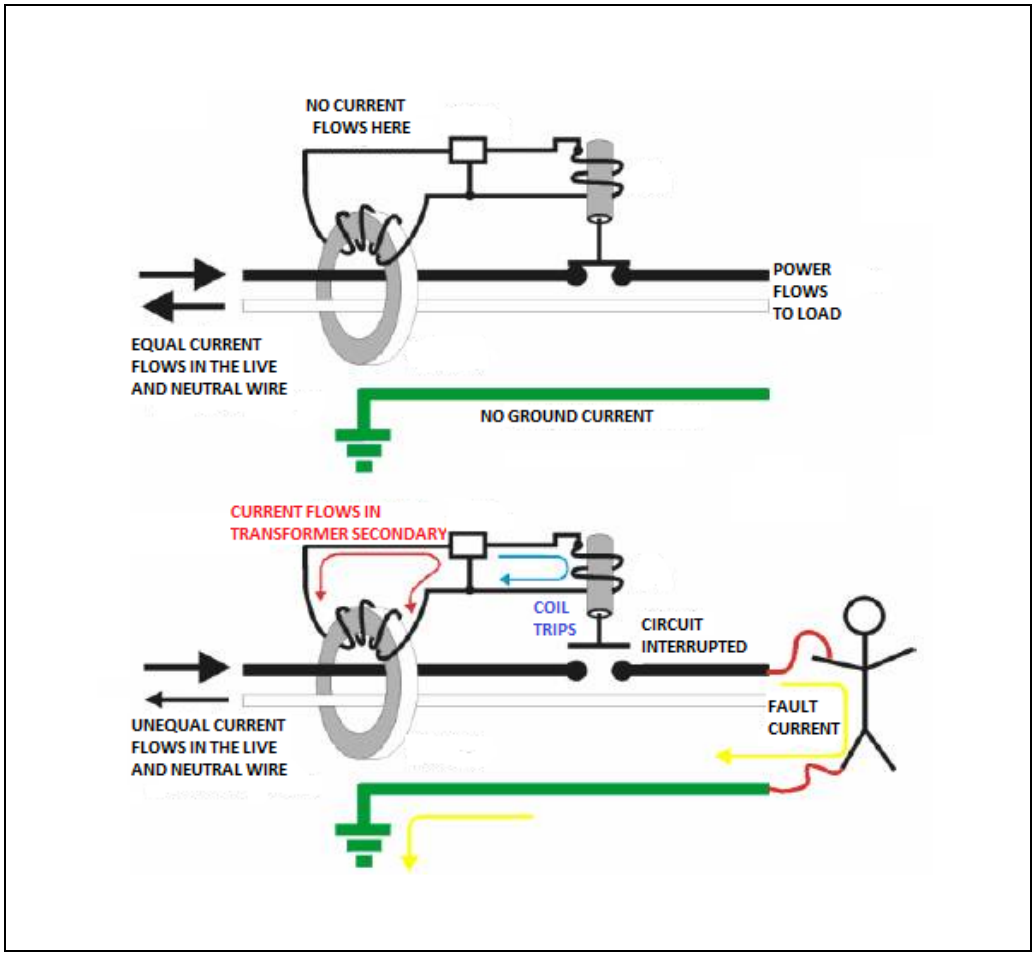


Figure 3.6. Operation of RCDs

Residual Current Devices cannot be made sensitive enough to be tripped by microshock levels of leakage current. However, they can interrupt ground fault currents capable of causing potential differences in the grounding system that might be dangerous to an electrically susceptible patient. Thus, the effect of a major ground fault is reduced to a few milliseconds duration.

3.2.2. IT-M sytem

The IT-M system also known as IPS (Isolated Power Supply system) is a combined system powered by an isolation transformer (IT), equipped with a Line Isolation Monitor (LIM) and with all equipments connected to an equipotential node. Isolated Power Systems were first introduced into the hospital environment as a means of reducing the risk of explosions in operating rooms and any other area where flammable anesthetizing agents are used. Many feel that since hospitals no longer use flammable gases, isolated power is of no benefit. This opinion is not true. Today medical and nursing sciences are becoming progressively more dependent on electrical apparatus for the preservation of life of hospitalized patients. Year by year more cardiac operations are performed, in some of which the patient's life depends on artificial circulation of the blood, in other operations, life is sustained by means of electric impulses that stimulate and regulate heart action. At the same time the equipment, doctor or nurses may be standing in prepping solution, blood, urine and other conductive fluids that greatly reduce resistance to passage of unintended electrical current. Isolated Power reduces the ignition hazard from arcs and sparks between a live conductor and grounded metal and mitigates the hazard of shock or burn from electric current flowing through the body to ground.

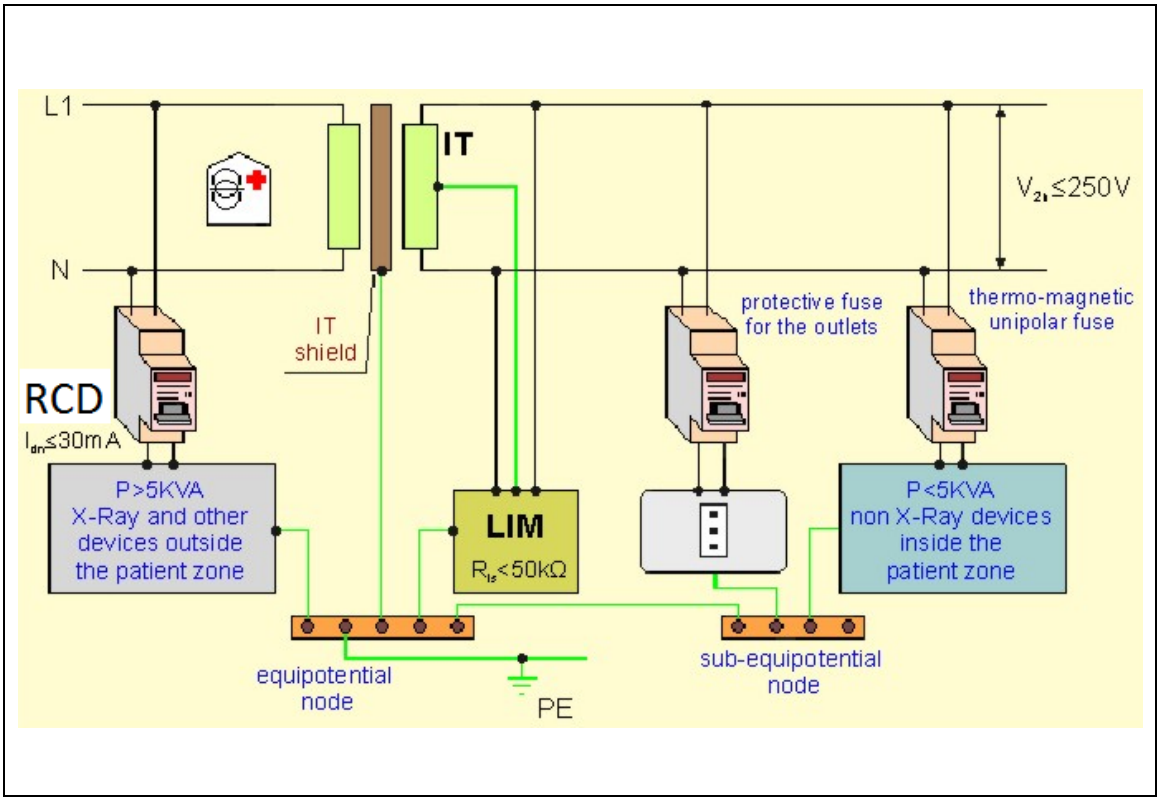
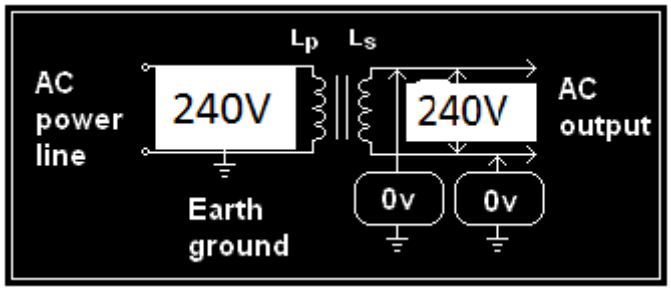


Figure 3.7. General IT-M System

As mentioned before the ICU area is located in Medical Locations of group 2, so for this group the medical IT-M system shall be used for creating a safer environment in the patient area in the circuits that are supplying electricity to the medical electrical equipment and also to systems that are for life support. Furthermore for each group of rooms which are serving the same function shall be used at least one separate medical IT system. The scope of the IT-M system is to electrically isolate the electrical supply from the earth ground which is the reference point for the mains power. Additionally it provides uninterruptible power supply in the installed area and informs the staff in real time in case of a ground fault. The system has an acoustic and visual alarm which alerts the medical staff. The normal operation of the IT-M system is indicated by green light. A yellow light indicates when the preset minimum value for the insulation resistance is reached. When the minimum preset insulation resistance of the IT-M system is reached then the acoustic alarm must sound. Both the acoustic alarm and the indication light should not be allowed to be muted or cancelled for safety reasons.

3.2.3. Isolation Transformer (IT)

The Isolation Transformer has primary and secondary windings that are kept physically separate. Sometimes isolation transformers are called "insulated transformers". This is called because the primary and secondary windings are insulated from each other. An isolation transformer, which often has symmetrical windings, is used to decouple two circuits, furthermore allows an AC signal or power to be taken from one device and fed into another without electrically connecting the two circuits. Isolation transformers can be used to block transmission of DC signals from one circuit to the other, but allow AC signals to pass. This type of transformers will also block interference caused by ground loops. Isolation transformers with electrostatic shields are used for power supplies for sensitive equipment such as laboratory instruments and medical equipment.



Isolation Transformer

Figure 3.8. Isolation Transformer

In critical care areas also can be found another type of improved transformers, the Shielded isolation transformers which have all the features of the standard isolation transformers plus they also incorporate a full metallic shielding. This shielding is often copper or aluminum between the primary and secondary windings. These shielded isolation transformers are then referred to as electrostatic shielded isolation transformers. The electrostatic shield ("Faraday Shield") is connected to earth ground and filters both voltage spikes and common mode noise with attenuation of approximately 40 and 30 dB. Shielded isolation transformers are preferred over standard isolation transformers because they provide protection for sensitive and critical equipment and can be used in hospital environment for increased safety.

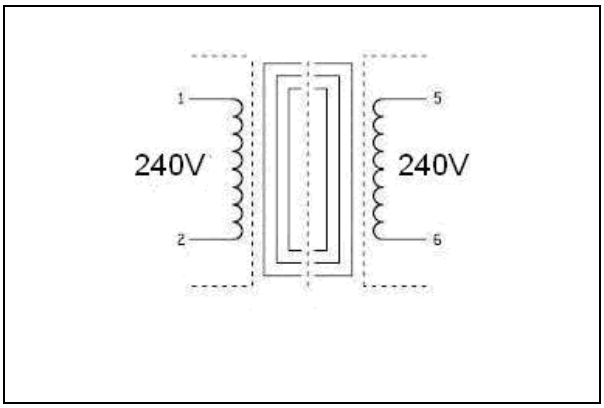


Figure 3.9. Shielded Isolation Transformer

When more than one shielded isolation transformer is installed between the source and the load, this is referred to as "cascading" and this can be done to improve the power quality, reducing any harmonics and spikes to the electrical distribution system.

The medical Isolation transformers shall be installed in well ventilated enclosures and cannot be located within MRi Scanner Faraday Cage's because of the interferences with the static magnetic field. So transformers must be close enough to, inside or outside, the medical location and placed in cabinets or enclosures to prevent unintentional contact with live parts. The rated voltage Un on the secondary side of transformers shall not exceed 250 V AC, according to the IEC 61558-2-15: 1998 for a medical IT transformer.

Also in accordance to the IEC 61558-2-15, the medical transformer should comply with the following requirements; the leakage current of the output winding to earth and the leakage current of the enclosure, when measured in no-load condition and the transformer supplied at rated voltage and rated frequency, shall not exceed 0.5 mA, rated output of the transformers shall not be less than 0.5 kVA and also shall not exceed 10 kVA, or three-phase IT-M system a separate three-phase transformer shall be provided with output line-to-line voltage not exceeding 250 V.

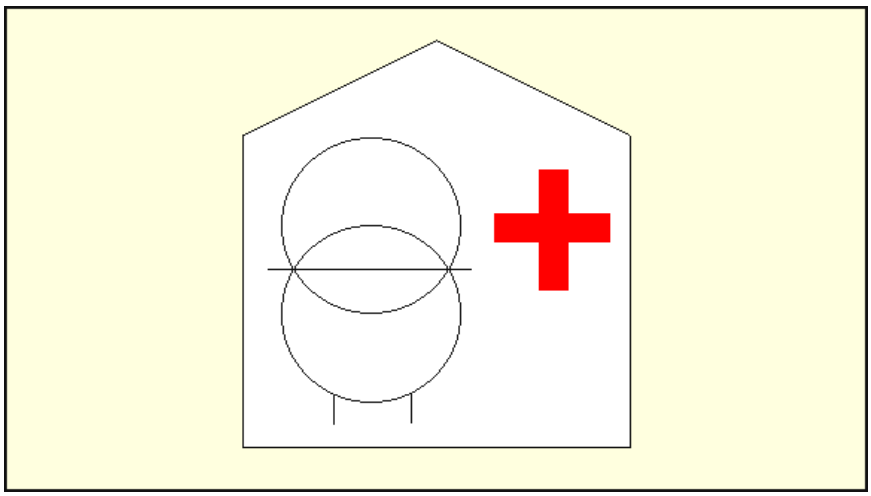


Figure 3.10. Symbol of Medical Isolation Transformer

In the ICU area the use of a medical Isolation Transformer creates a safer environment and must be present according to the IEC 61558-2-15. The output of the isolation transformer, the secondary coil is not connected to the ground but only the primary coil is grounded. Such connection prevents lethal shock and **ideally** macrosock and microshock due to the absence of low impedance to the earth. Thus patient and the medical staff are kept away from electrical hazards. Furthermore ensures continuity of the supply under single fault conditions which is very important in the ICU area. The isolation provided by the isolation transformer, limits the ground leakage current to the amount of 1-2 mA. Additionally the ground current which might flow through patient is about to 1μA which is much lower than the suggested safe limit of the 300 μA and therefore cannot cause any shocks.

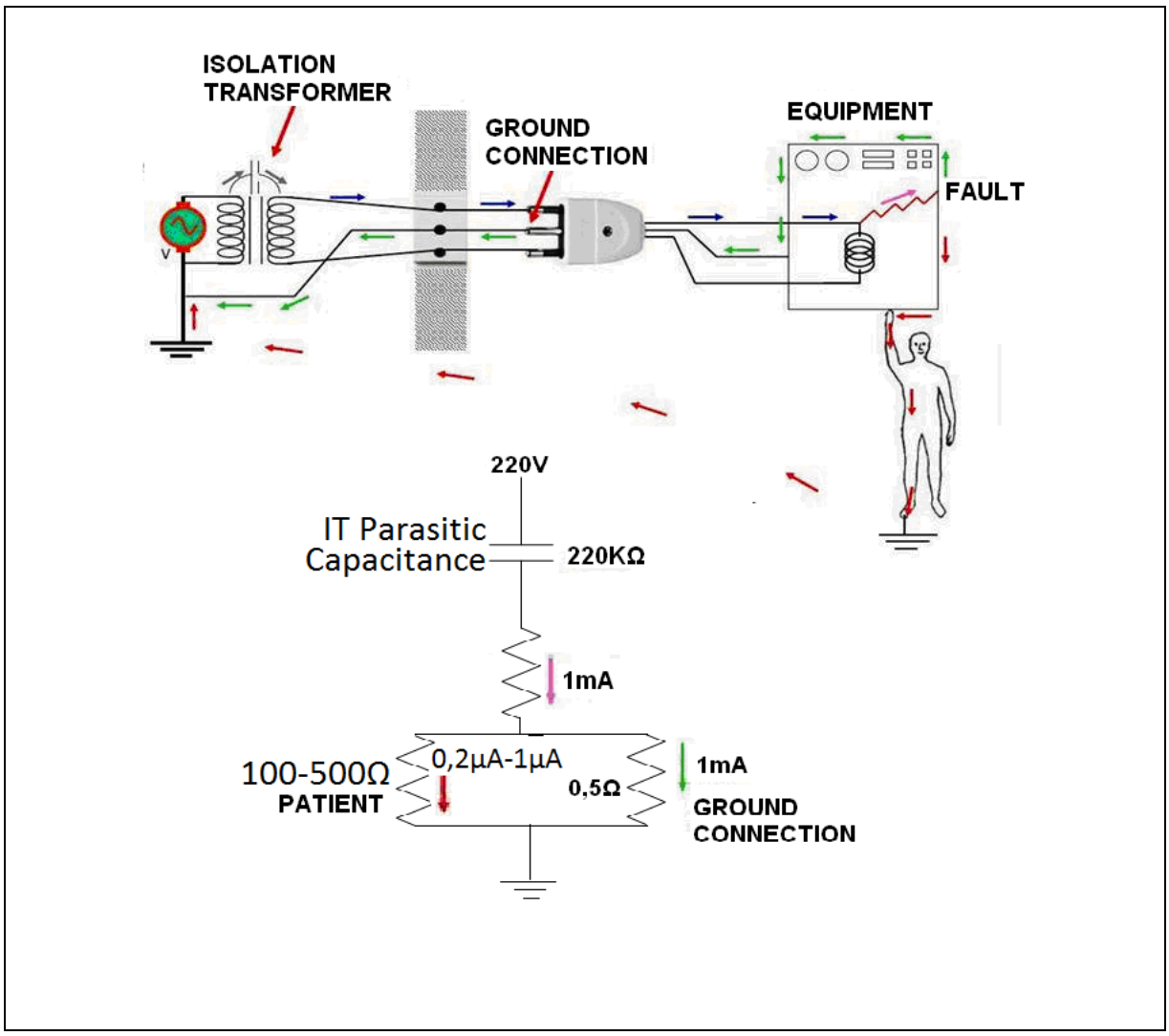


Figure 3.11. Purpose of the Isolation Transformer

As shown in figure 3.8 the IT **ideally** eliminates any hazards from microshock and macroshock to the patient and to the medical staff due to the absence of low impedance earth return path. The phrase ideally is due to the capacitance of the line conductors to earth, because always will be a capacitive current flow to the earth. That makes the transformer not safe enough to withstand alone because cannot protect from microshock, so the medical isolation transformer must be associated with circuit monitoring device and supplementary equipotential earth bonding. It parasitic capacitance

3.2.4. Line Isolation Monitor (LIM)

The Line Isolation Monitor (LIM) known also as Insulation Monitoring Device (IMD) is an active device that can monitor continuously the insulation of the circuits that are connected to the

device and should be in the clinical area connected with Medical Isolation Transformer to create the IPS system in accordance to the IEC 61557-8. Line Isolation Monitor (LIM) is a testing device that continually measures the balanced and unbalanced impedance from line-to-ground on each line of an ungrounded electrical system. The value of the measured impedance displays on the meter of the LIM as hazard current. Hazard current is the amount of current that would flow through a low impedance ground fault on an ungrounded electrical system. The hazard current is predicted as fault current. As high is the measured impedance from each line-to-ground, then the value of the hazard current is lower.

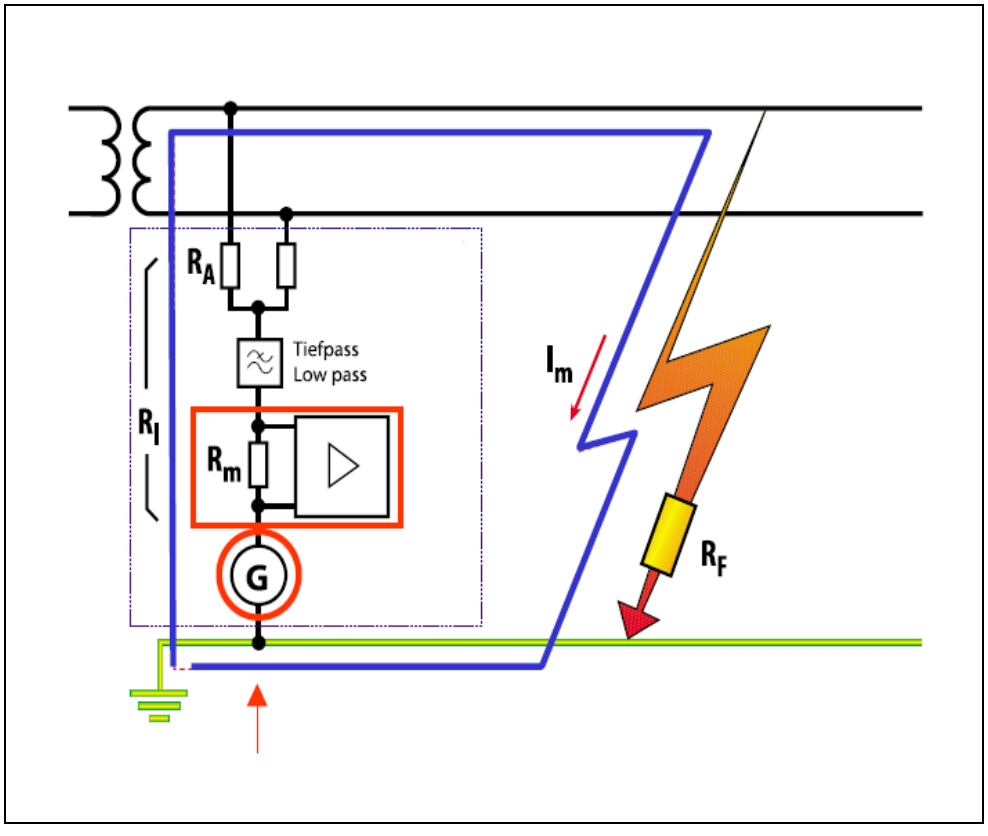
Each Line Isolation Monitor should comply with the following requirements due to the IEC 61557-8 standard.

- The internal impedance of the LIM shall be at least 100kΩ.
- The test voltage shall not be greater than 25V d.c.
- The test current shall not be greater than 1mA peak under fault conditions.
- Indication shall take place when the insulation resistance has decreased to 50kΩ.
- With each LIM the manufacturer shall provide to the customer a testing device for preventive and corrective maintenance with the factory setting. The testing device shall be calibrated every 6 months.

Figure 3.12. Line Isolation Monitor

To perform measurement and derive a result, the LIM injects a small test signal of a fixed current and frequency, then it measures the voltage offset and phase angle offset of the test signal. The measured and fixed values are analyzed using electrical laws to determine the line-to-ground impedances of the system to which the LIM is connected. The LIM can measure impedances that are either pure resistive, pure capacitive, or a combination of both resistive and capacitive faults. Additionally, the impedances are either equally balanced or unbalanced between each line and ground. The LIM displays a meter reading for the line of the system with the lowest impedance to ground, or in other words, the highest hazard current.

To connect the insulation monitoring device with the electrical system must be connected between live conductors and earth as shown below. The measuring voltage U_m generated by G is superimposed onto the system via the coupling R_i, the measuring resistance R_m and a low pass filter. An insulation fault R_F between system and earth closes the measuring circuit. I_m causes a voltage drop U_m proportional to the insulation fault R_F across the measuring resistance R_m.



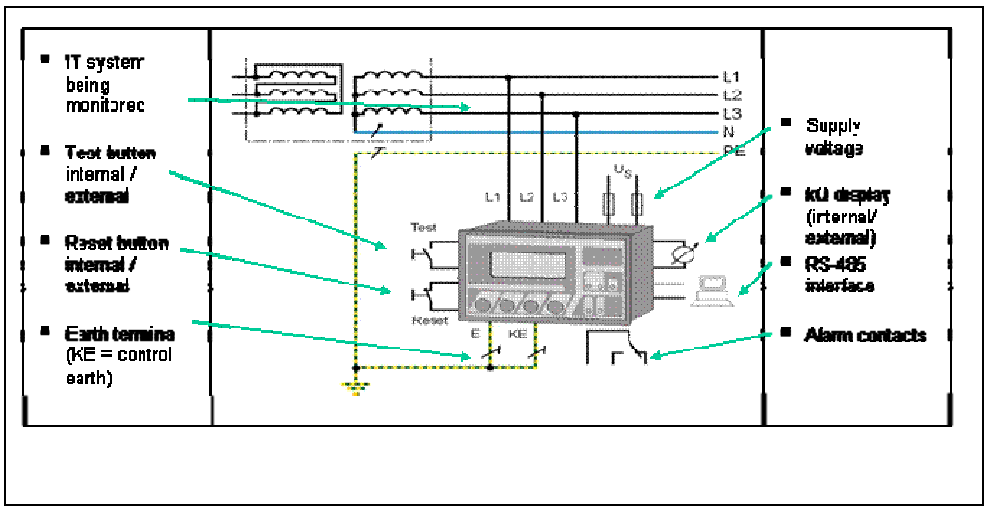


Figure 3.13.Connecting LIM to the System and the IT system

3.2.5. Equipotential Grounding

Equipotential grounding is the bonding of all conductive surfaces in the room together and to earth, and should be implemented in the patient care environment. It is crucial to keep all conductive surfaces at the same potential, or on the same ground plane. A level ground plane prevents a different voltage potential between all conductive surfaces in the room, avoiding current flow from one object to another. Also, a controlled, low impedance path to ground is needed for any fault current that may develop in the patient environment. In 7671 – IEE Wiring Regulations 16th and 17th Edition, is define that another one grounding wire is needed from each chassis to a central point called as equipotential node, which is in parallel with the third wire in the power cord. The reason is for keeping the chassis of all equipment at the same potential, in order to prevent current leakage between the devices through the heart.Engineers designed an effective ground system to reduce the risk of shock hazard. However, in the hospital environments can be particularly hazardous, and patients are often exposed to fault current and leakage current. During a surgical or invasive procedure in a critical care area, the patient's natural resistance is lowered, increasing sensitivity to leakage current, fault current, and potential danger from microelectronic shock, so creating an effective equipotential grounding reduces this hazard.

Proper equipotential grounding is essential in both macroshock and microshock protection. In a macroshock situation, where equipment generally becomes dangerous only if a malfunction occurs, grounding of the chassis, cabinet and other accessible conductive parts assures that in the event of a short between an energized conductor and the chassis, the accessible conductive surfaces will not become energized. Furthermore with an effective ground system the risk of a

microshock can be reduced preventing any lethal shock. In case of removing the grounding between the conductive surfaces of the equipment and ground then the leakage currents could reach the patient and cause microshock.

According to the international standards, IEC 60364-7-710:2002-11and IEC 60364-4-410 the following should be connected to the equipotential node:

- All chassis of the equipments that are localized in the patients' zone.
- The grounding wires of all power outlets in the medical room
- The shield that may be present between the primary and the secondary winding of the transformer.
- The shields for the reduction of the electromagnetic fields.
- The conductive structure under the antistatic floor.

Equipotential grounding should be used in critical care areas such as operating rooms and cauterizations labs. All the metal surfaces in the critical room should be bond together and at the end the whole grounding system of the building should be tested to verifying the limitations of 0.2Ω. For the equipotential ground a reference point should be set for the entire test. Equipment used in the patient care environment also needs to be tested and comply with the above directives. Installing and effectively testing an equipotential ground system should be a priority for hospital facilities. Especially in the ICU, the resistance between the equipotential node and the chassis should not exceed **0.2Ω** and outside this area should not exceed the **0.5Ω** as is mentioned to the British standards, BS 7671 – IEE Wiring Requlations 16th Edition.

An example of this grounding is shown below:

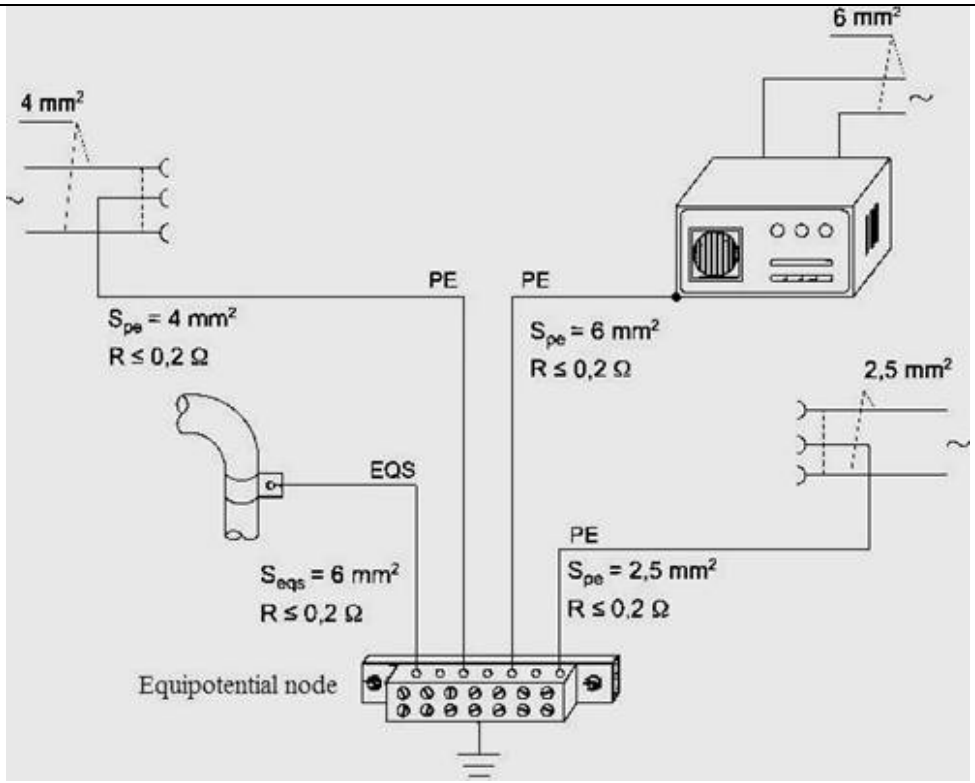


Figure 3.14.Connection to an Equipotential Node

4. Fault-Free Operation in ICU

4.1. Methods and Means of Protection against Equipment Malfunction

4.1.1. Protection from Overloading and Short Circuit

The designer of an electrical system has the responsibility to meet code requirements and to ensure that the equipment and conductors within a system are protected against current flows that will produce destructive temperatures above specified rating and design limits. Protection against temperature is termed “overcurrent protection.” Overcurrents are caused by equipment overloads, by short circuits or by ground faults. An overload occurs when equipment is subjected to current above its rated capacity and excessive heat is produced. A short circuit occurs when there is a direct but unintended connection between line-to-line or line-to-neutral conductors. Short circuits can generate temperatures thousands of degrees above designated ratings. A ground fault occurs when electrical current flows from a conductor to an uninsulated metal that

is not designed to conduct electricity. These uninsulated currents can be lethal. In the market there are a lot of overcurrent protection devices to choose.

The two most common are fuses and mini circuit breakers MCBs.

Figure 4.1.Fuse

Figure 4.2.MCB

Fuses are the simplest form of overcurrent protective device but it can be used only once before it must be replaced. A fuse consists of a conducting element enclosed in a glass, ceramic or other non-conductive tube and connected by ferrules at each end of the tube. The ferrules fit into slots at each end to complete a split in a circuit. Excess current flowing through the fuse melts the device's conducting element and interrupts current flow. Fuses are rated by the amperage they can carry before heat melts the element. The fuse is ideal for protection against short circuits. Short circuits produce enough amperage to vaporize a fuse element and break connection in one cycle of a 60-cycle system. Fuses are more commonly used in devices connected to a system than within the system's circuit. In the hospital and especially in the medical rooms of group 2 the fuses are prohibited, it cannot be used because in case of emergency it will take too long to change the fuse and the most equipment is for life support so hospitals uses mini circuit breakers. Nowadays all the circuits in an electrical panel are protected by circuit breakers MCBs. Tripped circuit breakers can be reset after the fault is cleared, an advantage over fuses that must be replaced. A molded case circuit breaker, or MCB, has two distinct operating components.

Thermal Trip Component: This component is a bimetal strip that carries the current. When the current exceeds a predetermined limit, heat produced by the excess current causes the strip to bend and trip the trip mechanism, which breaks the contact and interrupts the current.

Magnetic Trip Component: This component is a solenoid that generates a magnetic field created when an electric current passes through its coil. When the flow exceeds predetermined levels, the resulting magnetic force is sufficient to move an armature, held back by a spring, to trip the trip mechanism. This locks the circuit contacts in the open position.

Circuit breakers are available in three types. Systems designers will choose among inverse time trip, adjustable trip or instantaneous trip circuit breakers, depending on the protection sought.

Breaker Types:

Inverse Time Trips, trip faster as current increases. This provides overload protection but also allows equipment and conductors to carry excessive loads briefly.

Adjustable Trips, are used when the operation of several protection devices in a system must be coordinated. Designers place the lowest rated trips nearest to the devices being protected so that a fault in one area is isolated but allows current elsewhere in the system to continue to flow.

Instantaneous Trips, are used only for the magnetic element of the trip and provide no overload protection. Also known as motor circuit protectors, or MCPs, they normally are used to protect large motors from short circuits and ground faults.

Rating protection devices: Short circuits can produce enough thermal and electromagnetic forces to destroy any protective device. When selecting a protective device, it is very important to consider the available short circuit amperage, or SCA, which is the potential amperage at any site in the system. The SCA will be measured at the equipment terminals, the utility transformer and the distribution panel. The highest value will be at the power transformer. The conductivity of the material, its size and its length will reduce the SCA down the line from the transformer.

The correct size for overcurrent protection device can be chosen when the system's SCA is known. SCAs are measured in amperes. Fuses and circuit breakers are assigned amperage interrupting capacity, or AIC, which indicates the SCA that can be sustained before tripping. Unless otherwise designated, fuses are rated 10,000 AIC and circuit breakers are rated 5,000 AIC.

Protection devices are rated to manage both the normal maximum load and the potential short circuit amperage at any given part of the system. Equipment controls should have a short circuit rating that enables them to absorb current while the protective device clears the circuit. If the rating of the controller is lower, a fast-clearing fuse with a lower rating than the controller should be used. In an emergency situation when the power supply should be interrupted only to a small number of devices inside the ICU area, the power system should be divided in smaller circuits.

In the particular case of wall plugs connected to an IT-M system, they have to be:

- Supplied by two separated circuits or
- Protected against overloading individually or in groups.

It this way, in case of a fault to a plug, we can have a selective turn off of the systems, as described in the figure bellow:

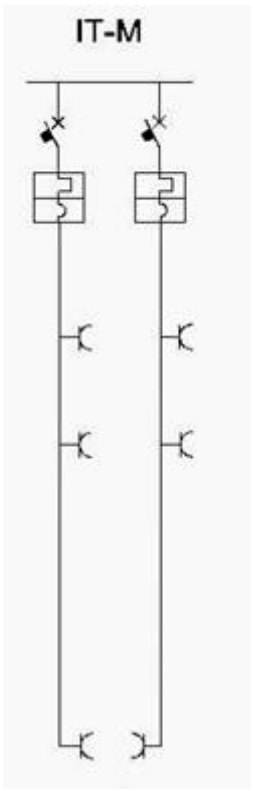


Figure 4.4.Wall plugs connected to two circuits

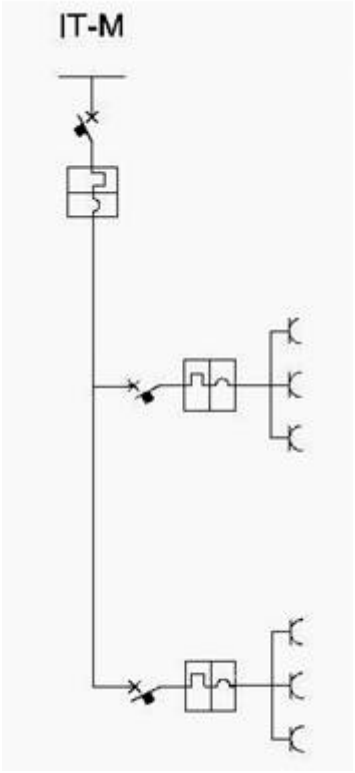


Figure 4.5.Wall plugs protected against overloading in groups

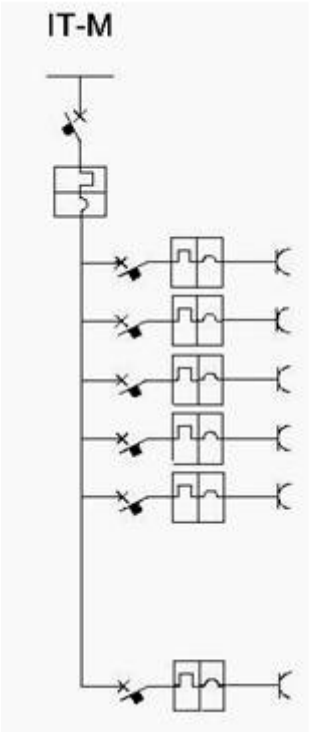


Figure 4.6.Wall plugs protected against overloading individually

4.1.2. Protection of Electrostatic Discharges (ESD)

Further to the critical care areas the floor covering is important to keep the safety level high and the reasons can be understood from the following aspects:

- Electrostatic Discharges (ESD).
- Easily cleanable without using any chemicals material.
- Absorb sound, material that absorbs the noise and keep the noise level low.
- Keeping infection control.
- Able to withstand when heavy equipment is moving around the ICU area.
- Slip resistant and comfortable to walk on.

- Keep the temperature constant, lower than the room temperature to avoid the growth of microorganisms.
- Keep the humidity in low levels.

4.1.2.1. Electrostatic Discharges (ESD)

4.1.2.1.1. Generation of Electrostatic Charges

Electrostatic charges are generated because of friction and separation of two materials coming into contact with each other (triboelectric charge) or due to an electrical field influencing a body (influence). When the two materials are separated, one of them will become positively charged, and the other negatively charged. The amount of the charge depends on the material's tendency to charge and the relative humidity of the ambient air.

Static electricity can be found everywhere in nature it manifests itself most often in the form of storms and lighting. It also occurs in homes, factories and also in the hospital. Static electricity rarely has harmful consequences for people, occasionally resulting in an unpleasant shock. However in some circumstances and much more seriously, electrostatic discharge can lead to disaster. Even in small quantities, it can trigger a fire or an explosion, for example in areas where there flammable or even explosive materials. Similarly electrostatic discharge is becoming an increasing hazard in the electronic industry. Many components are becoming susceptible to the inherent risks of electrostatic discharge and may be damaged or even destroyed when rapid uncontrolled discharged occur. In order to avoid incalculable risks and costs, adequate measures are to be taken to protect against electrostatic discharges. In this respect, the floor covering with electrostatic properties plays an important role. This floor covering must be bonded conductively and must be grounded to offer appropriate protection.

4.1.2.1.2. Body Voltage Generation

Walking on a floor covering, electrostatic charges at the body are produced because of separation processes between shoes and floor covering. The amount of the body charge above all depends on the material of the shoes and the floor covering. Charge voltages of several thousands of Volts may be generated which are not harmful to human because of their low energy. They, however, pose a risk to electronic component parts and devices and may also trigger explosions in areas with explosion hazards.

4.1.2.1.3. Discharge of Electrostatic Charges

It is not only by walking on floor coverings that the body of a person may be charged but also by sitting on non-grounded chairs or by wearing clothing not suitable for ESD (insulating clothing) and so an uncontrolled discharge of body charges may lead to damages of highly sensitive

component parts and devices. Voltages as low as 10 V are sufficient to damage a medical device. There also exists the risk that explosions are triggered in areas with explosion hazards.

4.1.2.1.4. Permanent Electrostatic Conductivity

The conductivity of many floor coverings may be impaired during their period of use, e.g. by drifting plasticizers and an extremely low humidity (drying of the entire system), and the system no longer provides the required conductivity values to protect devices and persons against electrostatic discharges and to protect against explosions.

4.1.2.1.5. Cleaning and Care

If a floor covering is not cleared and cared for properly, its electrostatic properties might not survive. This may be due to:

- Coating of the floor covering
- Permanent contamination with dirt

Discharge of electrostatic charges is no longer guaranteed because the permanent discharge through ground may be interrupted because of insulating layers (e.g. dirt, coatings) forming.

4.1.2.1.6. Solution

Generally in the Health Care environment electrostatic discharges (ESD) reduce the performance of electronic hardware. Due to a research it appears that 30% to 70% of the faults in electronic components are due to ESD with the help of the above mentioned parameters. These electronics discharges can also cause explosion in areas classified as explosive atmospheres from (ATEX directive), which ICU area is included.

The main duty is to have limiting charge and second a controlling discharge. The two parameters that limit the accumulation of charge are the low charge generation and the earth resistance.

It is advisable to institute strict measures to reduce risks. Various solutions may be implemented with the aim of limiting or even eliminating charges. The simplest solution is to provide an earth point to limit or eliminate the risks of an accumulation of electrostatic charges, easy solution but in most cases due to the external equipment in the area is not feasible.

The use of electro-conductive flooring combined with antistatic footwear guarantees a low body voltage generation.

The ESD risk analysis must be carried out throughout the premises, to take into account the working environment and the various types of risk associated with the processes and the sensitivity and susceptibility of the components. The elimination of electrostatic charges at source by use of specific electro-conductive flooring which is the most efficient solution to limit the risks associated with ESD.

Now in the market there are a lot of electro-conductive materials for flooring, so first a research is needed to find out what is the best material to be installed in the ICU area and avoid any of the above mentioned problem.

4.1.3. Protection from Electromagnetic Interference (EMI)

Electromagnetic interference (EMI), also called radio frequency interference (RFI) is a disturbance that affects an electrical circuit due to either electromagnetic induction or electromagnetic radiation emitted from an external source. The disturbance may interrupt, obstruct, or otherwise degrade or limit the effective performance of the circuit. The source may be any object, artificial or natural, that carries rapidly changing electrical currents, such as an electrical circuit or equipment connected to the electrical circuit. In the clinical area and especially in the ICU area, there are present a lot of sensitive equipment for measuring physiological parameters. Those equipments are working with electronics and for this reason the electromagnetic interference affect the results of the equipment and the electrical supply of the hospital must be free of noise and without feeding any spikes to the electrical system and be able to eliminate the EMI. Thank to the IPS system which contains advance shielded isolation transformer as mentioned before, reduce or eliminate line to line and line to ground noise, so lot of the EMI are blocked before pass to the medical equipment and do not affect their operation. A way to keep the ICU area free of EMI is to supply the equipment one by one direct to the power system. With this connection each device will have direct electricity from the electrical panel. That will avoid passing the interferences from one device to the other. Also if is feasible it can be also install a transformer with the first windings be Y and the secondary in D delta. This will enclosed in the secondary windings the harmonics and will not pass to the electrical system. Electromagnetic interference can be also blocked if every supply wire that passes near to equipment is shielded or is enclosed to a metallic pipe. Furthermore to avoid interferences from the environment outside the ICU area the walls and the floor should be incorporate with metallic pieces.

4.2. Methods and Means of Protection against Mains Power Failure

Emergencies situations could happen everywhere either by a mistake of personnel or by physical phenomena. In the critical care areas that cases should affect the way that the department works and provide the appropriate safety, means by using any equipment for an operation, lighting purposes and etc.

4.2.1. Uninterruptible Power Supply (UPS)

An uninterruptible power supply is an electrical apparatus that provides emergency power to a load when the input power source, fails. UPS differs from an auxiliary or emergency power system or standby generator in that it will provide instantaneous or near-instantaneous protection from input power interruptions by means of one or more attached batteries. On those batteries are only connected the circuit that are providing safety for users and patients. The UPS system is connected with the main power and when a failure occur senses that the main cannot provide the specific circuit with power and the UPS start fitting the circuits. For the UPS system the only characteristic is the capacity of the UPS. Capacity can be derived from the needs that will serve and the time. In the hospital area are using mostly, the on line UPS system. The British standards BS EN 50091 Specifications for Uninterruptible Power Systems and BS EN 620040-3 Uninterruptible Power Systems UPS , Methods of specifying the performance and test requirements, provide all the specifications that the UPS shall be compliance.

UPS SYSTEM

Figure 4.7.UPS Sytem

4.2.2. Emergency Power Supply System (EPSS)

The Emergency Power Supply System EPSS is a stand-by source connected to the main power supply system through a transfer switch. The EPSS is generator able to start working and supply all the circuits that are connected to the main power source when the main power source is not working. The National Fire Protection Association, with the standard NFPA 110: Standard for Emergency and Standby Power Systems, covers construction, installation, maintenance and operational testing requirements for EPSS. Further the NFPA 99, Standard for Health Care Facilities (particularly Chapter 4, Electrical Systems, and Chapter 14, Other Health Care Facilities) provide information about EPSS. Through standard NFPA110, is clearly define that

shall be installed an emergency generator when failure of any equipment could result loss of human life or serious injuries. In the ICU area the standby generator is obligatory since the area is located in Group 2. Selecting a generator for emergency situations except from the specific requirements that the NFPA110 defines there are also three characteristics, the run time hours, the transfer time and output power of the generator. The previous three characteristics should be selected correctly so on an emergency situation the safety in the area will not be affected.

Figure 4.8.EPSS

4.2.3. Automatic Transfer Switch (ATS)

The Automatic Transfer Switch (ATS) is a critical part of any emergency power supply system (EPSS). The ATS is the device that selects a power source, either normal utility power or standby generator power and conducts the power to critical loads. Transfer switches are installed in the emergency power system to transfer the electrical load form the normal power source to the emergency power source upon failure of normal power. The ATS must transfer and retransfer the load automatically when receives the appropriate signals. The ATS plays an important role on emergencies situations and for that reason the NFPA 110: Standard for Emergency and Standby Power Systems, covers construction, installation, maintenance and operational testing requirements for EPSS, describe the ATS in chapter 6 what are the minimum requirements and how often shall be tested.

Figure 4.9.Automatic Transfer Switch

5. Design of a sample ICU

Design an ICU area is a very complicate procedure due to the advanced technological equipment that are installed in the area and also every equipment that is installed there is for life support.
The electrical engineer that will provide the drawings of the ICU area, the electrical consultant, should have all the parameters and all the equipments that will be installed in the future, which of them requires uninterruptible power supply, what height, what is the power demand and a lot of other important information which make the project more complicate.
Building and design a sample ICU area with the basic but important requirements should be done and the whole area will provide ergonomic, quality and of course safety. Everything that will cover in this design will be for the electrical installation providing safety and the numerical quantities of all the structure is analogical either to smaller ICU area or larger. The sample ICU area will also provide the best deal on a cost effective design with the assurance of the above mentioned requirements.

5.1. ICU Area

An ideal Intensive Care Unit area, after lot of discussion and evaluations of other ICU departments the specialist decided that the best ICU area is consisted from 8 to 12 beds. With 8 to 12 beds is the best combination to provide to the department a cost effective area because lot of money are spend to build such areas. In the follow case the ICU area will be constructed with the ability to accommodate 10 beds in the ICU area which is the mean value of the 8 to 12 beds. Each patient bed area in an adult ICU requires a minimum floor space of 18,00m^2 to 22,00m^2 to accommodate patient, staff, and equipment without overcrowding. Dealing with 20, 00 m^2 per

bed so the total size of the ICU area should be 200, 00 m^2. Also is required space from each bed to the other, approximately to 2,50m. The final size of the ICU area including the space from each of the 10 beds with their equipment, excluding the toiled room, laundry room, offices or other spaces that are needed should be 250,00 m^2. For sure there is enough space for the 10 beds/250, 00 m^2 but the corridor is including the whole area which in our case is approximately 22, 50 m^2.

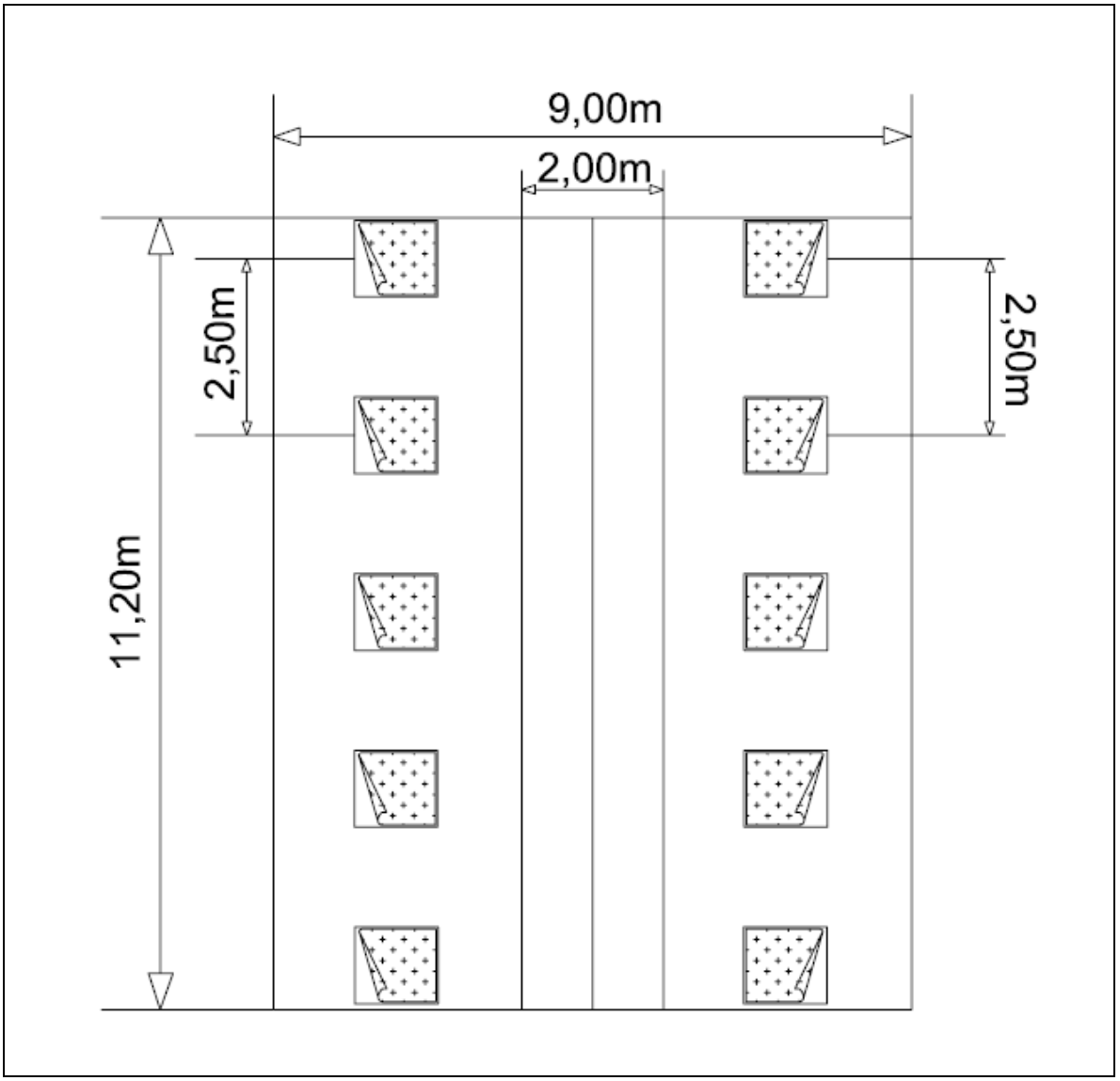


Figure 5.1.Schematic of a proposed ICU area

5.2. ICU Electrical Installation and Dedicated Devices

The electrical supply in the ICU area, voltage should be 240V single phase. The fluctuations of the voltage supply should not exceed the 253V and not be less than 207V, with a single common earth ground.

All the power outlets in the ICU patient area should be also connected on the same phase and the electrical supplies must be provided in PVC insulated cables concealed within steel conduits.

In the ICU patient area the power outlets should be sufficient to avoid the need of extension leads and trailing wires, taking into account the possibility of extra equipment that the ICU patient area will need for the future. After lots of evaluations the number of power outlets should be minimum 24 outlets per bed. In our building case the use of 24 outlets per bed is a satisfied condition. The outlets are mounted at the same location but are distributed equally on both sides of the patient bed. Each bed area requires at least another 3 to 6 outlets with an uninterruptible power supply. These priority power outlets should be disguised from the others so the use of different color should be made. Furthermore these UPS outlets have a visible and audible warning that the UPS has taken the load, or is failing to charge.

For the 24 power outlets we are using the electric white color and that means that they are connected to the main electrical supply. On the other hand the 6 UPS priority outlets are colored red so the medical staff and the biomedical engineers know that these sockets are connected to the UPS. Further except from those outlets, placing one double outlet electric white in every 3m helps the medical staff for connecting any other equipment that may need. This is not mandatory by the IEC 60364-7-710 Electrical installations of Buildings Requirements for special installations or locations – Medical locations. Every outlet behind the patient bed is an un-switched socket to prevent any mistakes of switching off. Also the height of the sockets that is on the head of the bed is in 90cm from the floor to help the staff on the connection. The outlets that are installed at the sides and foot of the bed are close to the floor to avoid tripping over electrical cords.

The lights in our sample ICU area also are divided in two circuits. For our convenience we separate the two lighting circuits, to the emergency circuit and the non-emergency circuit. The reality behind the lighting circuits is that both circuits are connected together but in case of power failure we need the second circuit which connects only specific lights, the emergency, the exit signs and also the lights that are mounted to the patient beds to work unstoppable. This emergency circuit is also connected to the UPS and to the emergency power supply which will give the power to operate the lights. An ideal ICU consisted by lighting controls on variable-control dimmers. With that, permits changes in lighting at night from outside the room, allowing a minimum disruption of sleep during patient observation. Night lighting should not exceed 70 lux for continuous use or 200 lux for short periods.

From all the above that were described the ICU area needs two distribution boards (DB). The first distribution board is connected to the main power supply so we should write it on the DB

that is the one from the main supply DB/MAIN. The second one is the distribution board that is connected to the UPS system, DB/UPS.

In the first one are connected all the outlets and lights that are working when everything works properly and the other one when an electric failure occur.

Very important information is everything that needs power to work in the ICU area is connected to the IPS system, so in any case everything in the ICU area will be isolated even in case of electric failure the whole electrical system will be powered from the UPS system and is steel isolated.

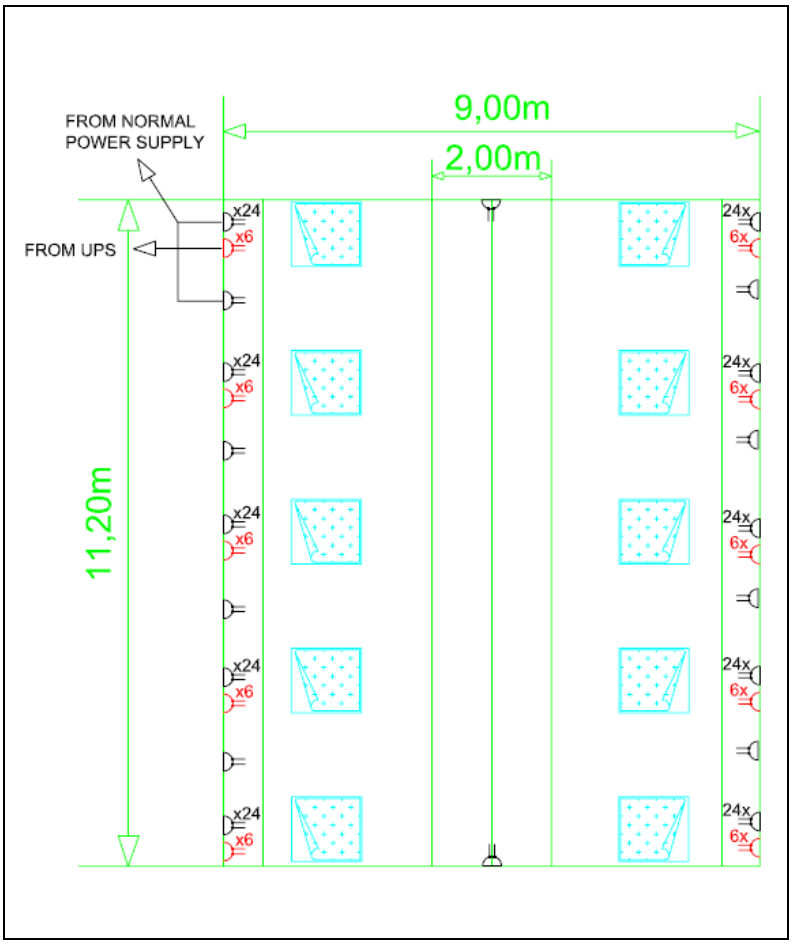


Figure 5.2.Power Outlets in ICU Room

5.2.1. General Description of the main electrical modules and devices

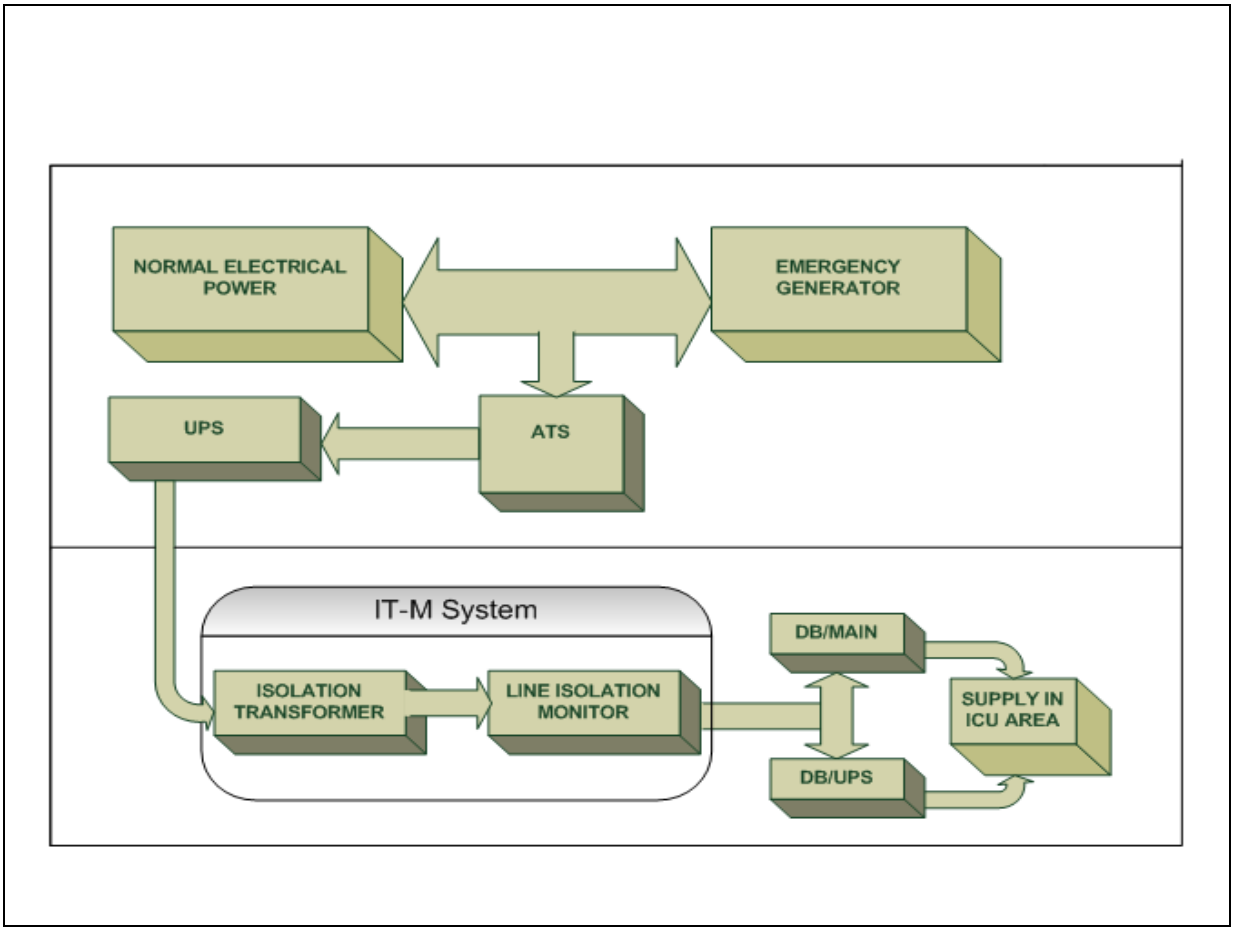


Figure 5.3.General Description of the main electrical systems and devices

5.2.2. Uninterruptible Power Supply

The uninterruptible power supply system is one of the most important systems in the ICU area due to the fact that lots of equipments in the area are for life support and need uninterruptible power in any situation.

The UPS system will be activated in case of electric failure and support the ICU area with the power that was stored in the batteries of the UPS system. The UPS system is connected before the IPS system, so in case of failure the power that will be serving the area will be isolated and the area is kept free of any leakage currents with the needed safety conditions as shown below.

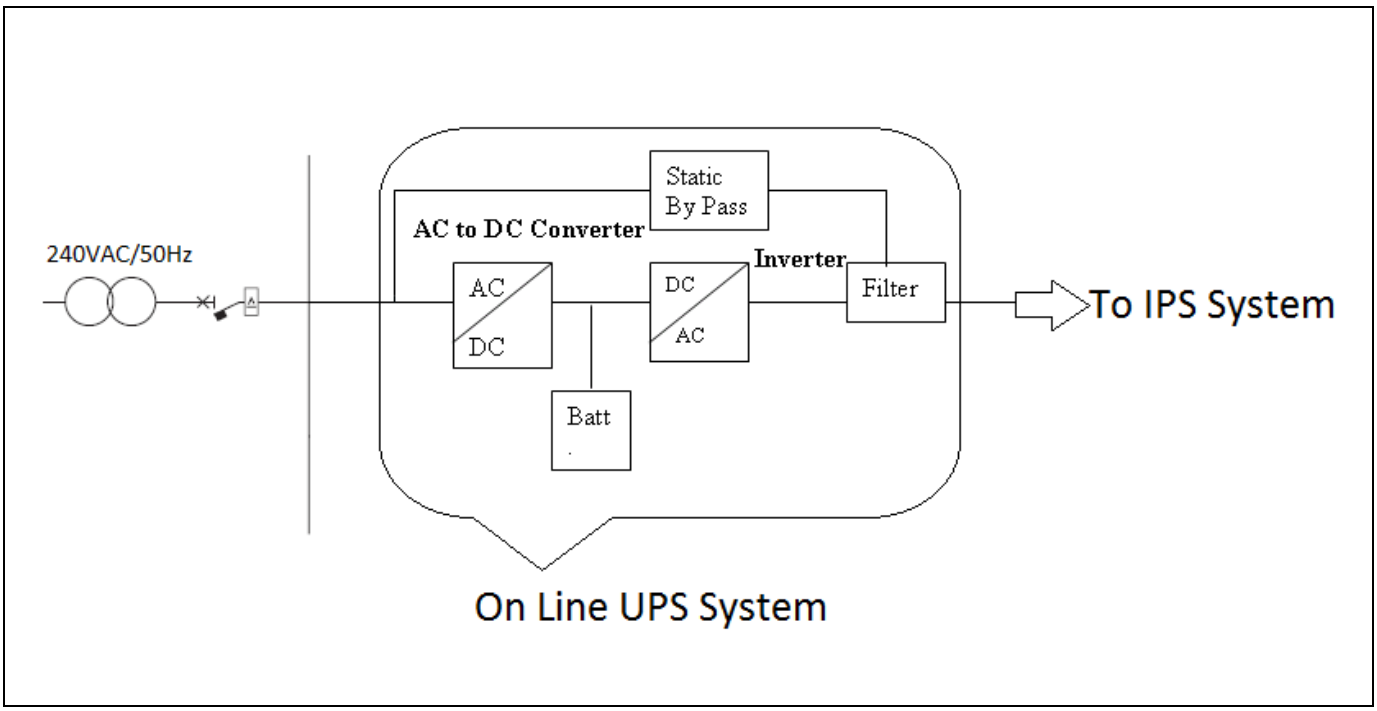


Figure 5.4.Schematic of the UPS connected to the IPS System

The important is to calculate the capacity of the UPS system without any mistake, so in case of electric failure to support the specified equipment for at least one hour. Of course if everything in the area is working properly the need of the UPS system will not be for one hour but only 5 to 15 seconds maximum. This really short time is the time that the emergency power supplies, the generator need to warm up and be ready to provide the whole area with power.

The UPS system output in the ICU area is 240V AC, 50Hz, taking the worst scenario that the stand-by power source, the generator failed to start due to malfunction the capacity of the UPS must be for one hour full load.

Calculating the capacity of the UPS system in our case, we have to measure what equipments are for life support, how many of such equipments are installed in the area and what is the power consumption. Also the needs of emergency lightings and exit signs should be added to the capacity of our UPS.

In our building case scenario we focus on the six UPS sockets and for the lightings in each bed plus the Exit signs. The follow calculations are from specific equipment and may be different if other hospital uses other brand equipments.

For the six UPS sockets red color is connected the following equipment in each bed:

Type of Equipment/BED	Estimated average load current
Patient Monitor	3,5A
Life Support/Ventilator	2,0A

Defibrillator	1,6A
4 X Syringe Pumps	0,4A
Volumetric Pumps	0,2A
Overhead Warmer	4,0A
TOTAL PER BED	**11,7A**

The ICU room has 10 beds, so the total in the room for the equipment only is approximately 117,0A. We also need to add the lighting for each bed plus the Exit signs. For each bed the lighting is approximately 100W and for the whole room the two exit signs another 120W (60W each).

The total is:

$$I = 11,7A * 10beds = 117,0A \quad (5.1)$$

$$P_{per\ bed} = V*I = 240V * 117A = 28080W \quad (5.2)$$

$$P_{lighting} = (100W * 10) + 120W = 1120W \quad (5.3)$$

$$P_{Total\ ICU\ Room} = P_{per\ bed} + P_{lighting} = 28080 + 1120 = 29200W$$

$$\mathbf{P_{Total\ ICU\ Room} = 29200W} \quad (5.4)$$

For UPS capacity we must derive the KVA from our total power consumption using the following:

$$KVA = P_{Total\ ICU\ Room} / (1000 * PF) \quad (PF=Power\ Factor)$$

$$KVA = 29200 / (1000 * 1) \quad PF = almost\ 1\ assuming\ an\ ideal\ ICU\ area$$

$$\mathbf{KVA = 29,2KVA} \quad (5.5)$$

The UPS system should be at least 30KVA and be able to withstand for 1 hour. In the market there are lots of on line UPS system but in our case of the ideal ICU area, the best one that fits our requirements should be 32 KW which is 40KVA and incorporated with 4 batteries to withstand for more than one hour.

When the UPS system is installed in the area the output from the UPS system is connected to the IPS system and from the IPS system is connected to the distribution board DB/UPS which is located in the ICU area.

Figure 5.5.UPS System 40KVA

5.2.3. Emergency Generator – Back up Power Supply

The emergency generator in the ICU area is very important due to the life support equipments. The generator is connected to the Automatic Transfer Switch system and the controller of the ATS sends signals to the generator when to start and when to stop.

To choose the generator that is fits to the requirements of the area are the only consideration of the engineer except from the maintenance and the safety tests. To find out the output power of the generator you just calculate the power that the area needs in case of power failure. In our case we are taking the results of the UPS system which is approximately 40KVA, and we installed the generator.

Another aspect of the generator is the time that needs to be ready and be able to be connected to the power system. From the regulations of the IEC 60364-7-710, defines that in medical locations the maximum time is 0,5s to 15s. In this time the generator should have it maximum load in the 50Hz frequency without spikes and harmonics so it can access the power system from the ATS system.

5.2.4. Automatic Transfer Switch (ATS)

The automatic transfer switch is used for transferring electrical load from the normal power source to the “emergency” stand-by power source. Such a transfer of electrical loads occurs automatically when the normal power source has failed or is substantially reduced and the emergency source voltage and frequency have reached an acceptable level. The transfer switch prevents electrical feedback between two different power sources (such as the normal and

emergency sources) and, for that reason, codes require it in all standby electric system installations.

The transfer switch consists of a transfer mechanism, service disconnects circuit breaker, a relay control, fuses, and a terminal strip for connection of sensing wires.

The Automatic Transfer Switch is the connection between the power supply and the back-up power supply. The generator is connected to the ATS, and when the ATS senses the drop of the voltage under 185V in case of single phase power supply as in the ICU area, gives signals to the generator to start warming up and when the generator is ready to give the output power in the right frequency of 50Hz allows the power to flow. While the power system has a voltage drop that means the whole system has power failure, so the transfer switch leave the generator to supply the system with power. Also the ATS are embedded with a micro-processor based technology which allows switching of the supply from the normal line (N-Line) to the emergency line (E-Line) in case any of the following anomalies occurs on the main network:

- Over voltages and voltage dips/spikes
- Lack of one of the phases
- Asymmetries in the phase cycle
- Frequency values out of the setting range.

Then, when the network standard parameters are recovered, the system switches again the power supply to the main network (N-Line).

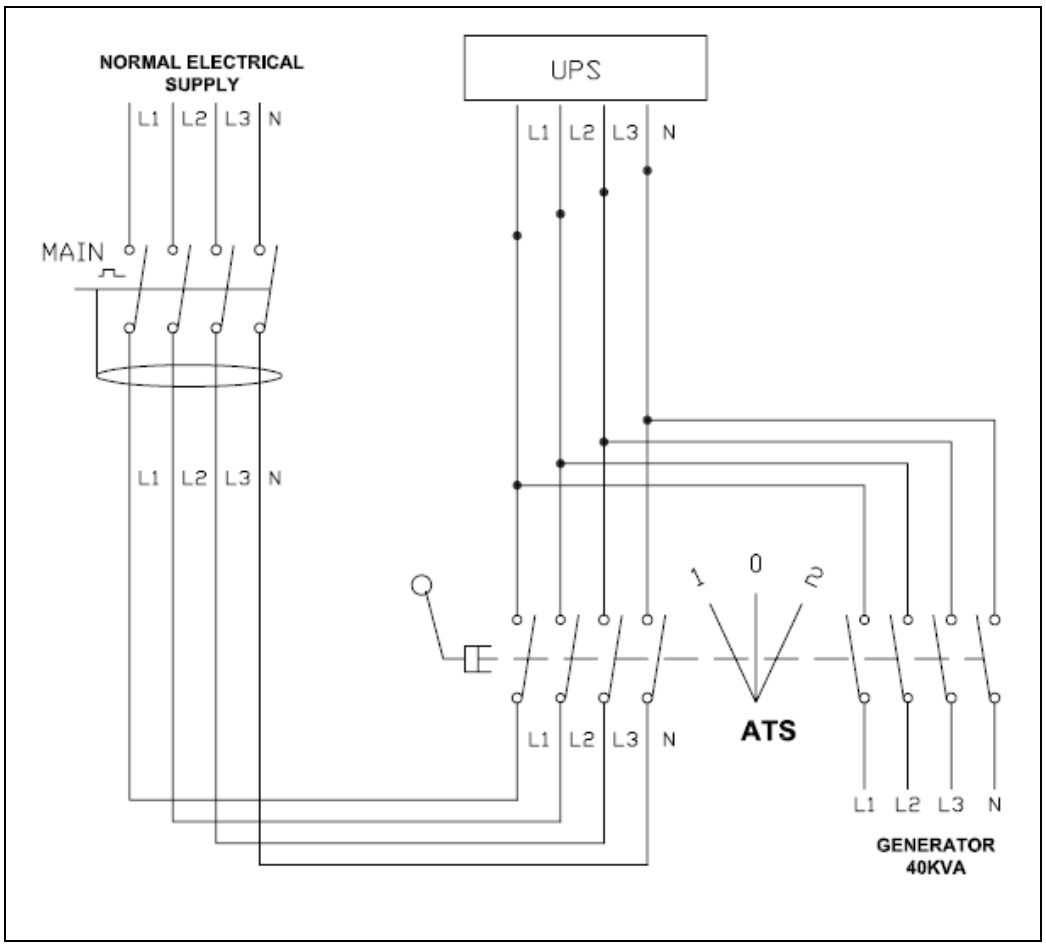


Figure 5.6.Typical Transfer Switch Mechanism

Due to the NFPA 99 D.4.2.1 the input power circuits shall be provided with low pass filters for preventing injection of high frequency energy which this energy is noise to the power system. Also the NFPA 99 4.4.2.5 and the IEEE 446-1995, section 4.3.8 specifies that the ATS shall be able to disconnect the alternate source of power and connect the load to the normal power source.

In the ICU area, the Automatic Transfer Switch is connected between the normal power supply and the backup power supply before the IPS system. Because everything in the ICU area needs supply, are emergency equipment and for life support, we are not separate the system in two circuits as in other cases, but are connected directly to the UPS system and then to the IPS system but the connection should be as the above directives, as shown below in the schematic.

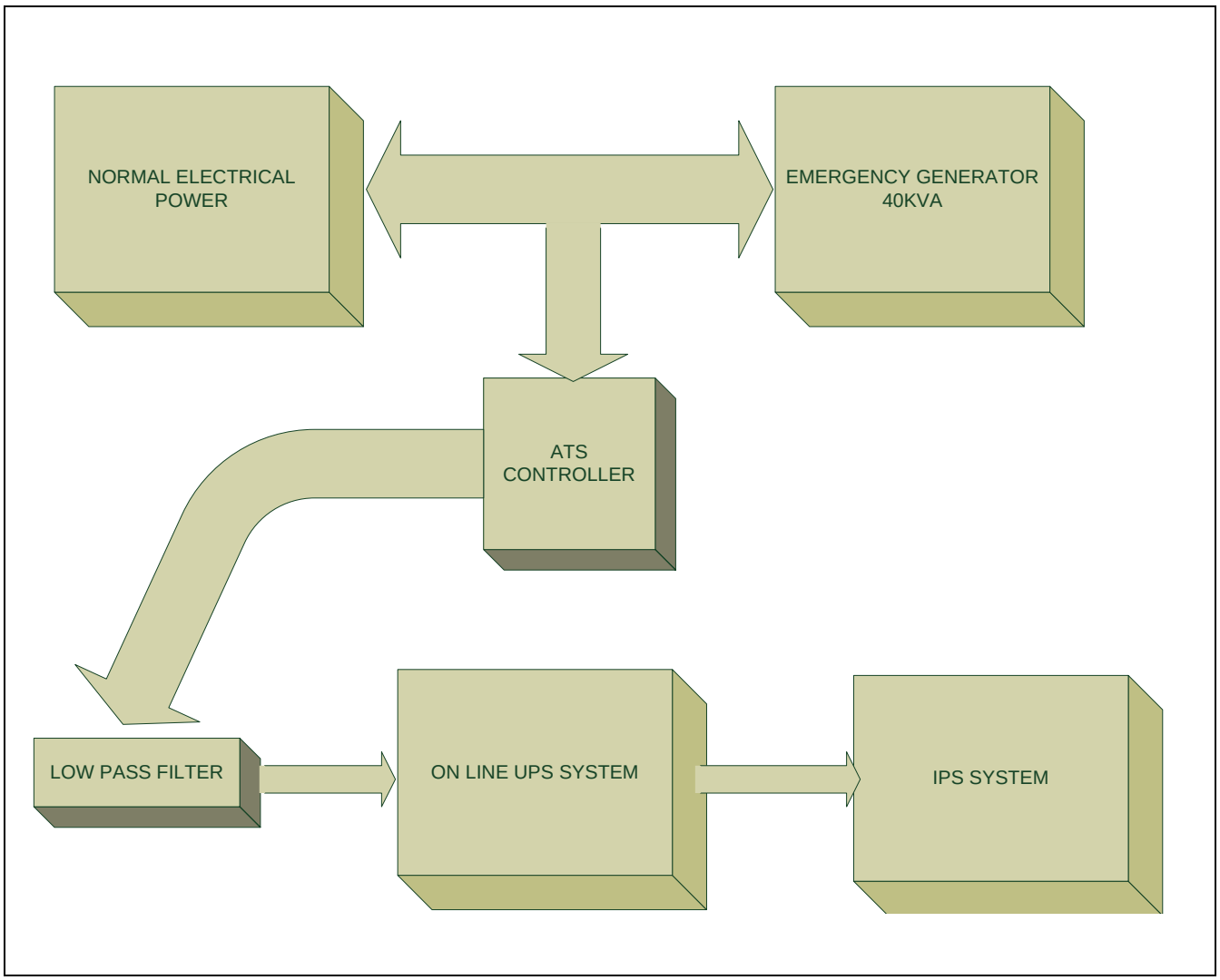


Figure 5.7.Connection of the ATS Block Diagram

5.2.5. Isolation Transformer (IT)

The Isolation Transformer as mentioned before is limited for the output voltage in ICU areas to 250V AC, from the IEC 61558-2-15: 1998. This states that everything should be single phase and that confirms that are for life support. Also should not be less than 0.5KVA and to not exceed the 10KVA.

In our ideal sample of ICU area, we calculate the power that the ICU room needs to find out the UPS system. The result is:

$$P_{Total\ ICU\ Room} = 29200W \quad (5.6)$$

And the KVA

$$KVA = P / 1000 * PF$$

$$KVA = 29200 / (1000 * 1)$$ *PF = almost 1 assuming an ideal ICU area*

KVA = 29,2KVA

(5.7)

From our result of approximately 30KVA and from the IEC 61558-2-15: 1998 directives, to built safe ICU we tried to used 3 Isolation transformers with the maximum of 10KVA that the directives states to support the room but from our evaluations we faced a problem which is shown below and further we added another one isolation transformer with output of 5KVA. So we made 4 rings of power output supply in the room and also we created a balanced power supply system.

Case 1 – 3 IT of 10KVA/IT

The first IT, supply three beds in the room and the emergency lights. That means that the first ring has load of:

$$P_{1st\ IT} = (11,7A * 240VAC * 3beds) + P_{Exit\ Signs}$$

$$P_{1st\ IT} = 8424W + 120W$$

$$P_{1st\ IT} = 8544W$$

$$KVA = 8,544$$

The second IT, supply three beds and the lights of each

$$P_{2nd\ IT} = (11,7A * 240VAC * 3beds) + P_{BedLights}$$

$$P_{2nd\ IT} = 8424W + 1000W$$

$$P_{2nd\ IT} = 9544W$$

$$KVA = 9,544$$

The third IT, supply three beds and the lights of each

$$P_{3rd\ IT} = (11,7A * 240VAC * 4beds)$$

$$P_{3rd\ IT} = 11232W$$

$$KVA = 11,232$$ **ERROR – out of the accepted limits**

Final - Case 2 – 3 IT of 10KVA/IT & 1 IT of 5KVA

The first IT, supply three beds in the room. That means that the first ring has load of:

$$P_{1st\ IT} = (11,7A * 240VAC * 3beds)$$

$$P_{1st\ IT} = 8424W$$

KVA = 8,424 - Which is the 84,24% of the 10KVA

The second IT, supply three beds:

$$P_{2nd\ IT} = (11,7A * 240VAC * 3beds)$$

$$P_{2nd\ IT} = 8424W$$

KVA = 8,424 - Which is the 84,24% of the 10KVA

The third IT, supply three beds

$$P_{3rd\ IT} = (11,7A * 240VAC * 3beds)$$

$$P_{3rd\ IT} = 8424W$$

KVA = 8,424 - Which is the 84,24% of the 10KVA

The last IT, supply one bed and the lighting with the Exit signs

$$P_{4th\ IT} = (11,7A * 240VAC * 1bed) + P_{Exit\ Signs} + P_{BedLights}$$

$$P_{4th\ IT} = 2808W + 120W + 1000W$$

$$P_{4th\ IT} = 3928W$$

KVA = 3,928 - Which is the 78, 56% of the 5KVA

With this connection we are able to connect future equipment without any problem and further we balanced the load equally which is very important. The IT will serve the area with isolated power supply providing safety to the patients and staff by minimizing hazards from touch voltages. Also ensures continuity of the power supply when a single fault occurs.

5.2.6. Line Isolation Monitor (LIM)

The Line Isolation Monitor is connected to the Isolation Transformer in accordance with the IEC 61557-8. LIM are active devices and continuously measures the balanced and unbalanced impedance from line-to-ground on each line of an ungrounded electrical system. The main ungrounded part is the Isolation Transformer, so in our ICU area we will need four Line Isolation Monitors to monitor the four Isolation Transformers. This is an ideal connection but it allows to the medical staff and also to the engineers to maintain the area better than installing one LIM. All the four LIM are installed in near the nurse station and in other situations in suitable place so it can be permanently monitored by the medical staff.

The reason of installing four LIM, ensures that in case of malfunctions and when the limits of the insulation resistance is reached, then you focus in specific locations in the area because is already known which beds are serve from each LIM. The medical staff knows that the first IT serves only three beds 1, 2, and 3. So in case of alarm on the first LIM, the medical staff focuses only to the three first beds. Of course the cost to build such area is greater but ensures more safety and quickly action when there is a fault in the area. All the other requirements that are defined in the IEC 61557-8 and were described in 2.2.5 are med.

5.2.7. General Description of the main electrical modules and devices

The circuit breakers are the devices that protect the wiring of an electrical supply system. The MCB, miniature circuit breakers protect the wires when overload or current fault occurs. The MCBs are installed in the distribution board (DB) near the ICU area with other electrical components. The MCBs are categorized by the type and the strength which are the only one that the engineer will choose.
The categories are shown below:

MCB type	Nominal Current (I_n)	Overload Characteristics	Instantaneous Tripping range	Instantaneous Tripping
B	All	1.45 I_n	3 I_n to 5 I_n	5 I_n
C	All	1.45 I_n	5 I_n to 10 I_n	10 I_n
D	All	1.45 I_n	10 I_n to 20 I_n	20 I_n

Table 5.1.Discriminations of MCBs

In the ICU area from the following regulations and standards,

- **BS 7671:2001.** Requirements for electrical installations. IEE Wiring Regulations. Sixteenth edition. British Standards Institution, 2001
- **BS EN 60898-2:2001.** Circuit-breakers for overcurrent protection for household and similar installations. Circuit-breakers for a.c. and d.c. operation. British Standards Institution, 2001
- **IEC 60364-7-710.** Electrical installations of buildings. Requirements for special installations or locations – Medical locations. International Electrotechnical Commission, 2002

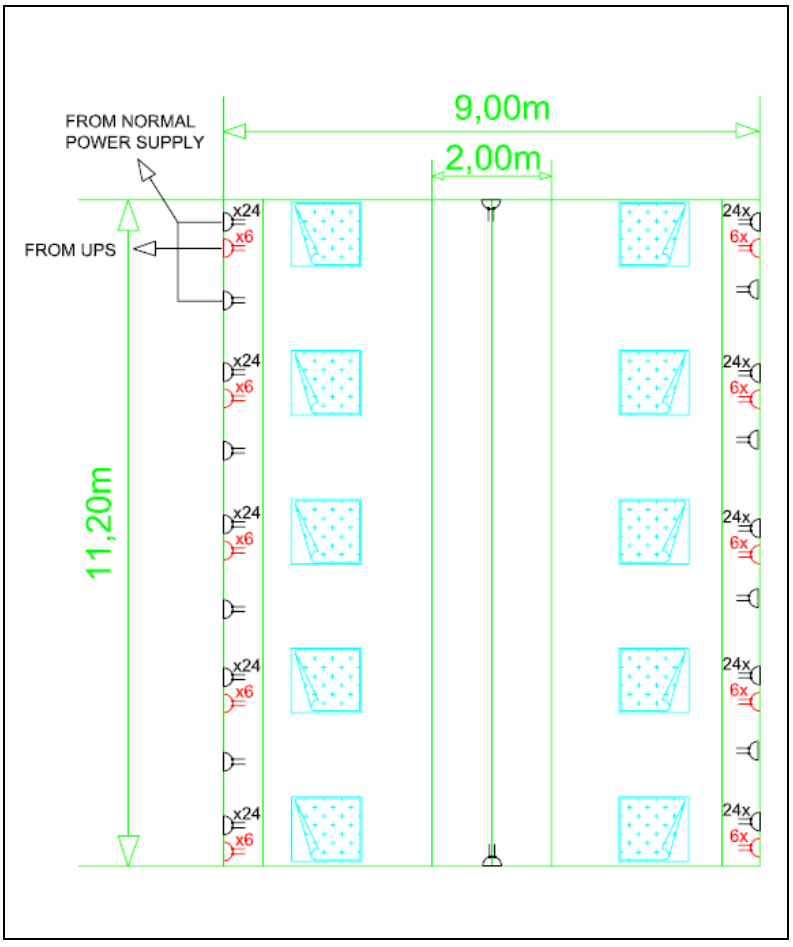
We are using the MCBs type B, where the instantaneous tripping is 5In, and rated to 32A for the outlets. Using the 32A MCBs in the final circuit automatically all the circuits from the IPS system will be connected in Ring Format and the maximum outlets should be 24.In our sample ICU area we have two distribution boards. The first distribution board, DB/MAIN all the sockets from the beds that are from the normal power supply with the color of electric white should be connected to the DB/MAIN.

The area has 10 beds; each bed has 24 outlets electric white and 6 sockets red, from the DB/UPS. Also in every three meters in the area we placed a twin outlet which is serve only the room of the ICU as separate circuit.

In our case to the DB/MAIN we used 10 MCBs type B, 32A with 2,5mm^2 wire and the connection is Ring Format. Also another one MCB type B for the rest 10 sockets which is placed every three meter in the ICU room. Here it can be also used Radial Format but in our case we used Ring Format.

In the DB/Main we placed another one MCB Type B, 6A, for lighting purposes except from the bed lights and the Exit Signs which are connected to the DB/UPS.

In the DB/UPS we have 6 sockets outlets of each bed which are red color, the bed lights and the Exit signs. So we placed 10 MCBs type B, 6A and another one MCB same as the other for the lights of beds and exits.



Power Outlets in ICU room

Figure 5.7.Power Outlets in ICU room

Both Distribution Boards are single phase and we used the Fix Bus Bar distribution board 6 way, the needs where for 4 ways DB but on purpose for future equipment we used 6 way. The two distributions boards with all the information of the MCBs, types and size of the wire are shown below and are also available in AutoCAD Drawings.

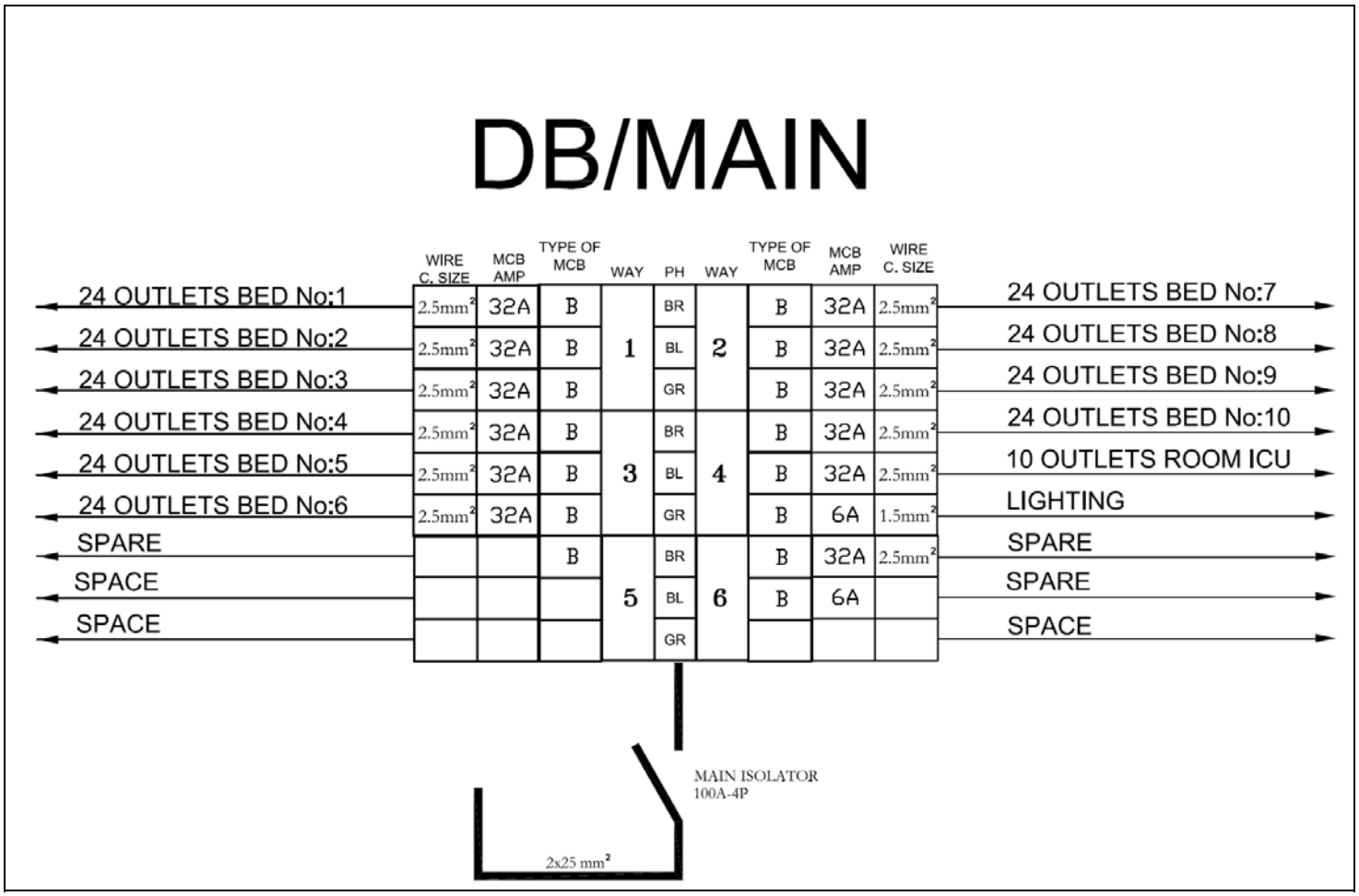


Figure 5.8.Distribution Board Main

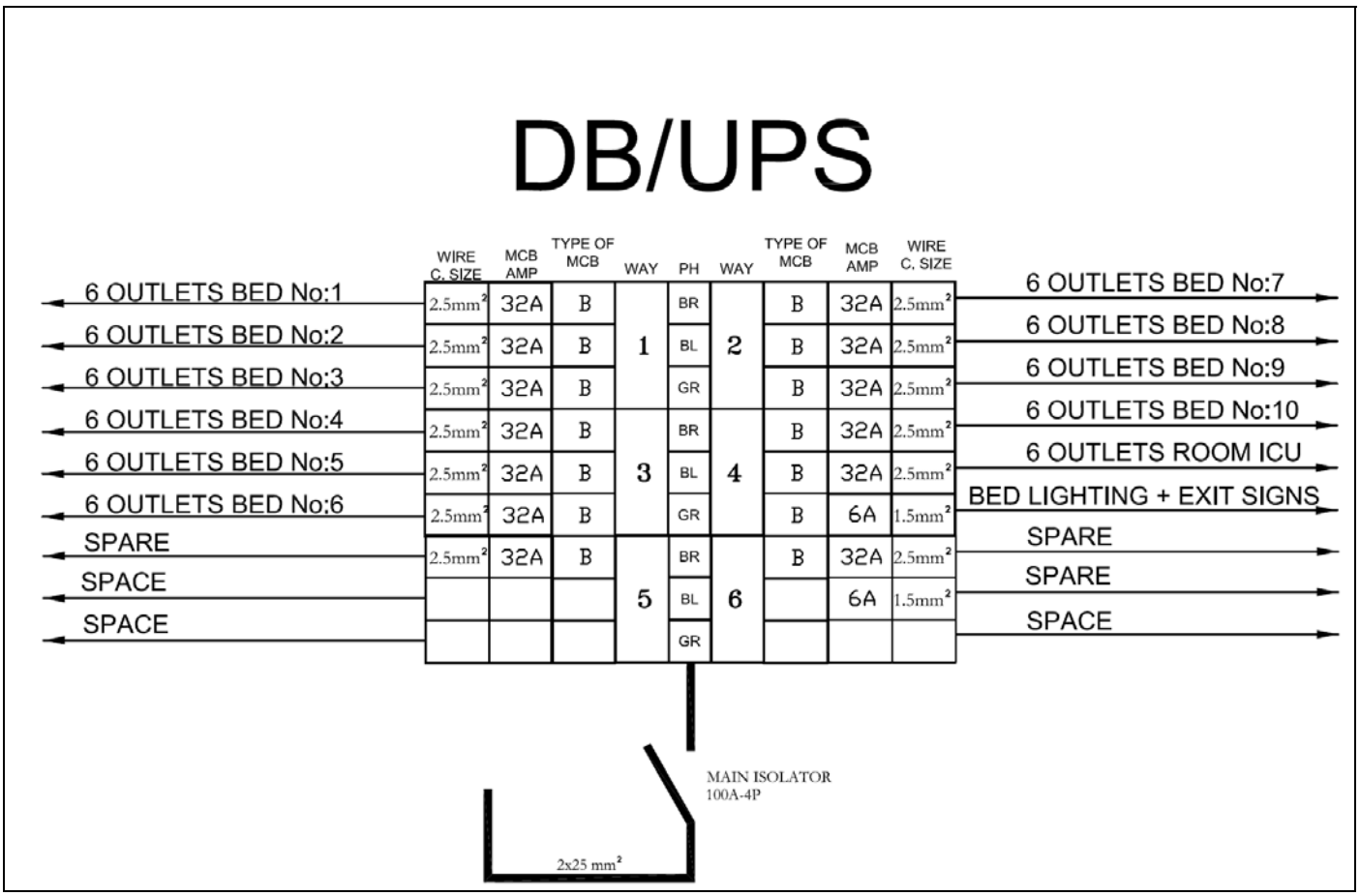


Figure 5.9.Distribution Board UPS

5.2.8. Equipotential Bar

Generally earthing arrangement for the full electrical system should comply with the requirements of BS 7430:1998 and BS 7671:2001.The exceptions to these fundamental requirements are some specific areas which meet the earthing requirements of an IT-earthed system.

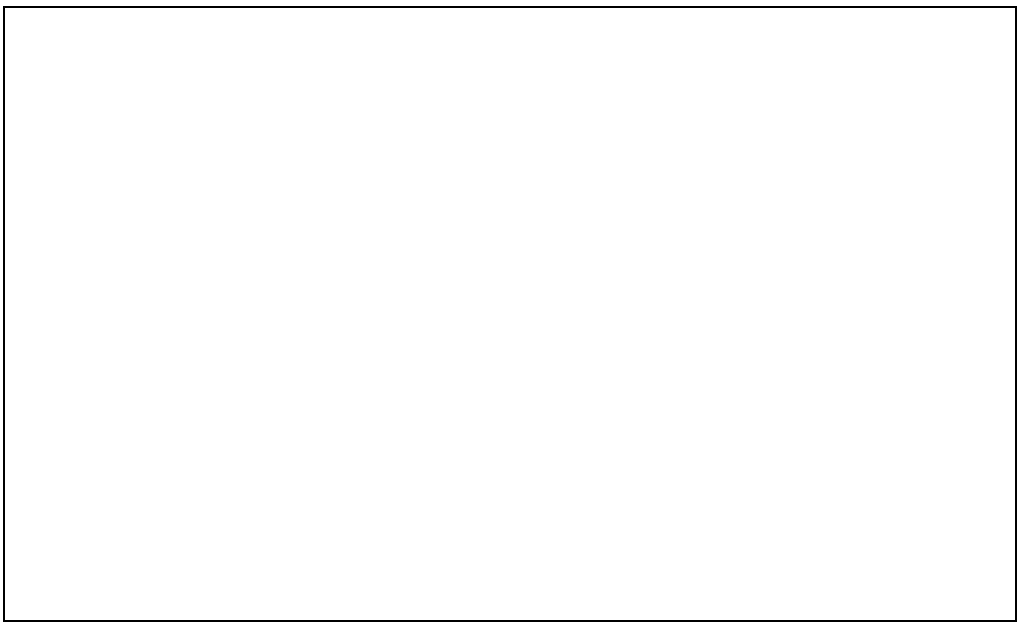
In the ICU area which is locate to the Medical Group 2, is one of the exception areas so we are following the Medical IT or Isolated Power Supply earths.

In all areas defined as Medical Location Group 1 and 2, an earth reference bar (ERB) will be provided adjacent to the local final distribution board of the IPS. The IPS circuits will be bonded to a protective earth terminal (PET), which should be easily accessible from the IPS distribution board and IPS isolation transformer housing. An earthing conductor will be directly bonded between the PET and a local ERB. Both the PET and ERB will be visible and accessible by authorized people only.

The ERB is located within the vicinity of the Medical Group 2 location to allow short lengths of earthing cables to be connected. The size of the wire should be 6 mm^2 where the resistive values remain within the 0.2 Ω.

The additional earth reference bar is located some distance away from the group 2 location within the vicinity of the distribution board of the IT (IPS) transformer panel. This allows the connection between these two boards to be made by a larger size earthing cable such as 10 $mm^{2.}$

To our sample ICU area, after our research everything in the room is connected to the IPS system. For these reason all the earthling wires are connected directly first to the distribution boards which are located in the ICU room and then to the Medical IT (IPS) Earth Bar, which also is located to the ICU room near to the medical staff with the LIM so it can be easily monitored. After the IPS earth bar, the earth wire is connected to the ERB which is located just outside the room and at the end to the Main Earth Bus bar, which is the IPS transformer panel, for the whole area. Of course from the area the ending of the earth wire will be connected to the earth. With such connection we remain to the 0, 2 Ω, which are the resistive values. In our case we used the following wire sizes for each case. From all the outlets and lighting 2,5mm^2 earth wire was used to be connected to the DB/MAIN. From the DB/MAIN one wire 4mm^2 was connected to the IPS earth bar. From the IPS earth bar one 6mm^2 wire was connected to the ERB and from there to IPS Transform Panel earth bar a 10mm^2 wire. After that to go outside from the area 16mm^2 wires is connected to the earth.



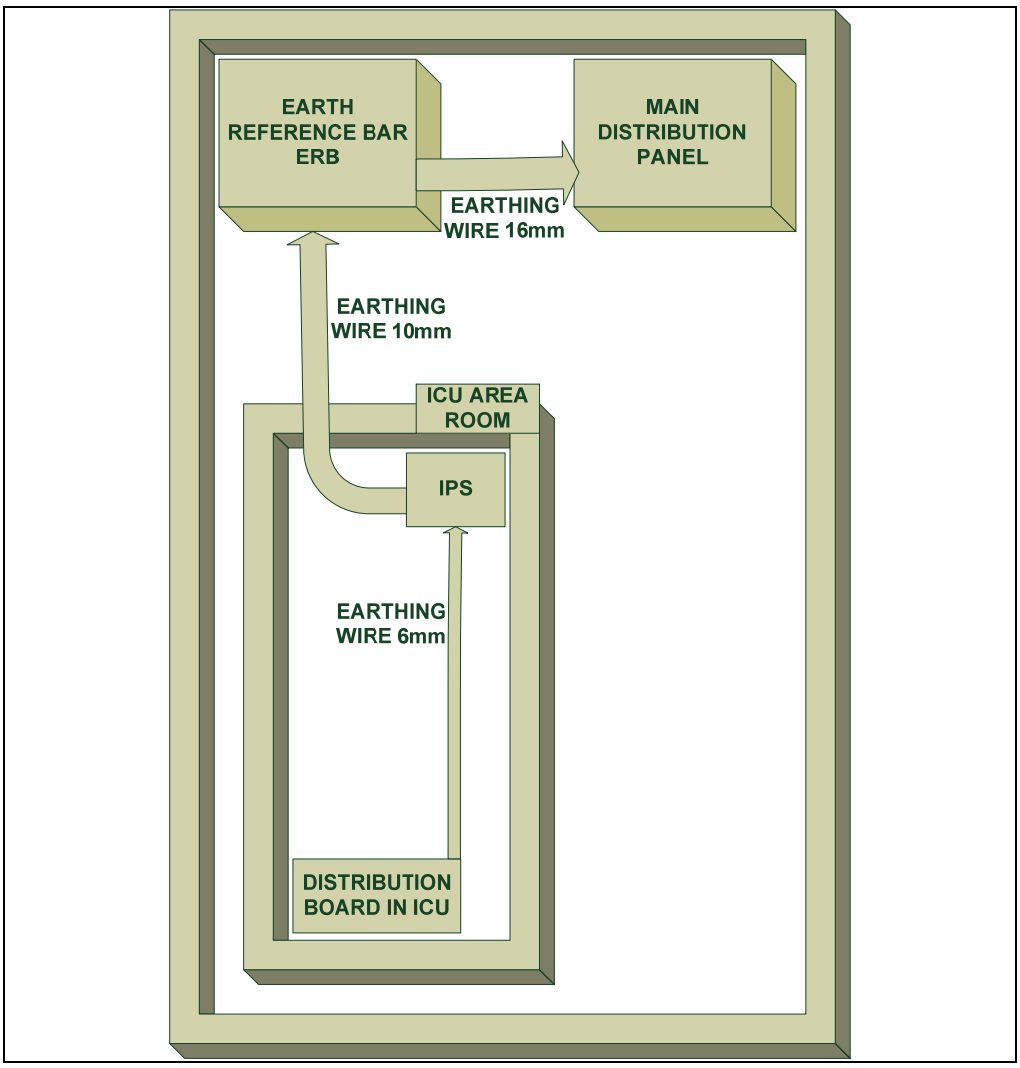


Figure 5.10.Equipotential Bar

6. Electrical Safety Tests in ICU

In our daily life there are more indispensable relationship between safety and life. The multitude of accidents with subsequent personnel and material damages show that safety cannot always be guaranteed by human intervention. This is especially so in the hospital environment, where the application of electrical devices in diagnostic and therapy for instance means exposure to increased electrical hazards, through faults in the current supply or defective devices. The safety tests should be performed as the directives state and periodically.

6.1. Isolation Transformer Leakage Current Tests

Leakage current is the current that flows from a device through the grounding conductor into general grounding bond to the earth. Leakage current could shock an individual if the grounding bond is not sufficient or there is an intentional or unintentional interruption of grounding connection.

Leakage Current Testing Equipment refer to international standard, IEC 60990 Touch Current and Protective Conductor Current, were previously referred to as Leakage Current. This standard is a general standard for all the equipment but in case of medical equipment should be also added and the IEC 60601-1 (the International Electrotechnical Commission's electrical safety standard for medical electronic equipment).

- Touch Current (TC):

The touch current flows when a human body touches a device and the current flow through body. If the measured TC does not exceed the value hazardous to a human body as defined by a safety standard or the like, the equipment meets the requirements for preventing electric shock.

- Protective Conductor Current (PCC):

Current that flows through the protective conductor of equipment that is furnished with normal protective bonding. The measurement of the PCC also serves the purpose of checking the compatibility with the distribution system of the equipment.

The Isolation Transformer as we mentioned before is very useful equipment because is the one that gives first level safety to the ICU area and also reduces the electromagnetic interferences.

Every six months as the standards and the most manufactures specify should be perform leakage current test to the Isolation Transformer. To perform a leakage current test to an Isolation Transformer is very simple and the values from the tests must be saved for ISO purposes. The limits that are specifying from the directives are shown below. Above these values the Isolation transformer must be repair otherwise should be replaced.

Current	Normal Condition	Single Fault Condition
Earth Leakage Current	0.5mA	1mA

Type of Equipment	Maximum Leakage Curren
Portable Unit	0.5mA
Stationary Unit	0.75mA

Table 6.1.Limits for Leakage Current Tests

The measurement of the leakage current for the Isolation Transformer should be made with nominal values of the operation. The secondary coil of the transformer should be free without any load and only the primary coil must be connected to the electrical supply. So in the secondary coil we have free two active wires, one that brings the electricity to the following equipment and the other returns. These two wires must be connected one by one each time with an amperometer from the one side and from the other side with the ground. The current that is displayed to the amperometer should not be exceeding the 0,5mA as the limits for the leakage currents test specify. After performed both wires the electrical supply in the primary coil of the transformer should be changed into 110% of the rated supply and make the measurements again. All the measurements should not exceed the 0,5mA, if a measurement is above the 0,5mA, the operator should measure again and then if steel exceed the transformer should be repaired otherwise should be replaced with a new one.

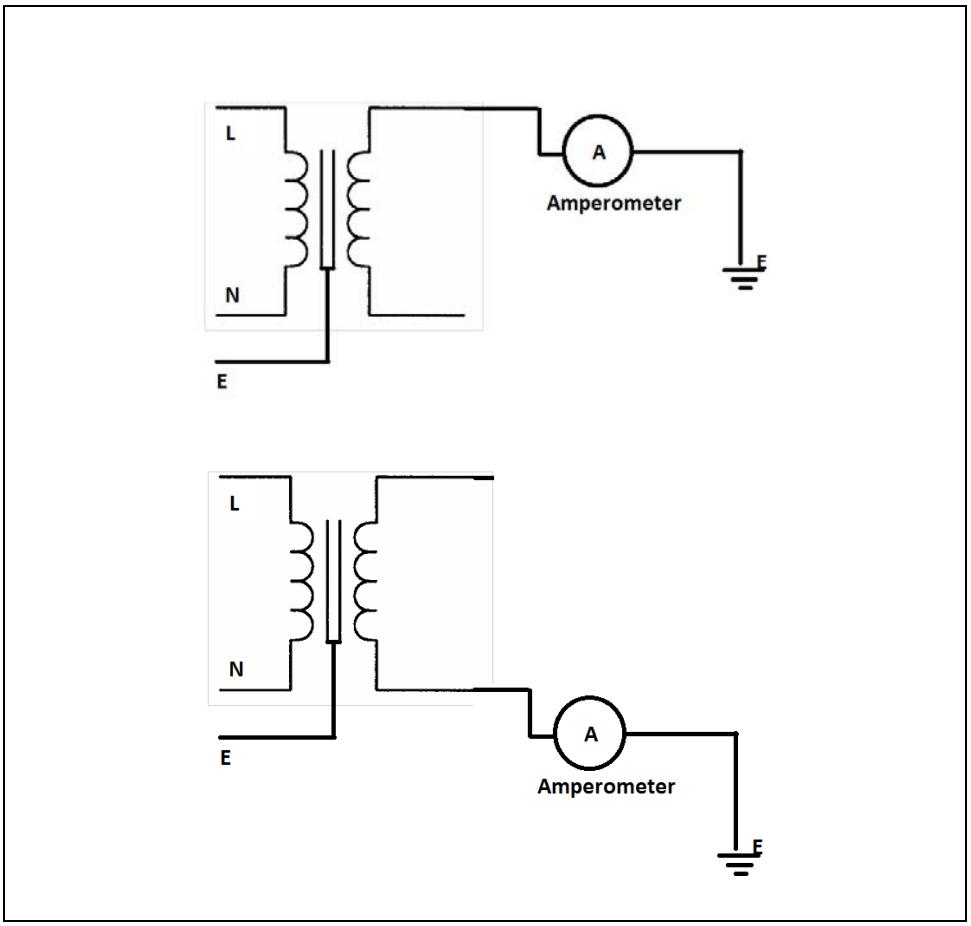


Figure 6.1.Leakage Current Tests to an Isolation Transformer

6.2. Line Isolation Monitor Tests

The Line Isolation Monitor also needs every six months to be check with making tests to be sure that is working properly. The personnel that is making the tests should be get notes for each test that makes and keep the records to a safe place for the quality assurance and for ISO purposes that everything were checked and works properly. To test if the Line Isolation Monitor, works properly there are two ways. The first way is the easy one and can be done by pressing the "Test" button on the front side of LIM. By pressing the test button the device make a self-test, a simulation of a ground fault and if the device working properly the visual and audible alarm should be started.

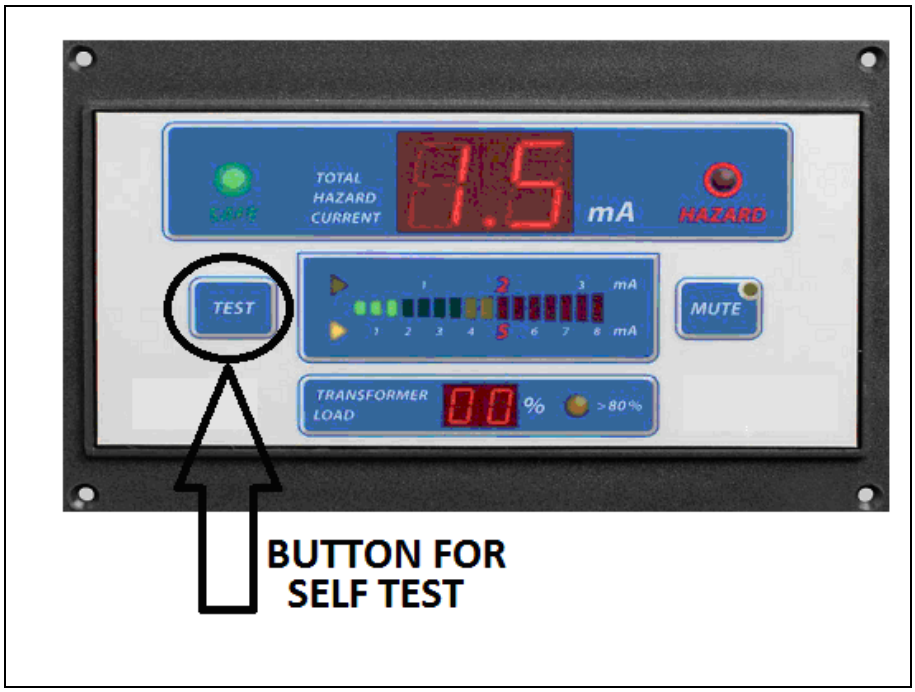


Figure 6.2.LIM Self-Test

The second way for testing the LIM which is the best way to test it, is to use the LIM Tester. Every manufacturer of LIM produces also and LIM testers and is better to use the recommended one.

The LIM tester generally speaking is a potentiometer that is connected between each of the two active wires of the secondary side of the isolation transformer and to the equipotential node. The equipments that are supplied by the LIM should be disconnected before the test, so in case of malfunction will not cause any problem. For the testing, the resistance should be decreased between the IT and the LIM and at the same time current leak to equipotential node. When the resistance is under 50KΩ, the visual and audible alarm should be start.

Nowadays the LIM Tester works very simple and makes everything automatically, the operator should only read the instructions from the manufacture and the test is very simple. The operator

plug the LIM tester into any wall outlet rated 240V, 50Hz and run a simple pretest to confirm the integrity of the isolated system. With so give assurance that the system is properly grounded. The display will indicate the system voltage, 'V' and LCD will be lit and the PRETEST LCD (Hazard Current) will light. If the L1 or L2 button is pushed, the system leakage on each line will be indicated in mA (milliampere). Pushing the top push button will get the unit in the compliance test mode and the "LIM" LED will light. Depress and hold the Set Current button and adjust the current knob (potentiometer) until the desired milliampere setting is displayed. The set current button can be released. Pushing the L1 or L2 button will cause the LIM to indicate the desired leakage and if resistance is below the 50KΩ due to currents that leak the LIM must take an action and start the visual and audible alarm.

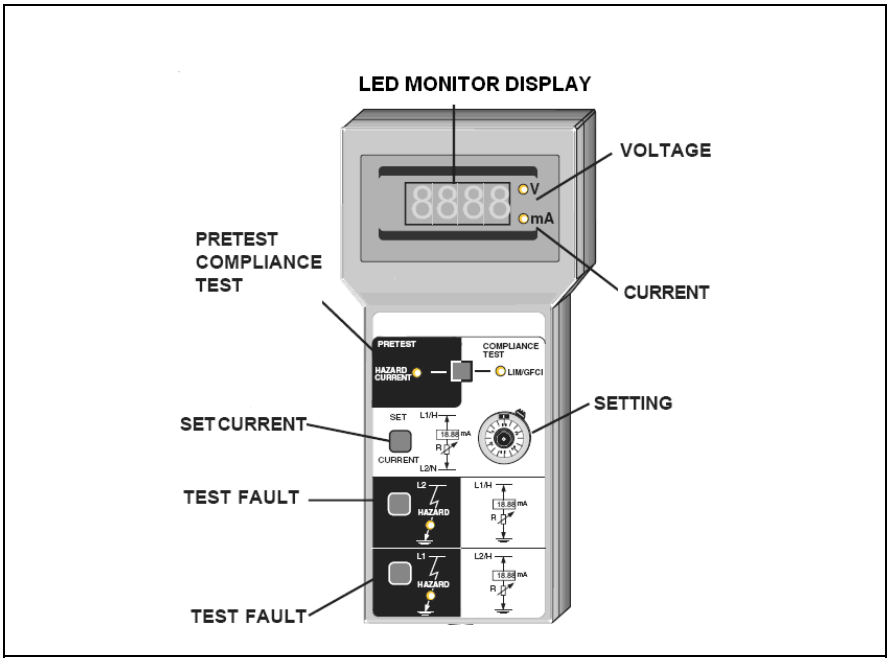


Figure 6.3.LIM Tester

6.3. Residual Current Device (RCD) Tests

The RCD must be checked annually. To check the RCD, the easiest way is to push the test button of the RCD and will simulate a ground fault by releasing current approximately to 2.5 IΔn (IΔn=50/Zs the IΔn is the rated operating current of the RCD, 50 is the touch voltage and the Zs

is the measure loop impedance) , so it produces imbalance between the live and the neutral wire. If it works properly the RCD must trip and interrupt the electrical supply.

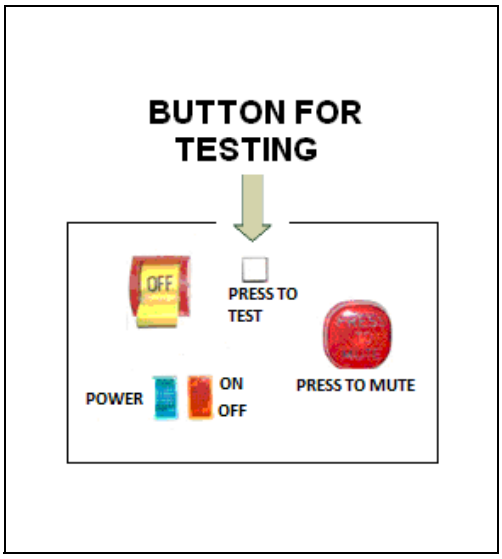


Figure 6.4.Hospital RCD

The second way which also is the most accurate, and the British Standards BS7671, specifies that is the only one that should be done for testing RCDs requires RCD tester. The RCD tester is the same device as the LIM tester and can be used for testing the RCDs.

Figure 6.5.RCD Tester

The tester first must be plug in a wall socket and is connected between phase and protective conductor on the load side of the RCD after disconnecting the load. A precisely measured current for a carefully timed period is drawn from the phase and returns via the earth, thus tripping the device.

The tester measures and displays the exact time taken for the circuit to open. This time is very short and in most cases is between 10 to 20 ms, although it can be much longer, especially for S-type which has delayed operation.

The medical RCD shall be trip when the current is imbalanced approximately at 5mA. The time that take to open the circuit is about 10ms.

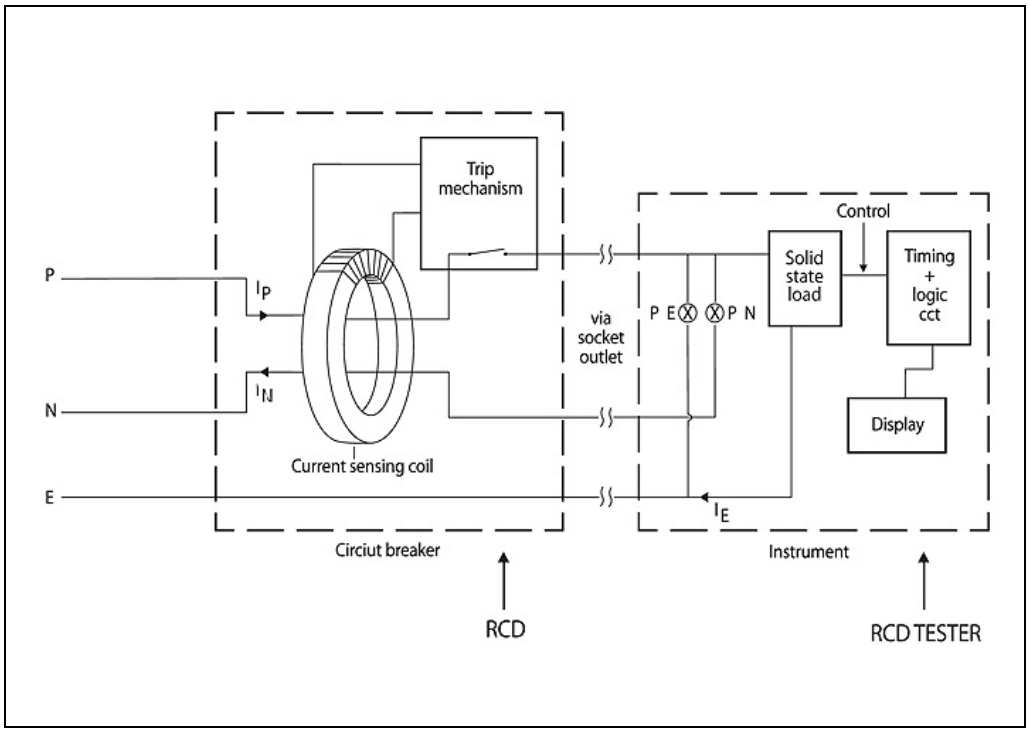


Figure 6.6.Connection of the RCD Tester

6.4. Equipotential Grounding Tests

Equipotential Grounding Test should be implemented every three years.

In order to measure the resistance between the biomedical equipment and the equipotential node, the operator should have a device with four pins (volt-ampere system), that has an output voltage (without load) between 4 and 24V DC or AC and a current of at least 10A.

This test should take into account the resistance between the equipotential node and:

- The ground contact of the wall outlets
- The ground contact of all the devices inside the patient zone

More precisely the device should measure R_1 (resistance of the connection to the node), R_0 (resistance of the conductor), R_2 (resistance of the connection to the chassis of the equipment).

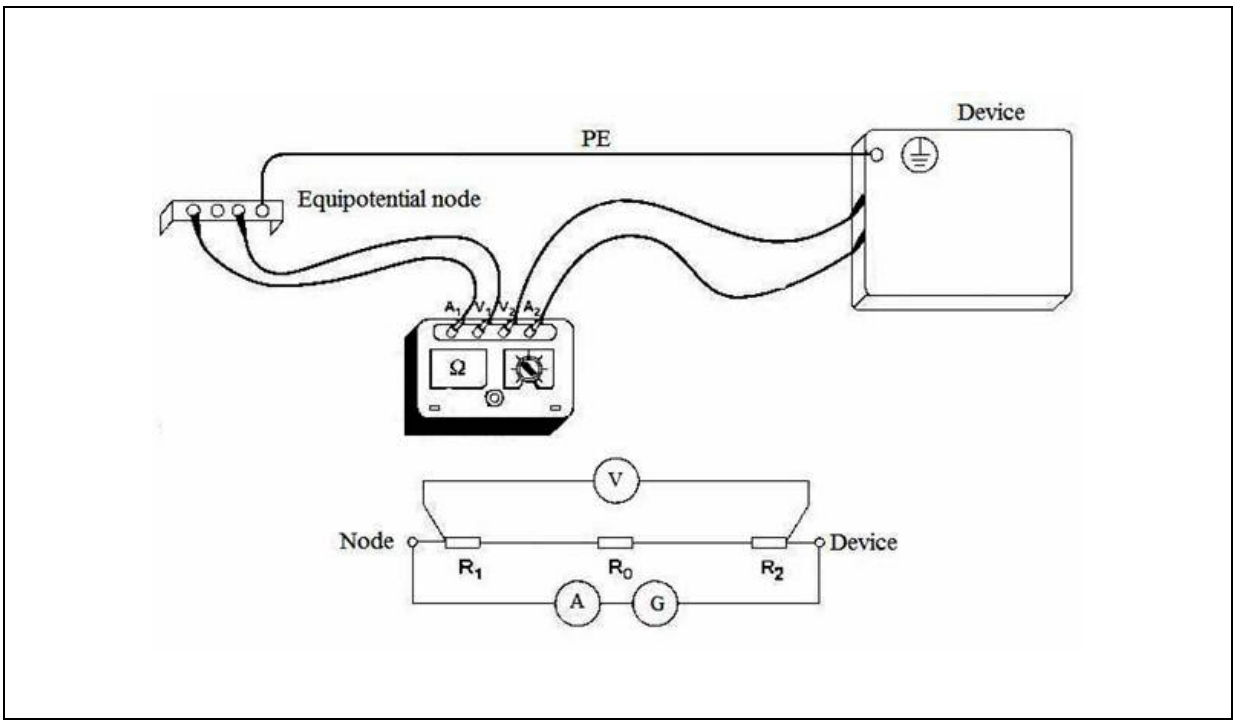


Figure 6.7.Testing an Earth Resistance between the Equipotential Node and a Biomedical Device

The test current is flowing through the pins A_1 and A_2 , and the measurement is done trough pins V_1 and V_2. The terminals of the device must be placed in such a way, in order to measure also the voltage drop over resistances R_1 and R_2 (and not only R_0). For locations of Group 2 the limit is set to **0.2Ω.**

Also there is a possibility that every area in the hospital has a direct earth busbar, so from the equipotential node there is a direct connection to the earth. In such cases, the department should also measure the resistance between the node and the earth and due to IEE Wiring Requlations 16th Edition should be under **5Ω** less for sensitive areas as is the ICU area.

6.5. Uninterruptible Power Supply (UPS) Tests

UPS systems are very sensitive devices and at the same time very complicate devices when we are speaking for large 3-phase UPS systems.

The testing of such systems includes more than one test but series of tests to determine if the UPS system working properly and it will give to the system the necessary output power when ever need it.

These tests should be done every six months or as the manufacturer specifies.

Steady – State Load Test

Under a steady-state test, you should check all input and output conditions at 0%, 50%, and 100% load.

Tests should be done to the following parameters: input voltage, output voltage, input current, output current, output frequency, input current balance, and output voltage regulation.

The analysis will reveal if input currents match across all phases of a module as well as determine if all modules equally share the load. Because power is equal to voltage times current, a degraded voltage from a single module or phase means other modules or phases must produce more current to accommodate the voltage drop.

Harmonic Analysis Test

The input and output of the UPS for harmonic content during the steady-state load test should be monitor. Observing the harmonic content at 0%, 50%, and 100% load allows you to determine the effectiveness of the input and output filters. It is important to note that most manufacturers design UPS filtering systems for the greatest efficiency at full load. Consequently, the harmonic distortion is greatest when the system is least loaded and smoothes out as load increases. As long as the distortion is consistent across phases and modules, there is no reason for alarm. Total harmonic distortion (THD) is essentially a measure of deviation from a perfect sinusoidal wave. A load with high THD requires more energy to sustain than a unit with low THD. The wasted energy dissipates as heat. Although inefficient, a UPS operating with high THD at low load is in no danger of damaging conduction components. A UPS operating with high THD at high load is extremely taxed because the unit produces energy to sustain the load along with additional heating and for this reason should be test harmonics at the following points: input voltage, output voltage, input current, and output current.

Filter Integrity Test

Most UPS systems, constructed with three basic filter elements

- Input
- Rectifier
- Output

These filters commonly use an arrangement of resistors, inductors, and capacitors to remove unwanted waveform components. Thermal scans typically pick up indications of an inductor failure. Capacitors are more prone to failure under stress. Depending on the capacitor, they’re subject to rapid expansion and leakage of acidic electrolyte when overstressed or drying out over time.

In large 3-phase UPS systems, there are virtually hundreds of capacitors wired in series and arranged in banks. Identifying a single failed capacitor can be difficult and time-consuming.

Performing a relative phase current balance is a simple means of checking filter integrity. By checking phase current through each leg of the filter, you can make a quantitative evaluation. A marked difference in phase currents drawn through a filter assembly is an indication that one or more capacitors have degraded.

Transient Response Load Test

The transient response test simulates the performance of a UPS with large instantaneous swings in load. The UPS accommodates full-load swings without a distortion in output voltage or frequency. Periodically testing the response to load swings and comparing them with the original specifications will help keep your UPS healthier.

To observe the response to rapid load swings, connect a recording oscillograph and load banks to the UPS output to monitor the three phases of voltage along with a single phase of current (the current trace acts as a telltale sign when you apply or remove load). As you apply and remove load, you can see the effect on the voltage waveform. The voltage waveform should not sag, swell, or deform more than 8% under any given transient. You can perform similar tests on loss of AC input power and then measure the AC input restoration.
Conduct load testing using the following power increments:

- 0% - 50% - 0%
- 25% - 75% - 25%
- 50% - 100% -50%

Module Fault Test

Also a multi-modules systems test should be implemented to verify that the system continues to maintain the critical load in the event of a module failure. By applying full system-rated load (via load banks), a single module should be simulated to fail. The system should continue to maintain the load without significant deviation of voltage or frequency as verified by a recording oscillograph.
Test each module similarly. Failing multiple modules will test the system transfer to bypass.

Battery Rundown Test

The final test should be a battery rundown. Often a battery system may be subject to failures that go undetected. The most meaningful test of a battery is to observe temperature, voltage, and current under load conditions. Dissimilar voltages from cell-to-cell or string-to-string are a clear indication of battery degradation. The load test will depend on the type of batteries connected to the UPS. Wet-cell batteries are more robust and are capable of going a year between full battery-

rundown tests. Valve-regulated batteries are easily overstressed by a full battery rundown, so you should test them more often.

While conducting a discharge test, you should continuously check the battery cell voltages manually or with a cell monitor. When the battery string is no longer able to provide designed discharge time (e.g., 15 min), or 80% of the rated capacity, then it's time to consider full battery replacement.

Effective UPS testing is a complex and potentially dangerous operation if you don't do it correctly. Hiring a test-engineering group with strong experience in UPS maintenance and testing is usually best. Although thorough testing of your UPS unit can be costly and time-consuming, the costs associated with an unanticipated loss of business and production far exceeds those incurred from testing.

Except from the above tests that inform the biomedical engineering department that the UPS system is ready to provide power in case of electric failure there are also some software programs that monitor and control the UPS system.

These software programs displays in real time, the information in the form of bar charts and values for critical data such as mains voltage, UPS load and battery charge%.

Also it allows remote interrogation of UPS logs and operating parameters to help diagnose alarms and potential fault conditions. With such program the UPS system can be controlled easily and inform you when there is any problem to be repaired.

6.6. Automatic Transfer Switch (ATS) Tests

The automatic transfer switch (ATS) is a critical system component of the emergency power system, and proper maintenance of an ATS depends on the type of switch and its position in the critical power infrastructure.

An automatic transfer switch is an electromechanical device with moving parts. The moving parts in an ATS can seize if they're left in one position for months or years, so regular exercise will help ensure that moving parts will continue to operate smoothly.

NFPA110, the standard for "emergency and standby power supply system", states that every month should test the Automatic Transfer Switch, by switching from the standard position to the alternate position and then a return to the standard position. Furthermore this standard also requires a monthly generator run. The best way to perform both these tests is by operating the test toggle on the ATS when the generator isn't running, and confirming that the ATS properly signals the generator to start and run before transferring building load.

The following list provides the tests that should be done to the Automatic Transfer Switch:

1. De-energize the switchgear (ATSs equipped with an isolation bypass feature do not need to be de-energized).

2. Remove the arc chutes and pole covers. Consult the manufacturer's information for proper procedure. This step will allow visual inspection of the main and arcing contacts.

3. Test and recalibrate all trip-sensing and time-delay functions in the switchgear. Depending on the manufacturer, the steps required here will vary. The focus here should be to verify and record what current settings are and to ensure the current adjustments meet the customer's needs and expectations. If adjustments are necessary, the means to make and verify those adjustments need to be examined. For example, a voltage pick-up or dropout adjustment may require the use of a variable source such as a variable ac transformer. The standby engine can be a source of variable frequency, etc. In any case, the manufacturer is your source for information concerning these adjustments.

4. Vacuum the accumulated dust from the switchgear and accessory panels. Never use air to blow out dirt. Subjecting the TS unit to compressed air may have a detrimental effect by forcing dirt and debris into the switch mechanism.

5. Inspect for moisture or signs of previous wetness or dripping.

6. Clean grime with an approved solvent. Consult the OEM for a recommendation.

7. Inspect all insulating parts for cracks or discoloration due to excessive heat. Part of any complete maintenance program is an infrared scan. This work is done prior to maintenance with normal loads applied to the gear being scanned. The resultant report will define problem areas. The use of this information will allow the maintenance provider to take a proactive approach.

8. Inspect all main arcing contacts for excessive erosion. Arcing contacts are intended to be sacrificial by nature. They take the brunt of the energy when making or breaking the load. Careful attention should be paid to these contacts.

9. Inspect all main current-carrying contacts for pitting and discoloration due to excessive heat.

10. Inspect all control relay contacts for excessive erosion and discoloration due to excessive heat.

11. Manually operate the main transfer movement to check proper contact alignment, deflection, gap, and wiping action.

12. Check all cable and control wire connections to the transfer switch control and sensing panel and other system components and tighten if necessary.

13. Re-energize the switchgear and conduct a test by simulating a normal source failure.

Frequency of checks required*	Note Clause # on page two	Qualified Inspector Key O = Operator of switch D = Authorized dist/dealer		Required Action Adjust Repair Replace	Clean	Test	Transfer Switch (ATS) and System's Compo Recommended for Examination and Te
		Visual	Physical				
Electrical System							
Yearly	2.0	O	O				Check wiring and connections are tight with no discolo of metal, melted plastic and odor indicating excessive h
Yearly	2.0	O			D		Verify contractor's external operating mechanism is cle re lubricate if found dirty.
Yearly	2.0	O	D	D			Check for any deterioration of wiring insulation such as and abrasions. Replace or repair any damaged wiring.
Yearly	2.2		D			D	Check tightness of wiring connections. Retighten to specification if any loose wiring found.
Yearly	2.1	D		D	D		Check ATS main power switching contacts condition. C replace. Replace contactor assembly if necessary.
Control System							
Weekly	2.3					O	Exercise the generator set under load.
Monthly	2.3					O	Test the transfer switch's automatic control system.
Yearly	2.3					D	Test all indicators (LEDs) and all remote control systems operation.
General Condition of Transfer Switch and Controls							
Monthly	2.0	O			O		Inspect the outside of the transfer switch for any indica of wear, excessive vibration, leakage, high temperature contamination or other deterioration.
Monthly	2.0	O	O	O			Verify all external components are in place, firm, tighte and not excessively worn.
Yearly	2.1	D	D		D		Inspect the inside of the transfer switch for any indicat excessive vibration, leakage, high temperature, contam or any other deterioration.
Yearly	2.1	O	D	D			Verify all internal components are in place, firm, tighte and not excessively worn.
Visual Inspection	Items marked for visual inspection should be examined visually by a trained operator.						
Check	Check assumes physical contact with the part or component being inspected or the use of a nonvisual indication.						
Adjust, Repair, Replace	This includes tightening all hardware and lubricating where necessary. Replacement may be necessary if repair not possible.						
Clean	This means the removal of dust, dirt, contaminants and moisture. Remove by cloth or vacuum, never use compressed air.						
Test	Testing may require tools (some special), equipment, or training available only through an authorized distributor/dealer.						
Key to chart symbols:	O = Trained operator D = Distributor/dealer with trained technician *Service more frequently if system operates in dusty dirty areas						

Table 6.2.Automatic Transfer Switch Tests

6.7. Antistatic Floor Covering Tests

Testing the electrical resistance of an antistatic floor of an ICU area, the procedure and the results should be complying with the following standards to assure quality control purposes and safety issues:

- IEC 61340-4-1, {Ed.2.0/2003} Standard test methods for specific applications – Electrical resistance of floor coverings and installed floors
- IEC 61340-5-1, {Ed.1.0/2007} Electrostatics - Part 5-1: Protection of electronic devices from electrostatic phenomena - General requirements

The first standard IEC 61340-4-1 specifies test methods for determining the electrical resistance of all types of floor coverings and installed floors with resistance to ground, point-to-point resistance and vertical resistance of between 10^4 Ω and 10^{13} Ω.

The second standard IEC 61340-5-1 specifies test methods for determining the body voltage generation and the limits of 100VDC.

First of all the equipment that should have for completing the testing of an antistatic floor is an ohmmeter, a self contained resistance meter with ±10% accuracy. Furthermore two cylindrical metal electrodes made of stainless steel with terminals for connecting to the resistance measuring apparatus. Each electrode shall have a flat circular contact area of 65 mm ± 5 mm in diameter.

The total mass of each measuring electrode shall be either:

- 2,5 kg ±0,25 kg for measurements on hard, non-conformable surfaces

or

- 5,0 kg ±0,25 kg for measurements on all other surfaces.

The best option as the manufacture mentioned is the 5kg electrodes so it can be used on any surface in any area.

With that the operator is able to measure the point to point resistance and also the resistance to the ground.

For measuring the Body Voltage Generation also need a device that have an ESD sensitivity greater then 100V or equal.

Figure 6.8.Ohmeter with electrodes

Figure 6.9.ESD Sensitivity Meter

Testing the Point-to-point resistance, the operator place the two measuring electrodes on the test specimen 300 mm ± 10 mm distance centre to centre. Any ground points attached to the test specimens should be remain isolated from ground. Next step is to connect the measuring electrodes to the resistance measuring apparatus and starting the measurement with the voltage set to 10 V, take a reading of the resistance 15 s ±2 s after applying the test voltage. If the value exceeds 10^6 **Ω**, select 100 V and repeat the measurement. If the value for this second measurement exceeds 10^{11} **Ω**, select 500 V and make a final measurement. All the reading must be recorded and saved for the report. For the report file the operator should repeat the measurement procedure at other positions with the electrodes no closer than 100 mm from any previous measurement position.

Measurements shall be made in rectilinear directions, i.e. measurements with the electrodes placed in line parallel to the direction of manufacture and separate measurements with the electrodes in line orthogonal to the direction of manufacture. A total of at least six measurements per specimen shall be made or until the whole room tested.

Now testing the Resistance to Ground the same measurement as in the point to point should be done expect from the connection apparatus which only the one electrode is connected to the measuring device and the ground point to the device. This test should be done at least six times or again until the whole area is tested and in each measurement the electrode should have 1m distance from any other measurement. All the measurements should be recorded for the report file.

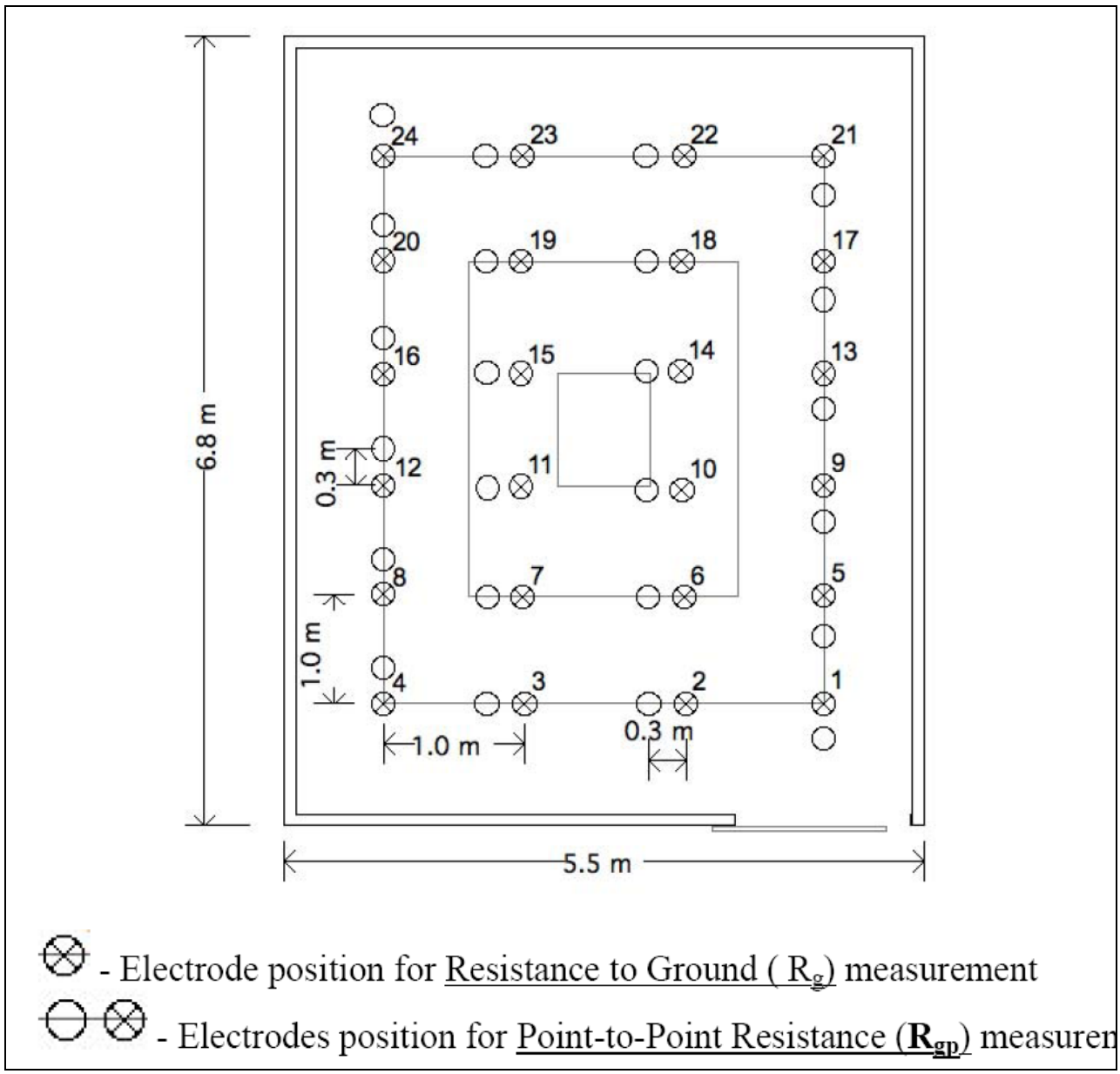


Figure 6.10.Testing Point to Point Resistance and Resistance to Ground

As all the records of the measurements are ready, then to get the final result the operator should calculate the geometric mean of the individual readings, measurements.
The limits are shown below:

LIMITS	Upper Limit, Ohms	Recommended Lower Limit, Ohms
Resistance to Ground, R_g	$R_g \leq 1_x 10^9$ Ohms	$R_g \geq 25_x 10^3$
Point-to-Point Resistance, R_{gp}	$R_{gp} \leq 1_x 10^9$ Ohms	$R_{gp} \geq 25_x 10^3$
Standards	IEC 61340-4-1, {Ed.2/2003}, IEC 61340-5-1, {Ed.1.0/2007}	

Table 6.3.Limitations

If the final result number of the Resistance to Ground or Point to point resistance, exceed the upper or is lower than the lower limit, the floor must be replaced or be repaired due to the IEC

61340-4-1, {Ed.2.0/2003} Standard test methods for specific applications – Electrical resistance of floor coverings and installed floors.

On the other hand form the second standard we must also measure the Body Voltage Generation, using the Electrostatic sensitivity meter. The operator is standing on the surface and the electrode is connected to the surface and also to the measuring device. Pressing the button on the device measures the Body voltage. The limit is under the 100VDC, if the measured record is under the limit of the 100VDC, the floor on the specific area is safe of ESD, otherwise should be repaired or replaced.

The safety tests for the antistatic floor should be completed every six months as most of the manufacturer's advice.

7. Conclusion

Safety can be achieved by ensuring the safety of the installation and the safe operation and maintenance of medical electrical equipment connected to it. The use of medical electrical equipment on patients undergoing intensive care has called for enhanced reliability and safety of electrical installations in hospitals so as to improve the safety and continuity of supplies which is met by application of this document.

Building and testing the electrical system in the Intensive Care Unit is very complicated procedure due to the technological equipment that is installed in the area. Focusing on the directions and following the standards can create a safer environment preventing and minimizing any accidents.

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