CHAPTER ONE

Introduction

General overview

Electrical disturbances can result in repeated diagnostic tests, wasted medical supplies, and expensive service and repair calls. These unexpected events are not covered by any healthcare insurance provider. The increasing use of healthcare insurance and the increased coverage limitations compel healthcare facilities to minimize all equipment malfunctions.

Electrical disturbances can alter the control parameters stored in electronic medical equipment and used to diagnose a patient's condition, it can also cause microprocessor-based equipment to lock up and fail to capture data used by caregivers to make critical medical decisions, and eventually it can damage an electronic component or circuit board in medical equipment causing the loss of data stored in memory or rendering the memory inaccessible [1].

The patient safety is the main reason for reducing the potential for equipment malfunctions; healthcare administrators must also consider the bottom line.

Power quality in the healthcare environment can be improved through enhancing the level of awareness among the stakeholders: utilities, healthcare facility and medical staff, healthcare facility designers, and medical equipment manufacturers.

Good grounding is essential for good power quality and safety at any healthcare facility [1]. There are several important reasons why a grounding system should be installed. But the most important reason is to assure patient safety. Secondary reasons include protection of structures and equipment from unintentional contact with energized electrical lines. The grounding system must ensure maximum safety from electrical system faults and from lightning. A good grounding system must receive periodic inspection and maintenance [2].

Problem statement

Most of the equipment used in healthcare facilities are electrically operated, such as; ECG machine, bedside monitor, anaesthesia machine, ventilators, catheter machine, suction machine, laboratory equipment, radiology equipment (X-ray, C.T Scan, ultrasound, mammographic etc) , incubators, infant warmer etc. As these equipment's are often in contact with the staff or patient, the danger of electrical hazard which can affect patients, operators and medical equipment, always persists in such environment.

The motivation of this study is to provide comprehensive view of implementing the grounding system in hospitals in order to evaluate the current situation of implement the grounding system in Khartoum state hospitals.

The research objectives

The objectives of this research are:

- To assess the implementation of earth system in healthcare facilities (case study on some of Khartoum hospitals).
- To identify the effects of implementing grounding system in healthcare facilities.
- To assess the current situation of grounding system in some of Khartoum hospitals.
- To suggest practical solutions the problems that faced the implementing of grounding system in healthcare facilities.

The research hypothesis

There are two main hypotheses:

- There is no any earthing system implemented in most hospitals.
- Most of grounding systems in hospitals are improper and doesn't match the international standard.

The study justification

- Every medical equipment or appliance must be 'Earthed' or 'Grounded' for the safety of equipment, network as a whole, operating personnel and patients.
- Fault in Grounding system directly impacts human safety and medical device malfunctions.
- Major accidents happen due to improper earthing, leakage current can passes through human body and result in fatality.

Thesis outlines

This thesis was divided into six chapters as the following:

- Chapter one includes general introduction to the grounding system in healthcare facilities, problem statement, the study objectives, researcher hypotheses, the study justifications and study outlines.
- Chapter two includes the literature review.
- Chapter three includes theoretical background.
- Chapter four includes the study methodology.
- Chapter five includes the results and discussions.
- Chapter six includes conclusion and recommendations.

CHAPTER TWO

Literature review

Osman *et al*. (1997) discussed the partial application of electrical protection and safety at medical institutions. Systems of neutralization and grounding are used with medical diagnostic and cure devices, which use very complicated electronics. These devices are especially sensitive to minimal transient potential differences which may have corresponding electromagnetic influence. An additional safety requirement and measures is therefore needed. Structural schemes for neutral and grounding protection application are described [3].

Engr (2003) has given an overview of the safety measures recommended by various national and international agencies through their standard specification; the main object of this article is to highlight appropriate measures for a high level of electrical safety in healthcare facilities [4].

Fukumoto (2003) discussed the electrical safety in hospitals from a point of view of power distribution system and protective devices like ground short circuit alarm, and an equipotential earth system [5].

Fred (1974) intended to provide the reader with a basic understanding of electrical safety problems in the hospital. The physiological effects of electricity in the body, electrical safety hazards in hospital and methods of protecting patient from both macroshock and microshock hazards are described and discussed. The paper concluded with recommendations for a relatively inexpensive, but effective and up-to-date electrical safety program for the hospital [6].

Paul and Dominique (2006) focused on the safety requirements for the DC bus distribution systems up to 1500 VDC, where regulations require double protection measures. The first protection is mostly provided by proper electrical insulation. A second active protection system is also installed; this detects insulation failure and switches off power supply. Often the residual current detector (RCD) is used to detect leakage currents in earthed systems but is difficult to build for DC systems. Another active technique is to install a flauting or unearthed system with an insulation resistance monitoring device (IMD) [7].

Bruner (1967) discussed eleven incidents of shocks and ventricular fibrillation during surgical procedures which were identified from 1960-1967. Five of these incidents were attribute to line current leakage of devices and implemented cardiac pacemakers, three of the incidents were attribute to ungrounded and/or defective medical equipment and three were of undetermined or incited cause [8].

Atkin and Orkin (1973) discussed accident that occurred where a patient connected to an electrosurgical return plate was intensely shocked when an electrocardiogram (EKG) device was powered by an incorrectly wired outlet with the ground and neutral leads transposed [9].

Gilbert *et al*. (1991) discussed an incident involving a bipolar electrosurgical device with an internal IT with damaged ceramic insulator mounts occurred, because it had been dropped. The damage caused the IT to become connected to ground [10].

Courtney et al. (2006) discussed an incident that occurred in Australia where an ungrounded operation table and placement of a (damaged) power cord under the operating room table support leg led to leakage current provided by another device (firstly an image intensifier and secondly electro surgical device) through the "live" table to earth, causing arc flashing and tripping of the GFCI into which the severed cord was plugged [11].

Theoretical background

CHAPTER THREE

3.1 Introduction

Grounding is connecting to a common point which is connected back to the electrical source. It may or may not be connected to earth. An example where it is not connected to earth is the grounding of the electrical system inside an airplane. Low-resistance grounds that can carry currents up to circuit-breaker ratings are clearly essential for protecting patients against both macroshock and micro shock, even when an isolated-power system is used.

A grounding system protects patients by keeping all conductive surfaces and receptacle grounds in the patient’s environment at the same potential. It also protects the patient from ground faults at other locations. The grounding system has a patient-equipment grounding point, a reference grounding point, and connections. The patient equipment grounding point is connected individually to all receptacle grounds, metal beds, metal door and window frames, water pipes, and any other conductive surface. These connections should not exceed 0.15 V. The difference in potential between receptacle grounds and conductive surfaces should not exceed 40 mV. Each patient-equipment grounding point must be connected individually to a reference grounding point that is in turn connected to the building service ground [2].

3.2 The importance of ground

There are several important reasons why a grounding system should be installed; the most important is to protect people. Secondary reasons include protection of structures and equipment from unintentional contact with energized electrical lines. The grounding system must ensure maximum safety from electrical system faults and lightning. A good grounding system must receive periodic inspection and maintenance, if needed, to retain its effectiveness. Continued or periodic maintenance is aided through adequate design, choice of materials and proper installation techniques to ensure that the grounding system resists deterioration or inadvertent destruction. Therefore, minimal repair is needed to retain effectiveness throughout the life of the structure [2].

The grounding system serves three primary functions which are listed below:

Personnel Safety: Personnel safety is provided by low impedance grounding and bonding between metallic equipment, chassis, piping, and other conductive objects so that currents, due to faults or lightning, do not result in voltages sufficient to cause a shock hazard. Proper grounding facilitates the operation of the over current protective device protecting the circuit.

Equipment and Building Protection: Equipment and building protection is provided by low impedance grounding and bonding between electrical services, protective devices, equipment and other conductive objects so that faults or lightning currents do not result in hazardous voltages within the building. Also, the proper operation of over current protective devices is frequently dependent upon low impedance fault current paths.

Electrical Noise Reduction: Proper grounding aids in electrical noise reduction and ensures:

The impedance between the signal ground points throughout the building is minimized. The voltage potentials between interconnected equipment are minimized. The effects of electrical and magnetic field coupling are minimized.

Another function of the grounding system is to provide a reference for circuit conductors to stabilize their voltage to ground during normal operation. The earth itself is not essential to provide a reference function. Another suitable conductive body may be used instead.

3.3 Definitions

Earth: The conductive mass of the earth, whose electric potential at any point is conventionally taken as equal to zero. (In some countries the term “**ground**” is used instead of “earth” ITU K27 [12].

Earth Electrode: A conductive part or a group of conductive parts in intimate contact with and providing an electrical connection with earth ITU K27 [12].

Earthing Conductor: A protective conductor connecting the main earthing terminal or bar to the earth electrode ITU K27 [12].

Earthing Network: The part of an earthing installation that is restricted to the earth electrodes and their interconnections ITU K27 [12].

Ground: A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth. NEC100 [13] .

Ground Grid: A system of grounding electrodes consisting of interconnected bare cables buried in the earth to provide a common ground.UL96A [14].

Ground terminal: The portion of the lightning protection system such as a ground rod, ground plate, or ground conductor, that is installed for the purpose of providing electrical contact with the earth. NFPA 780[15].

Grounded: Connected to earth or to some conducting body that serves in place of the earth. NEC 100 [13].

Grounded Conductor: A system or circuit conductor that is intentionally grounded.NEC 100 [13].

Grounded Effectively: Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the build up of voltages that may result in undue hazards to connected equipment or to persons.NEC 100[13].

Grounding Conductor: A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes. NEC 100 [13]

Grounding Conductor, Equipment: The conductor used to connect the noncurrent-carrying metal parts of equipment, raceways and other enclosures to the system grounded conductor, the grounding electrode conductor, or both, at the service equipment or at the source of a separately derived system. NEC 100 [13] (Green wire).

Grounding Electrode Conductor: The conductor used to connect the grounding electrode to the equipment grounding conductor, to the grounded conductor, or to both, of the circuit at the service equipment or at the source of a separately derived system. NEC 100 [13].

Main Earthing Terminal: A terminal or bar provided for the connection of protective conductors including equipotential bonding conductors and conductors for functionalearthing, if any, to the means of earthing. ITU K27 [12].

Minimum Approach Distance: The closest distance a qualified employee is permitted to approach either an energized or a grounded object, as applicable for the work method being used. ANSI C2 [16].

Neutral Conductor (N): A conductor connected to the neutral point of a system and capable of contributing to the transmission of electrical energy. ITU K27 [12].

3.4 Physiological effects of electricity on humans

For a physiological effect to occur, the body must become part of an electric circuit. Current must enter the body at one point and leave at some other point. The magnitude of the current is equal to the applied voltage divided by the sum of the series impedances of the body tissues and the two interfaces at the entry points. The largest impedance is often the skin resistance at the contact surface.

Three phenomena can occur when electric current flows through biological tissue:

- Electric stimulation of excitable tissue (nerve and muscle).
- Resistive heating of tissue

- Electrochemical burns and tissue damage.

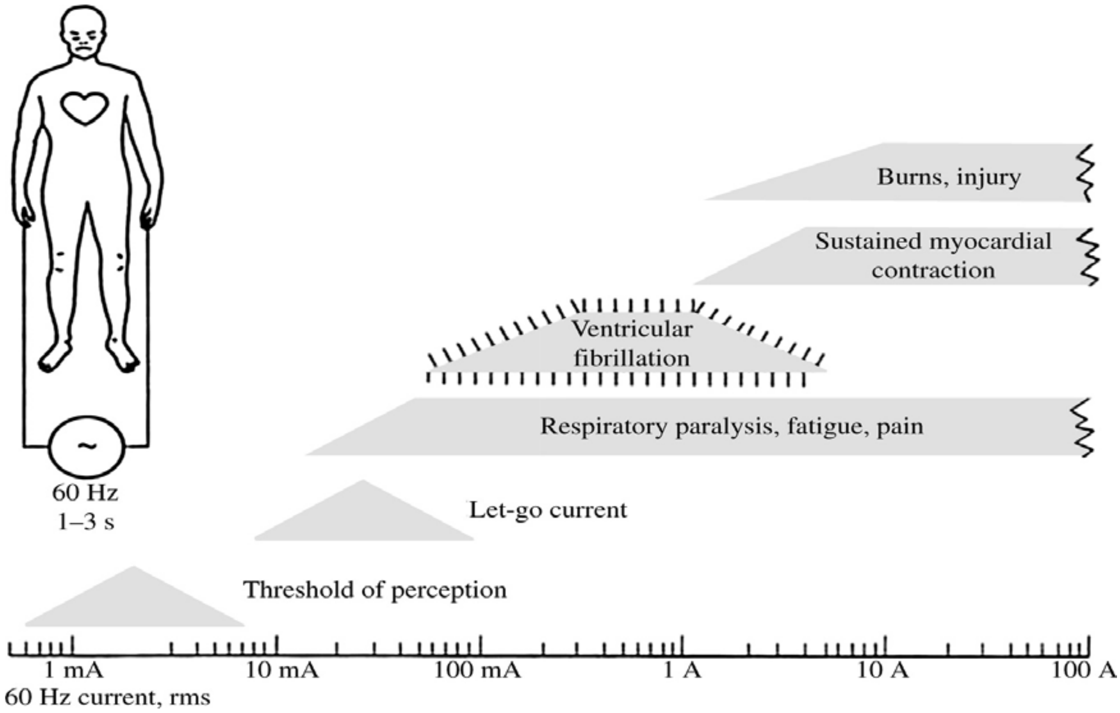


Figure 3.1: Physiological effects of electricity Threshold or estimated mean values are given for each effect in a 70 kg human for a 1 to 3 s exposure to 60 Hz current applied via copper wires grasped by the hands [17].

3.5 Distribution of electric power

Electric power is needed in health-care facilities not only for the operation of medical instruments but also for lighting, maintenance appliances, patient conveniences (such as television, hair curlers, and electric toothbrushes), clocks, nurse call buttons, and an endless list of other electric devices. A first step in providing electrical safety is to control the availability of electric power and the grounds in the patients' environment [18].

3.6 Patients' electrical environment

A shock hazard exists between the two conductors supplying either a240 V or a 120 V appliance. Because the neutral wire on a 120 V circuit is connected to ground, a connection between the hot conductor and any grounded object poses a shock hazard.

Microshocks can occur if sufficient potentials exist between exposed conductive surfaces in the patients' environment.

The following maximal potentials permitted between any two expose conductive surfaces in the vicinity of the patient are specified by the 2006 NEC,Article 517-15[19].

- General-care areas, 500 mV under normal operation
- Critical-care areas, 40 mV under normal operation

  In general-care areas, patients have only incidental contact with electric devices. For critical-care areas, hospital patients are intentionally exposed to electric devices, and insulation of externalized cardiac conductors from conductive surfaces is required. In critical-care areas, all exposed conductive surfaces in the vicinity of the patient must be grounded at a single patient grounding point. Also, periodic testing for continuity between the patient ground and all grounded surfaces is required.

Each patient-bed location in general-care areas must have at least four single or two duplex receptacles. Each receptacle must be grounded. At least two branch circuits with separate automatic overcurrent devices must supply the location of each patient bed. For critical-care areas, at least six single or three duplex receptacles are required for each location of a patient bed. Two branch circuits are also required, at least one being an individual branch circuit from a single panel board.

3.7 Macroshock and microshock Hazards

3.7.1 Macroshock Hazards

The high resistance of dry skin and the spatial distribution of current throughout the body when a person receives an electric shock are two factors that reduce the danger of VF. Furthermore, electric equipment is designed to minimize the possibility of humans coming into contact with dangerous voltages [20].

3.7.2 Microshock Hazards

Microshock accidents in patients who have direct electric connections to the heart are usually caused by circumstances unrelated to macroshock hazards.

Microshocks generally result from leakage currents in line-operated equipment or from differences in voltage between grounded conductive surfaces due to large currents in the grounding system. The microshock current can flow either into or out of the electric connection to the heart [18].

3.8 Electric faults in equipment

All electric devices are of course designed to minimize exposure of humans to hazardous voltages. However, many devices have a metal chassis and cabinet that medical personnel and patients may touch. If the chassis and cabinet are not grounded, as shown in Figure 3.2(a), then an insulation failure or shorted component between the black hot power lead and the chassis results in a 115 V potential between the chassis and any grounded object. If a person simultaneously touches the chassis and any grounded object, a macroshock results.

The chassis and cabinet can be grounded via a third green wire in the power cord and electric system, as shown in Figure 3.2(b). This ground wire is connected to the neutral wire and ground at the power-distribution panel. Then, when a fault occurs between the hot conductor and the chassis, the current flows safely to ground on the green conductor. If the ground-wire resistance is very low, the voltage between the chassis and other grounded objects is negligible. If enough current flows through the ground wire to open the circuit breaker, this will call people's attention to the fault.

Note that direct faults between the hot conductor (and any high voltage in the device) and ground are not common. Little or no current flows through the ground conductor during normal operation of electric devices. The ground conductor is not needed for protection against macroshock until a hazardous fault develops. Thus a broken ground wire or a poor connection of a receptacle ground is not detected during normal operation of the device. For this reason, continuity of the ground wire in the device and the receptacle must be tested periodically.

Faults inside electric devices may result from failures of insulation, shorted components, or mechanical failures that cause shorts. Power cords are particularly susceptible to strain and physical abuse, as are plugs and receptacles. Ironically, it is possible for a device's chassis and cabinet to become hot because a ground wire is in the power cord. If the ground wire is open anywhere between the power cord and ground, then a frayed cord could permit contact between the hot conductor and the broken ground wire leading to the chassis. Often, macroshock accidents result from carelessness and failure to correct known deficiencies in the power-distribution system and in electric devices.

Fluids; such as blood, urine, intravenous solutions, and even baby formulas can conduct enough electricity to cause temporary short circuits if they are accidentally spilled into normally safe equipment. This hazard is particularly acute in hospital areas that are subject to wet conditions, such as hemodialysis and physical therapy areas. The cabinets of many electric devices have holes and vents for cooling that provide access for spilled conductive fluids. The mechanical design of devices should protect patient electric connections from this hazard [18].

3.9 Basic approaches to protection against shock

There are two fundamental methods of protecting patients against shock. First, the patient can be completely isolated and insulated from all grounded objects and all sources of electric current. Second, all conductive surfaces within reach of the patient can be maintained at the same potential, which is not necessarily ground potential. Neither of these approaches can be fully achieved in most practical environments, so some combination of the two methods must usually suffice [18].

3.10Effects of in proper grounding in medical apparatus

In a fair number of cases, the cause of a power quality problem in healthcare facilities and medical clinics is simply a loose or corroded power or ground connection. Many medical equipment malfunctions attributed to poor power quality are caused by inadequate electrical wiring and grounding. Such problems frequently arise when, new electronic medical or office equipment is connected to existing facility wiring; permanently installed medical equipment is moved from one location to another; or underlying non-PQ-related equipment malfunctions are not resolved and changes to wiring and grounding are made in efforts to equipment.

Wiring and grounding errors also enhance the negative effects of neutral-to-ground transients, which disrupt electronic medical equipment. Reversal of neutral and ground conductors; poor, missing, or redundant neutral-to-ground bonds; and poor, missing, or redundant equipment grounds are a few examples of faulty wiring and grounding that can lead to medical equipment malfunctions [1].

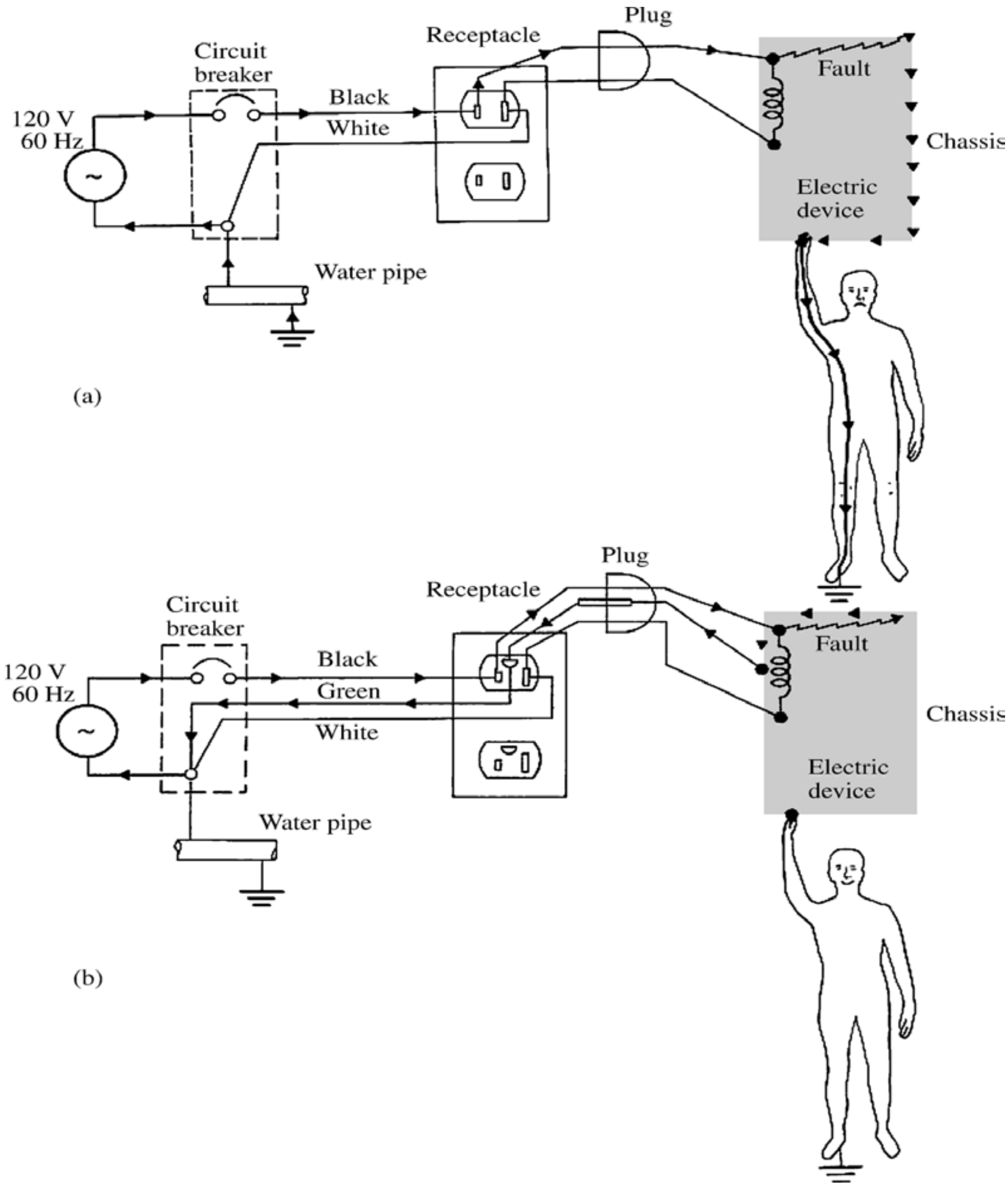


Figure 3.2: Macroshock due to a ground fault from hot line to equipment cases for (a) ungrounded cases and (b) grounded chassis [18].

3.11 Leakage currents

Small currents (usually on the order of microamperes) that inevitably flow between any adjacent insulated conductors that are at different potentials are called leakage currents. Although most of the leakage current in lineoperated equipment flows through the stray capacitance between the two conductors, some resistive leakage current flows through insulation, dust, and moisture.

The most important source of leakage currents is the currents that flow from all conductors in the electric device to lead wires connected either to the chassis or to the patient. Leakage current flowing to the chassis flows safely to ground if a low-resistance ground wire is available, as shown in Figure 3.3(a).If the ground wire is broken, and then the chassis potential rises above ground and a patient who touches the chassis and has a grounded electric connection to the heart may receive a microshock Figure 3.3 (b). If there is a connection from the chassis to the patient's heart and a connection to ground anywhere on the body, this could also cause a microshock Figure 3.3(c). [18]

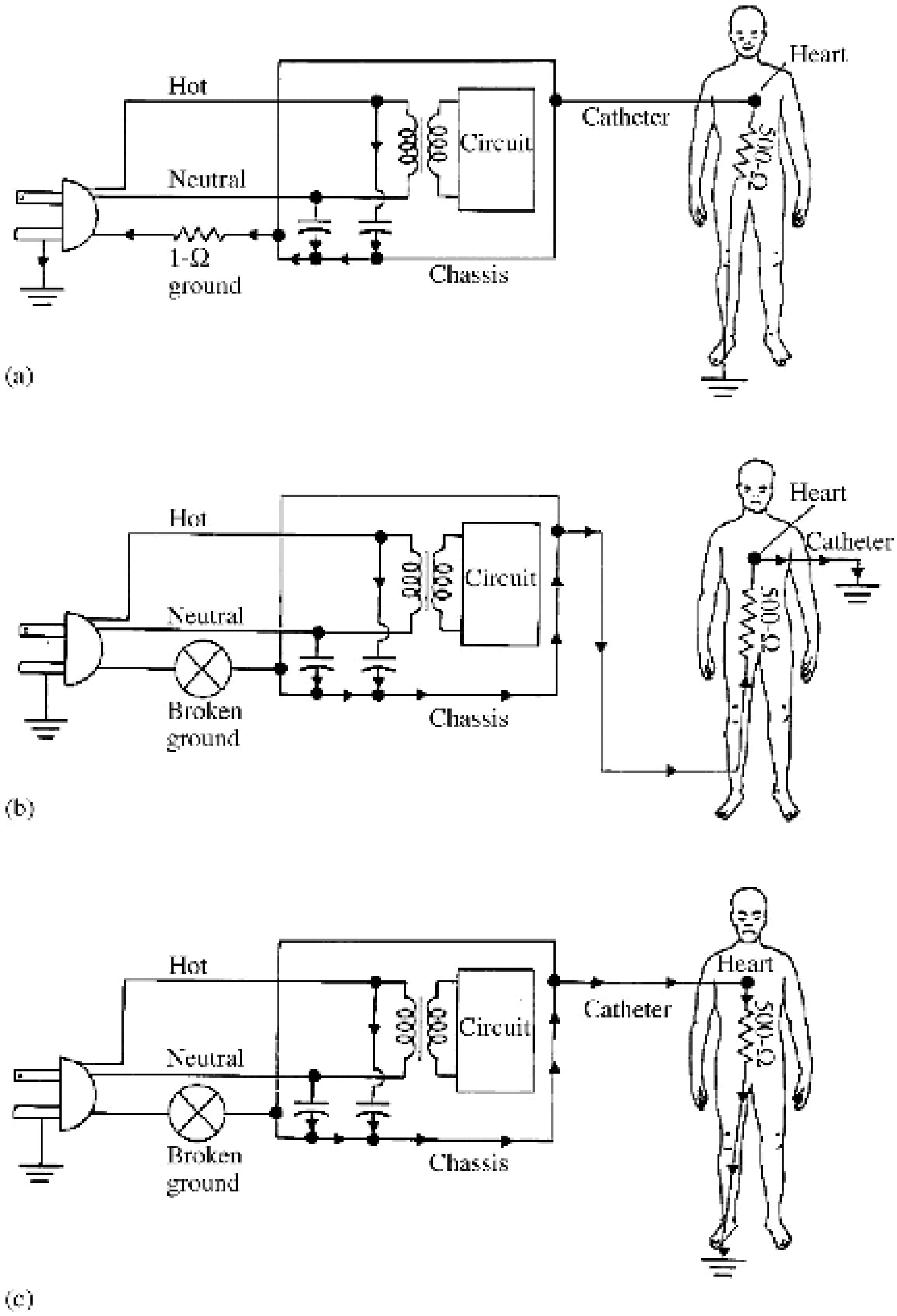


Figure 3.3:Microshock leakage-current pathways Assume 100 mA of leakage current from the power line to the instrument chassis, (a) intact ground;99.8 mA flows through the ground, (b) broken ground; 100 mA flows through the heart, (c) broken ground; and 100 mA flows through the heart in the opposite direction [18].

3.11.1 Causes of leakage currents

If any conductor is raised to a potential above that of earth, some current is bound to flow from that conductor to earth. This is true even of conductors that are well insulated from earth, since there is no such thing as perfect insulation or infinite impedance. The amount of current that flows depends on [21]:

a. The voltage on the conductor.
b. The capacitive reactance between the conductor and earth.
c. The resistance between the conductor and earth.

The currents that flow from or between conductors that are insulated from earth and from each other are called leakage currents, and are normally small. However, since the amount of current required to produce adverse physiological effects is also small, such currents must be limited by the design of equipment to safe values.

For medical electrical equipment, several different leakage currents are defined according to the paths that the currents take:

3.11.2 Types of leakage currents

There are four types of leakage currents mentioned as followed:

3.11.2.1 Earth leakage current

Earth leakage current is the current that normally flows in the earth conductor of a protectively earthed piece of equipment. In medical electrical equipment, very often, the main is connected to a transformer having an earthed screen. Most of the earth leakage current finds its way to earth via the impedance of the insulation between the transformer primary and the inter-winding screen, since this is the point at which the insulation impedance is at its lowest (figure 3.4).

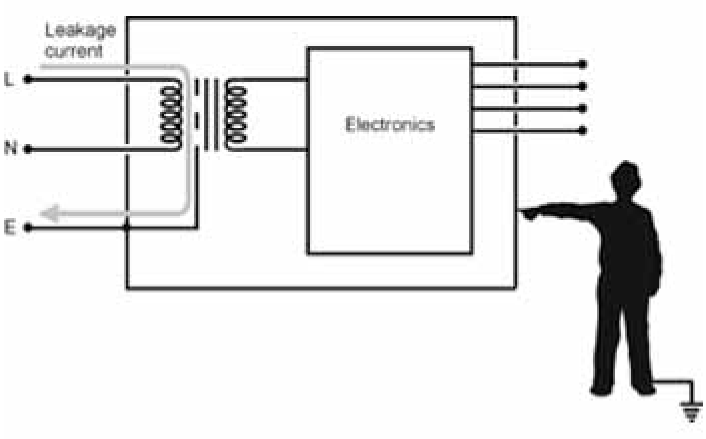


Figure 3.4: Earth leakage current path [21].

Under normal conditions, a person who is in contact with the earthed metal enclosure of the equipment and with another earthed object would suffer no adverse effects even if a fairly large earth leakage current were to flow. This is because the impedance to earth from the enclosure is much lower through the protective earth conductor than it is through the person ,however, if the protective earth conductor becomes open circuited, the situation will changes. Now, if the impedance between the transformer primary and the enclosure is of the same order of magnitude as the impedance between the enclosure and earth through the person, a shock hazard exists.

It is a fundamental safety requirement that in the event of a single fault occurring, such as the earth becoming open circuit, no hazard should exist. It is clear that in order for this to be the case in the above example, the impedance between the mains part (the transformer primary and so on) and the enclosure need to be high. This would be evidenced when the equipment is in the normal condition by a low earth leakage current. In other words, if the earth leakage current is low then the risk of electric shock in the event of a fault is minimised.

3.11.2.2 Enclosure leakage current or touch current

Enclosure leakage current is defined as the current that flows from an exposed conductive part of the enclosure to earth through a conductor other than the protective earth conductor.

If a protective earth conductor is connected to the enclosure, there is little point in attempting to measure the enclosure leakage current from another protectively earthed point on the enclosure, since any measuring device used is effectively shorted out by the low resistance of the protective earth. Equally, there is little point in measuring the enclosure leakage current from a protectively earthed point on the enclosure with the protective earth open circuit, since this would give the same reading as measurement of earth leakage current as described above. For these reasons, it is usual when testing medical electrical equipment to measure enclosure leakage current from points on the enclosure that are not intended to be protectively earthed (see figure 3.5). On many pieces of equipment, no such points exist. This is not a problem. The test is included in test regimes to cover the eventuality where such points do exist and to ensure that no hazardous leakage currents will flow from them.

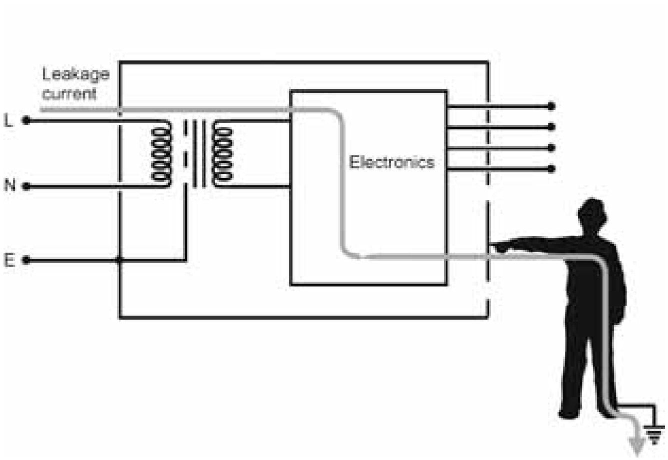
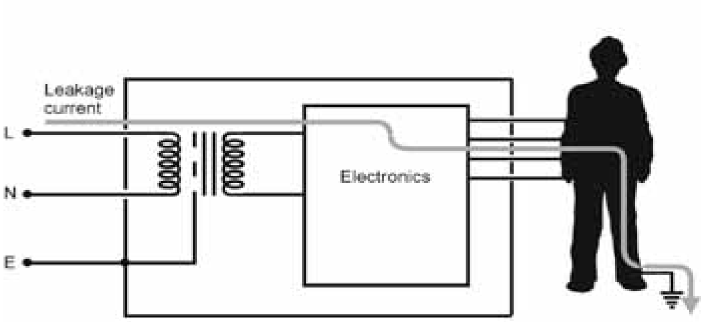


Figure 3.5: Enclosure leakage current path [21].

3.11.2.3 Patient leakage current

Patient leakage current is the leakage current that flows through a patient connected to an applied part or parts. It can either flow from the applied parts via the patient to earth or from an external source of high potential via the patient and the applied parts to earth. Figures (3.6 a) and (3.6 b) illustrate the two scenarios.



Figures 3.6(a):Patient leakage current path from equipment [21].

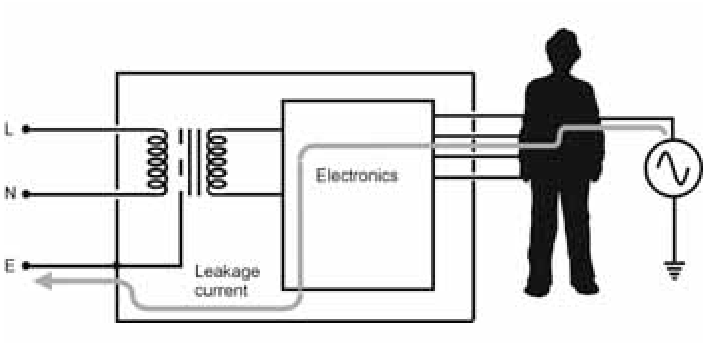


Figure 3.6 (b): Patient leakage current path to equipment [21].

3.11.2.4 Patient auxiliary current

The patient auxiliary current is defined as the current that normally flows between parts of the applied part through the patient, which is not intended to produce a physiological effect (figure 3.7).

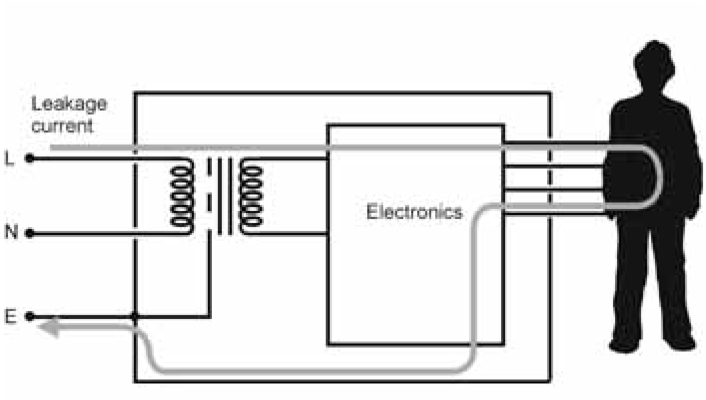


Figure 3.7: Patient auxiliary current path [21].

3.11.3 Reduction of leakage current

Reduction of leakage current in the chassis of equipment and in patient leads is an important goal for designers of all line-powered instruments. Special low leakage power cords are available (<1.0 mA/m). Leakage current inside the chassis can be reduced by using layouts and insulating materials that minimize the capacitance between all hot conductors and the chassis. Particular attention must be given to maximizing the impedance from patient leads to hot conductors and from patient leads to chassis ground. Old equipment with higher leakage should not be used with patients susceptible to microshocks unless proper grounding is ensured.

Classes and types of medical electrical equipment

The medical electrical equipment has three classes and three types as followed:

3.12.1 Classification of medical electrical equipment

3.12.1.1 Class I equipment

These appliances must have their chassis connected to electrical earth (US: ground) by a separate earth conductor (colored green/yellow in most countries, green in the US, Canada and Japan). The earth connection is achieved with a 3-conductor mains cable, typically ending with 3-prong AC connector which plugs into a corresponding AC outlet. The basic requirement is that no single failure can result in dangerous voltage becoming exposed so that it might cause an electric shock and that if a fault occurs the supply will be removed automatically (this is sometimes referred to as ADS = Automatic Disconnection of Supply)

Figure3.8: Symbols seen on earthed equipment [22].

A fault in the appliance which causes a live conductor to contact the casing will cause a current to flow in the earth conductor. If large enough, this current will trip an over-current device (fuse or circuit breaker (CB)) and disconnect the supply. The disconnection time has to be fast enough not to allow fibrillation to start if a person is in contact with the casing at the time. This time and the current rating in turn set a maximum earth resistance permissible. To provide supplementary protection against high-impedance faults it is common to recommend a residual-current device (RCD) also known as a residual current circuit breaker (RCCB), ground fault circuit interrupter (GFCI), or residual current operated circuit-breaker with integral over-current protection (RCBO), which will cut off the supply of electricity to the appliance if the currents in the two poles of the supply are not equal and opposite [22].

3.12.1.2 Class II equipment

A Class II or double insulated electrical is one which has been designed in such a way that it does not require a safety connection to electrical earth (ground).The basic requirement is that no single failure can result in dangerous voltage becoming exposed so that it might cause an electric shock and that this is achieved without relying on an earthed metal casing. This is usually achieved at least in part by having two layers of insulating material surrounding live parts or by using reinforced insulation.

In Europe, a double insulated appliance must be labelled Class II, double insulated, or bear the double insulation symbol (a square inside another square).

Insulated AC/DC power supplies (such as cell-phone chargers) are typically designated as Class II, meaning that the DC output wires are isolated from the AC input. The designation "Class II" should not be confused with the designation "Class 2", as the latter is unrelated to insulation (it originates from standard UL 1310, setting limits on maximum output voltage/current/power).Concentric squares illustrating double insulation as shown figure 3.9.

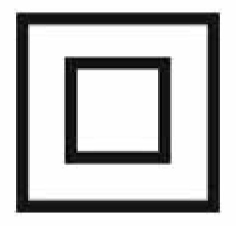


Figure 3.9: Symbol for class II equipment [22].

3.12.1.3 Class III equipment

A Class III appliance is designed to be supplied from a separated/safety extra-low voltage (SELV) power source. The voltage from a SELV supply is low enough that under normal conditions a person can safely come into contact with it without risk of electrical shock. The extra safety features built into Class I and Class II appliances are therefore not required. For medical devices, compliance with Class III is *not* considered sufficient protection, and further more-stringent regulations apply to such equipment [22].

3.12.2 Types of equipment

IEC 60601-1 uses the term applied part to refer to the part of the medical device which comes into physical contact with the patient in order for the device to carry out its intended function.

Applied parts are classified as Type B, Type BF or Type CF according to the nature of the device and the type of contact. Each classification has differing requirements from the point of view of protection against electrical shock. Type B applied parts may be connected to earth, while Type BF and CF are 'floating' and must be separated from earth.

3.12.2.1 Type B (Non-cardiac grounded, Applied Part) equipment

Type B is the least stringent classification, and is used for applied parts that are generally not conductive and can be immediately released from the patient.

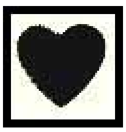
3.12.2.2 Type BF (Non-cardiac floating, Applied Part) equipment:

Type BF is less stringent than CF, and is generally for devices that have conductive contact with the patient, or having medium or long term contact with the patient.

3.12.2.3 Type CF (Cardiac floating, Applied Part) equipment:

Type CF is the most stringent classification, being required for those applications where the applied part is in direct conductive contact with the heart or other applications as considered necessary. Table 3.1show the symbols and definitions for each type classification of medical electrical equipment. All medical electrical equipment should be marked by the manufacturer with one of the type symbols above.

Table 3.1: Medical electrical equipment types [22].

Type	Symbol	Definition
B		Equipment providing a particular degree of protection against electric shock, particularly regarding allowable leakage currents and reliability of the protective earth connection (if present).
BF		As type B but with isolated or floating (F - type) applied part or parts.
CF		Equipment providing a higher degree of protection against electric shock than type BF, particularly with regard to allowable leakage currents, and having floating applied parts.

3.13 Medical locations

The IEC 60346-7 classifies medical locations use as follows:

3.13.1 Group 0 locations:

Group 0 rooms medical location where no applied parts are intended to be used. These include outpatients departments and massage rooms where electro medical devices are not used;

3.13.2 Group 1 locations

Group 1 rooms medical location where applied parts are intended to be used externally or invasively to any part of the body, except for the cardiac zone. These are rooms where electro medical devices with parts applied externally or also internally to the patient's body - except for the cardiac zone - are used;

3.13.3 Group 2 locations

Group 2 rooms medical location where applied parts are intended to be used in applications such as intracardiac procedures, operating theatres and vital treatment where discontinuity (failure) of the supply can cause danger to life These are premises where electro medical devices with catheters, with conductive fluids or electrodes are applied in the cardiac zone or directly to the patient's heart, with a consequent microshock hazard. Group 2 rooms also include those in which patients undergo vital treatments, such that the lack of power supply may involve a risk to life, as well as operation preparation rooms, surgical plaster rooms or post- operative waking up rooms for patients who have undergone general anaesthesia.

Electrical power systems in the healthcare facilities:

3.14.1 Grounded power system

Grounded power systems are used when a location is not classified as a wet procedure location. In this system there is a common ground. There is a high current threshold at the circuit breaker for interrupting power in the event of an electrical short or fault condition to a low impedance pathway. Connecting a low impedance pathway from the hot conductor at 120 VAC to the ground conductor will allow heavy current to flow. If this current passes through person, a macroshock can occur [20].

3.14.2 Isolated power system (IPS)

Even installing a good separate grounding system for each patient cannot prevent possibly hazardous voltages that can result from ground faults. Aground fault is a short circuit between the hot conductor and ground that injects large currents into the grounding system. These high-current ground faults are rare, and usually the circuit breakers open quickly. If the center tap of the step-down transformer were not grounded, then very little current could flow, even if a short circuit to ground developed. So long as both power conductors are isolated from ground, a single ground fault will not allow the large currents that cause hazardous potentials between conductive surfaces.

Isolation of both conductors from ground is commonly achieved with an isolation transformer. A typical isolated-power system is shown in Figure (3.10). In isolated system such as this, if a single ground fault from either conductor to ground occurs, the system simply reverts to a normal grounded system. A second fault from the other conductor to ground is then required to get large currents in the grounds [23].

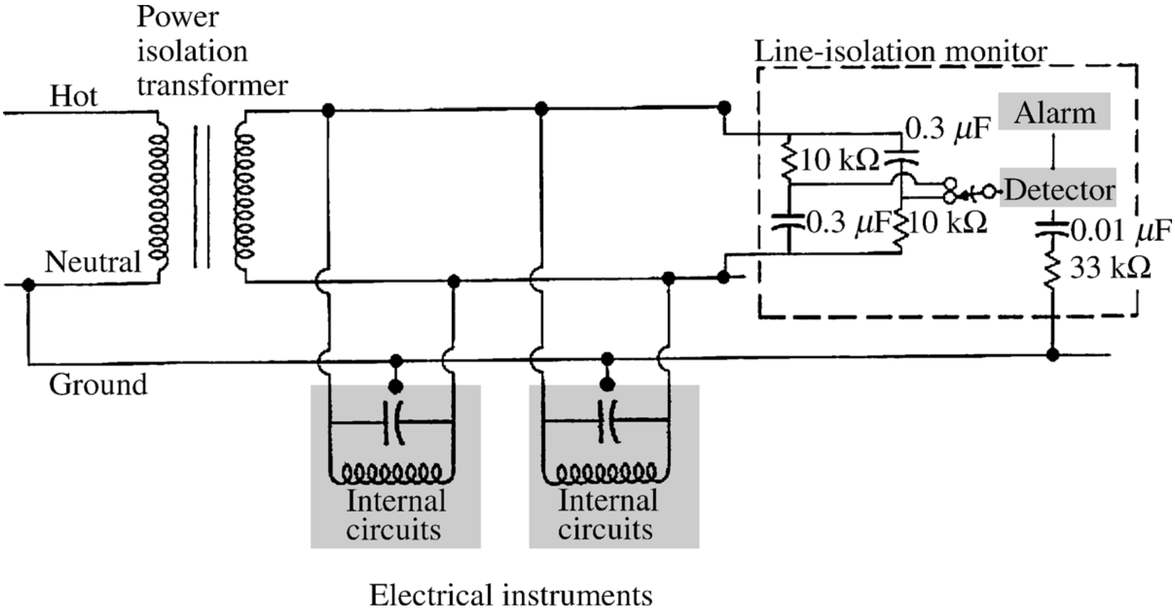


Figure 3.10: Power-isolation-transformer system with a line-isolation monitorto detect ground faults [23].

A continually operating line-isolation monitor (LIM) (also called a dynamic ground detector) must be used with isolation transformers to detect the occurrence of the first fault from either conductor to ground. This monitor alternately measures the total possible resistive and capacitive leakage current (total hazard current) that would flow through a low impedance if it were connected between either isolated conductor or ground. When the total hazard current exceeds 3.7 to 5.0 mA for normal line voltage, a red light and an audible alarm are activated. The LIM itself has a monitor hazard current of 1 mA. This makes the allowed fault total hazard current for all appliances served by the transformer somewhat less than 5 mA.

The kinds of corrective action that should be taken when the alarm goes off must be explained to medical personnel so that they do not overreact. The periodic switching in some line-isolation monitors produces transients that can interfere with monitoring of low-level physiological signals (ECG and EEG) and give erroneous heart rates. Or it can trigger synchronized defibrillators and aortic-balloon assist pumps during the wrong phase of the patient's heart cycle.

Some LIMs avoid these problems by using continuous two-channel circuitry instead of measuring the total hazard current by switching between each line and ground.

Isolated-power systems were originally introduced to prevent sparks from coming into contact with flammable anaesthetics such as ether. The NEC requires isolated-power systems only in those operating rooms and other locations where flammable anaesthetics are used or stored.

3.14.3 Uninterruptable power supply (UPS)

Unexpected power disruption could cause injuries, fatalities, serious business disruption or data loss. UPS units range in size from units designed to protect a single computer without a video monitor (around 200 VA rating) to large units powering entire data centers or buildings. The world's largest UPS, the 46 MW, Battery Electric Storage System (BESS) [24].

3.14.4 Emergency power supply system (EPSS)

Article 517 of the 2006 National Electrical Code specifies the emergency electric system required for health-care facilities. An emergency system is required that automatically restores power to specified areas within 10 s after interruption of the normal source. The emergency system may consist of two parts: (1) the life-safety branch (illumination, alarm, and alerting equipment) and (2) the critical branch (lighting and receptacles in critical patient-care areas) [23].

3.14.5 Ground-fault circuit interrupts (GFCIs)

Ground-fault circuit interrupters disconnect the source of electric power when a ground fault greater than about 6 mA occurs. In electric equipment that has negligible leakage current, the current in the hot conductor is equal to the current in the neutral conductor. The GFCI senses the difference between these two currents and interrupts power when this difference, which must be flowing to ground somewhere, exceeds the fixed rating. The devices make no distinction among paths the current takes to ground: That path may be via the ground wire or through a person to ground (Figure 3.10).

Most GFCIs use a differential transformer and solid-state circuitry, as shown in Figure 3.11(a). The trip time for the GFCI varies inversely with the magnitude of the ground-fault current, as shown in Figure 3.11(b). The GFCI is used with conventional three-wire grounded power-distribution systems. When power is interrupted by a GFCI, the manual reset button on the GFCI must be pushed to restore power. Most GFCIs have a momentary push button that creates a safe ground fault to test the interrupter [25].

3.15 Reliable grounding for equipment

Most failures of equipment grounds occur either at the ground contact of the receptacle or in the plug and cable leading to the line-powered equipment. Hospital-grade receptacles and plugs and ‘‘Hard Service’’ (SO, ST, or STO) or ‘‘Junior Hard Service’’ (SJO, SJT, or SJTO) power cords must be used in all patient areas. Molded plugs should be avoided, because surveys have shown that 40% to 85% of these plugs develop invisible breaks within 1 to 10 years of hospital service. Strain-relief devices are recommended both where the cord enters the equipment and at the connection between cord and plug. A convenient cord-storage compartment or device reduces cord damage. Equipment grounds are often deliberately interrupted by improper use of the common three-prong-to-two-prong adapter (cheater adapter).

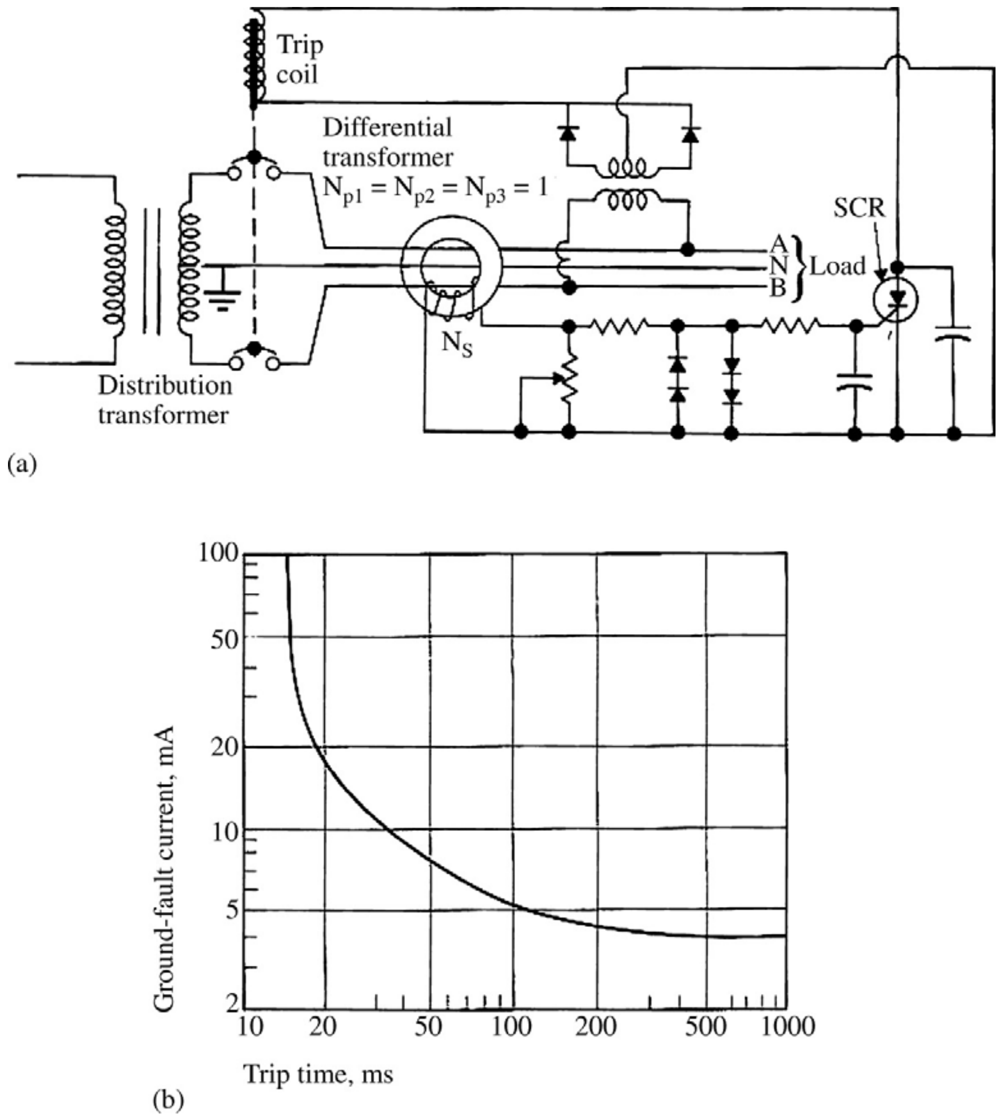


Figure 3.11: Ground-fault circuit interrupters (a) Schematic diagram of asolid-state (three-wire, two-pole, 6 mA) GFCI. (b) Ground-fault currentversus trip time for a GFCI[26].

3.16 Power line colour codes

Wiring for AC and DC power distribution branch circuits are colour coded for identification of individual wires. In some jurisdictions all wire colours are specified in legal documents. In other jurisdictions, only a few conductor colours are so codified. In that case, local custom dictates the “optional” wire colours [27].

IEC, AC: Most of Europe abides by IEC (International Electro technical Commission) wiring colour codes for AC branch circuits. These are listed in Table 3.2. The older colour codes in the table reflect the previous style which did not account for proper phase rotation. The protective ground wire (listed as green-yellow) is green with yellow stripe.

Table 3.2: IEC (most of Europe) AC power circuit wiring colour codes [27].

Function	Label	Colour, IEC	Colour, old IEC
Protective earth	PE	green-yellow	green-yellow
Neutral	N	Blue	Blue
Line, single phase	L	Brown	brown or black
Line, 3-phase	L1	Brown	brown or black
Line, 3-phase	L2	Black	brown or black
Line, 3-phase	L3	Grey	brown or black

UK, AC: The United Kingdom now follows the IEC AC wiring colour codes. Table below lists these along with the obsolete domestic colour codes. For adding new coloured wiring to existing old coloured wiring see Cook. [PCk]

Table 3.3: UK AC power circuit wiring colour codes [27].

Function	label	Colour, IEC	Old UK colour
Protective earth	PE	green-yellow	green-yellow
Neutral	N	Blue	Black
Line, single phase	L	Brown	Red
Line, 3-phase	L1	Brown	Red
Line, 3-phase	L2	Black	Yellow
Line, 3-phase	L3	Grey	Blue

US, AC :The US National Electrical Code only mandates white (or grey) for the neutral power conductor and bare copper, green, or green with yellow stripe for the protective ground. In principle any other colours except these may be used for the power conductors. The colours adopted as local practice are shown in Table below. Black, red, and blue are used for 208 VAC three-phase; brown, orange and yellow are used for 480 VAC. Conductors larger than #6 AWG are only available in black and are colour taped at the ends.

Table3.4: US AC power circuit wiring colour codes [27].

Function	**label**	**Colour, common**	**Colour, alternative**
Protective ground	PG	bare, green, or green-yellow	Green
Neutral	N	White	Grey
Line, single phase	L	black or red (2nd hot)	
Line, 3-phase	L1	Black	Brown
Line, 3-phase	L2	Red	Orange
Line, 3-phase	L3	Blue	Yellow

Canada: Canadian wiring is governed by the CEC (Canadian Electric Code). See Table below. The protective ground is green or green with yellow stripe. The neutral is white; the hot (live or active) single phase wires are black, and red in the case of a second active. Three-phase lines are red, black, and blue.

Table3.5: Canada AC power circuit wiring colour codes [27].

Function	**label**	**Colour, common**
Protective ground	PG	green or green-yellow
Neutral	N	White
Line, single phase	L	black or red (2nd hot)
Line, 3-phase	L1	Red
Line, 3-phase	L2	Black
Line, 3-phase	L3	Blue

IEC, DC: DC power installations, for example, solar power and computer data centers, use colour coding which follows the AC standards. The IEC colour standard for DC power cables is listed in Table below, adapted from Table 2, Cook. [PCk]

Table3.6: IEC DC power circuit wiring colour codes [27].

Function	**Label**	**Colour**
Protective earth	PE	green-yellow
2-wire unearthed DC Power System		
Positive	L+	Brown
Negative	L-	Grey
2-wire earthed DC Power System		
Positive (of a negative earthed) circuit	L+	Brown
Negative (of a negative earthed) circuit	M	Blue
Positive (of a positive earthed) circuit	M	Blue
Negative (of a positive earthed) circuit	L-	Grey
3-wire earthed DC Power System		
Positive	L+	Brown
Mid-wire	M	Blue
Negative	L-	Grey

US DC power: The US National Electrical Code (for both AC and DC) mandates that the grounded neutral conductor of a power system be white or grey. The protective ground must be bare, green or green-yellow striped. Hot (active) wires may be any other colours except these. However, common practice (per local electrical inspectors) is for the first hot (live or active) wire to be black and the second hot to be red. The recommendations in Table below are by Wiles. [JWi] He makes no recommendation for ungrounded power system colours. Usage of the ungrounded system is discouraged for safety. However, red (+) and black (-) follows the colouring of the grounded systems in the table.

Table3.7: US recommended DC power circuit wiring colour codes [27].

Function	label	Colour
Protective ground	PG	bare, green, or green-yellow
2-wire ungrounded DC Power System		
Positive	L+	no recommendation (red)
Negative	L-	no recommendation (black)
2-wire grounded DC Power System		
Positive (of a negative grounded) circuit	L+	Red
Negative (of a negative grounded) circuit	N	White
Positive (of a positive grounded) circuit	N	White
Negative (of a positive grounded) circuit	L-	Black
3-wire grounded DC Power System		
Positive	L+	Red
Mid-wire (center tap)	N	White
Negative	L-	Black

3.17 Grounding system

Low-resistance grounds that can carry currents up to circuit-breaker ratings are clearly essential for protecting patients against both macroshock and microshock, even when an isolated-power system is used. Grounding is equally significant in preventing microshock (see Figure 3.3). A grounding system protects patients by keeping all conductive surfaces and receptacle grounds in the patient's environment at the same potential. It also protects the patient from ground faults at other locations [18].

The grounding system has a patient-equipment grounding point, a reference grounding point, and connections. The patient equipment grounding point is connected individually to all receptacle grounds, metal beds, metal door and window frames, water pipes, and any other conductive surface. These connections should not exceed 0.15 V. The difference in potential between receptacle grounds and conductive surfaces should not exceed 40 mV. Each patient-equipment grounding point must be connected individually to a reference grounding point that is in turn connected to the building service ground.

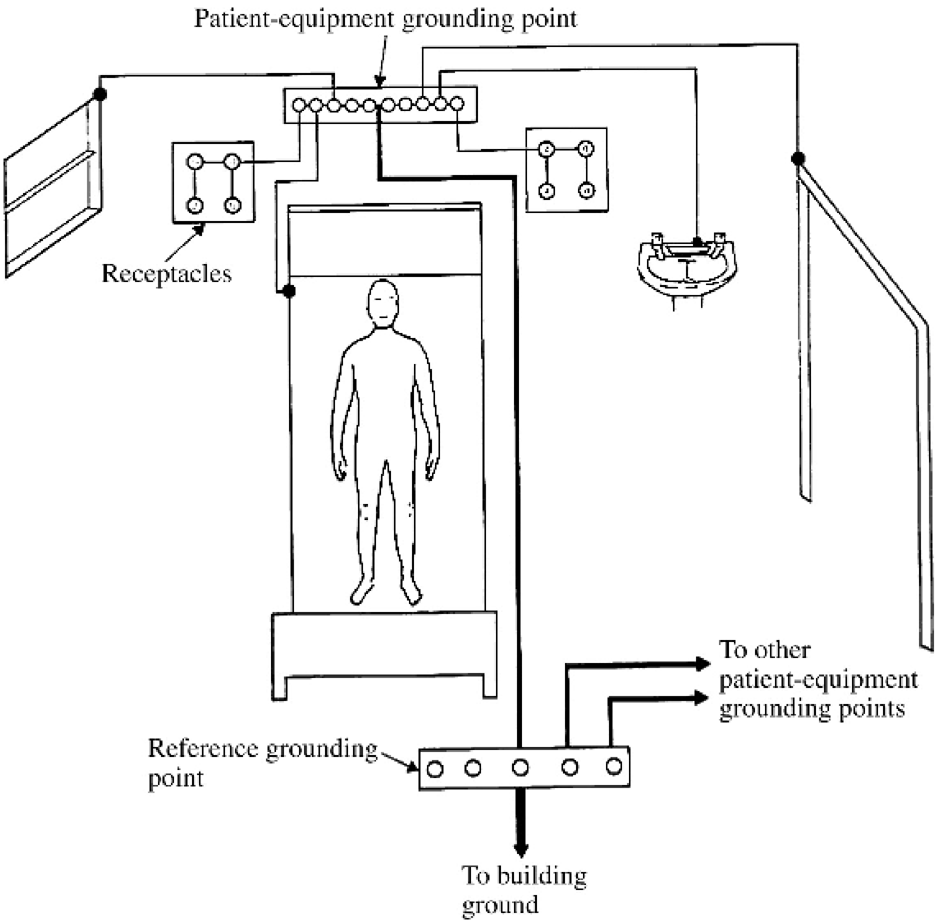


Figure 3.12: Grounding system all the receptacle grounds and conductive surfaces in the vicinity of the patient are connected to the patient-equipment grounding point. Each patient-equipment grounding point is connected to the reference grounding point that makes a single connection to the building ground [18].

3.18 Functional earth

Functional earthing systems are a method used to provide a zero reference point or a signalling path for communications equipment. A functional earth does not strictly provide any protection against electric shock or danger. The functional earth conductor may be connected directly or indirectly to the main earthing terminal (MET) in an installation where earth currents flow due to the normal function of load equipment [28].

3.19 Monitored earthing systems

Where it is assessed that a high degree of earth integrity is required, an earth monitoring system provides a means of maintaining a high degree of confidence in the impedance level of the protective conductor from the monitoring unit to the remote protected equipment. The monitoring unit may be connected between the source of energy (if accessible) and the equipment to be protected. The source of energy may be, for example, a generator or a transformer. It is therefore essential that any plug, socket and flexible cable provide not only the main protective path but also a return path, which is usually known as the pilot conductor [28].

3.20 Ground resistance

While many factors come into play in determining the overall effectiveness of the grounding system, the resistance of the earth itself (earth resistivity) can significantly impact the overall impedance of the grounding system. Several factors, such as moisture content, mineral content, soil type, soil contaminants, etc., determine the overall resistivity of the earth. In general, the higher the soil moisture content, the lower the soil's resistivity. Systems designed for areas which typically have very dry soil and arid climates may need to use enhancement materials or other means to achieve lower soil resistivity [2].

CHAPTER FOUR

Research Methodology

Study type

The study type is: across sectional hospital-based study.

This study has three stages as illustrated in the following block diagram:

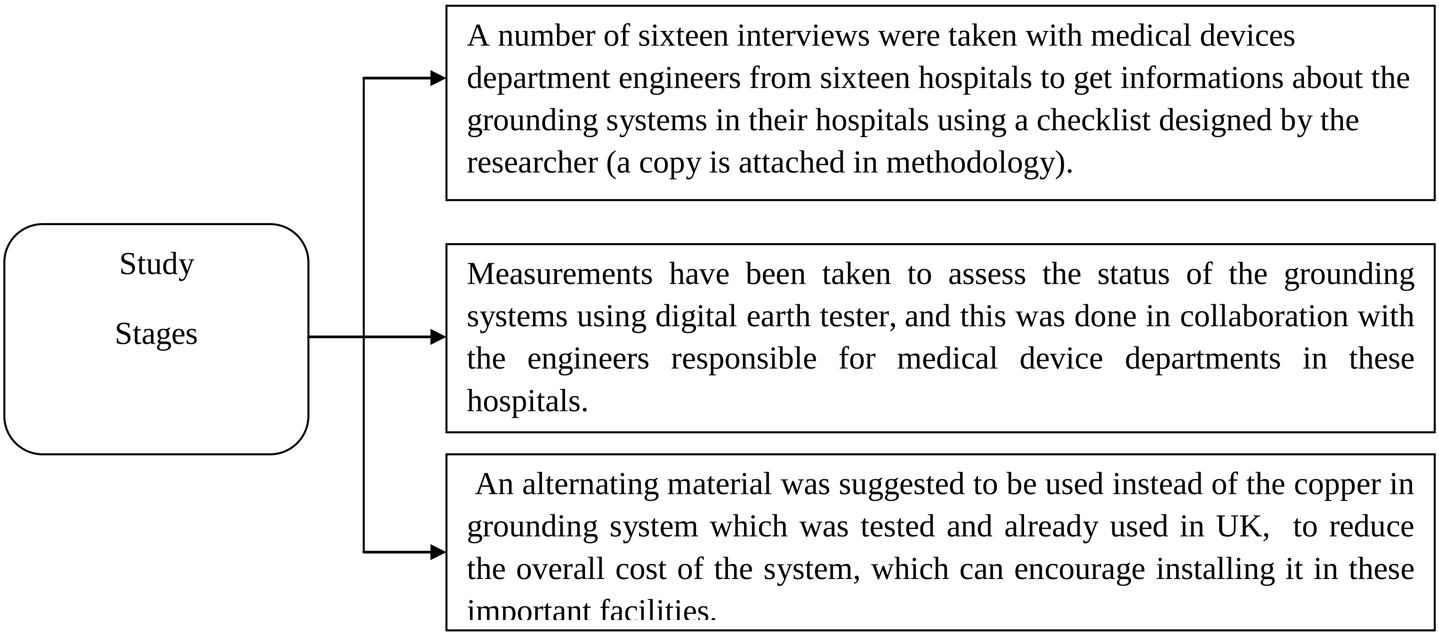


Figure 4.1: explanation block diagram for the research stages

Study area

The study will be carried out in sixteen of public and private hospitals in Khartoum state.

Study population

A number of public and private hospitals were selected randomly from all hospitals in Khartoum state. A statistical formula for determining an appropriate sample size was used in determining the study units and the selection was done randomly.

The study duration

The study was conducted during the period (from JUN 2013 to MAY 2014).

Data collection

The interviews were targeted biomedical engineers from medical device departments in those hospitals; the informations have been gotten about the current situation of grounding systems and the reasons that obstacle installing these systems in these important healthcare facilities. After that informations obtained were analyzed using SPSS.

The visual inspections were taken in seven hospitals to validate informations that obtained in interviews. The measurements were taken using digital earth tester which has a three poles, One of the poles of the device has been connected with the grounding rod, and the second one is connected to steel rod which installed inside the ground at five meters from the grounding system rod, and the third one also been connected with a rod of steel and then installed it at ten meters from the grounding rod and then measurements have been taken, see figure (5.3).

Data analysis

Data was analyzed using SPSS. SPSS is a Windows based program that can be used to perform data entry and analysis and to create tables and graphs. SPSS is capable of handling large amounts of data and can perform all of the analyses covered in the text and much more.

Questionnaire

1. Serial number ☐☐
2. Gender

   Male =1
   Female=2 ☐

3. Age (years) ☐☐
4. Years of experience: ☐☐
5. Earthing system:

Present = 1
Absent = 2 ☐

A. If present , does it provide all hospital needs?
   Yes = 1
   No =2 ☐

B. If present, has it been made according to the standards?
   Yes = 1
   No =2 ☐

C. If absent , mention the reasons:

Cost	Yes	☐	No	☐
Not important	Yes	☐	No	☐
The building is not allowed introducing this system	Yes	☐	No	☐
Administration's limited knowledge	Yes	☐	No	☐
Engineering limited knowledge	Yes	☐	No	☐

Others ____

6. Has anyone suggestion using it at the hospital before?

   Yes = 1
   No = 2 ☐

7. If it has been established,

   A. Do you think it will be critically important?

      Yes = 1
      No = 2 ☐

B. And what are the benefits of having it in use?

Equipment accuracy and safety?

Yes = 1

No = 2 ☐

Patient and operator safety?

Yes =1

No = 2 ☐

Others: ______________________________

8. Have there been any in convince or damage caused by the absence of it?

Yes = 1

No = 2 ☐

If (yes), mentioned?

Equipment related damage?

Yes = 1

No = 2 ☐

Patient or operator related injury?

Yes = 1

No = 2 ☐

Causing any types of fires accident?

Yes = 1

No = 2 ☐

Others: ______________________________

____

9. Do you have any suggestions?

Yes = 1

No = 2 ☐

If (yes), mention it ? ______________________________

____

____

____

Thank you for your cooperation ☺

CHAPTER FIVE

Results and Discussion

This research has been approached through across sectional hospital-based study, its main objective is to assess the presence of implementation of earthing system in healthcare facilities, the study passes through three stages as follow:

5.1 Stage one: The observations of the researcher during the visual inspections

5.1.1 The first case

The grounding system was not established with the hospital's opening, it was established later when the operators noticed that there is interference in most signal devices and another problems in imaging department. Hospital engineers established the earthing system just for some areas not for all hospital.

The measurements were taken as follows:

- First the rode were separated from the ground wire
- The rode have been set at a distance of 10 meters and the other after 6 meters.
- Only one point has been read from the device as follows: 2.8 Ω.

The challenges faced the measuring process:

- All points must be in wells.
- External grounding cables (subject to cut and tempering).
- Could not read from the other point to the difficulty of isolating the grounding cable from the radiology equipment.

5.1.2 The second case

The hospital has a full grounding system that was designed in a good way, but it is very old and was designed by the founder of the hospital. However, there were few observations:

Figure 5.1: image showed the earth terminal box which contains the main grounding terminal in case two hospital captured by researcher camera.

- The grounding points was unreachable ,which means that there was no checkpoint to refer to at any time.
- A lot of paving have been done (sidewalks, asphalt and umbrellas) and some checkpoints (grounding wells) were mixed with the sewage wells, so there is no longer any clear checkpoint that enables the proper measurements.

Figure5.2: image showed one of the inspection points of the earthing system which is mixed with the sewage in case two hospital.

- The readings were obtained from the test points only after baring part of the main grounding cable which is shown in figure 5.3 and the reading was as follow:

Total earth pits: 0.22Ω

Figure 5.3: image showed reading of the check point after baring part of the main grounding cable using digital earth tester. One of the poles of the device has been connected with the grounding rod system, and the second is connected to a rod of steel was installed inside the ground just 5 meters from the ground rod, and the

third also been connected with a rod of steel and then install it on just 10 meters from the ground rod.

Figure 5.4: image showed the earth terminal box which contains the main grounding terminal which connected to digital earth tester pole.

After that one pole of the measurements device was connected with the cable after baring it, and another pole at a distance of 6 meters and 10 meters away from the main well, so as shown in figure 5.5 and 5.6:

Figure 5.5: image showed the two poles of the digital earth tester that used to measure the earth resistance;

The red pole(on the left) at a distance of 5 meters from the main earth terminal and the yellow pole at 10 meters away from the main terminal earth.

Figure 5.6: image showed the green pole of the measurement device which connected to the main earth terminal in case two hospital.

(Note: this is an ideal reading, but it cannot be reliable ,so that when any malfunction happen we cannot determine the point that is the source of malfunction, and sometimes the problem is in one of the grounding points in this case the total reading is excellent, but still there is a problem).

5.1.3 The third case

- The hospital was established in the seventies of the last century, and since that time there has not been any follow-up process or periodic maintenance for the grounding system, because all officials now do not know the exact locations of the grounding points, not even whether the system works or not so far due to the loss of hospital documentation (or whatever reasons they gave you).
- Healthcare specialists who work in the neurology department have noticed the inaccuracy of the section devices, which indicates the presence of electrical interference, since the electrical graphic devices are generally of very high

sensitivity. As a result, officials' medical engineers connected grounding to the devices using only the main beam of the building. Nevertheless, the rest of the buildings do not contain grounding system.

- There were no checkpoints, so the reading was taken from the cable that was connected to the devices as follows:

. 0.2Ω - 0.3Ω

5.1.4 The forth case

the hospital is very large but does not contain any perfect grounding system, it has recently been established a grounding system one particular for the radiology department (created after the emergence of electrical problems in the department devices, and has been created by the hospital engineering alone and without the help of any competent bodies, and later a processes of continuous construction have limited accessibility to any measuring point).

The other grounding system was in the hospital was designed particularly for the Surgery Department (created by a competent company, but there was no follow-up by the officials engineers and no available descriptive maps for it, and therefore also we were not able to find the grounding system and the measurement process was not applicable.

5.1.5 The fifth case

- There is a grounding system since the establishment of the hospital.
- There is grounding for each section separately.
- There are no clear checkpoints (all points are buried at far depth from the earth's surface) so the measurement was taken from the main earthing cable and nutritious for all the building, as shown Figure 5.7:
- Officials claimed that a follow-up process and periodic measurement are made annually according to specific schedule by a competent company.

Figure 5.7: the image showed connecting digital earth tester pole (green pole) to the main earthing terminal in case five hospital.

The system is divided into four points, but two of them were inaccessible and only two points have been measured as follows:

Earth pit no 1: 0.12Ω

Figure 5.8: image showed the resistance earth read using digital earth tester in the fifth case.

And:

Earth pit no 2: 0.25Ω

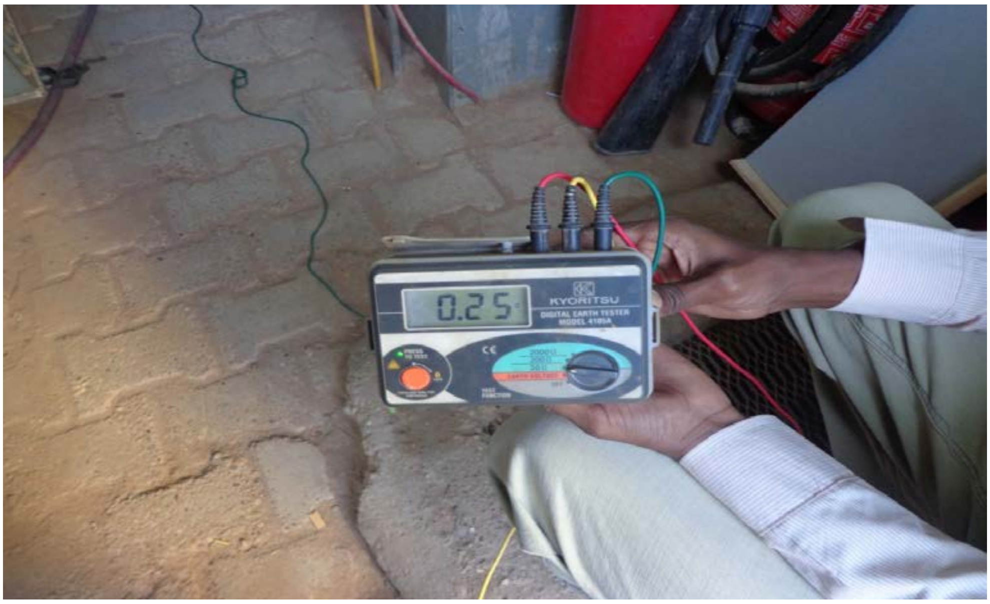


Figure 5.9: the image showed another reading for earth resistance from another point using digital earth tester.

Notice:

The Resistance of each point separately is good, but comprehensive judgment of the system is not applicable due the inability to access to the rest of the points. When the main Rod is inaccessible, the Ground inside it is being bared and then connected with one of the devices poles.

5.1.6 The sixth case

The official engineers (electrical engineers and medical engineers) were unable to identify the location of the grounding system, since worker who had thesis information has resigned and is now out of the country. They could only confirm the existence of the system somewhere.

5.1.7 The seventh case

- The building is very huge and has many sections and a large number of devices, and in spite of that, there is one main point for all the building.

- The soil has been treated and two Rod and two plate have been used in order to get proper reading.
- The pole of the grounding measuring device is connected with the wire that entering the grounding point, and that after baring the wire (for lack of a checkpoint) the reading was:

Figure 5.10: the image showed the earthing resistance read which was taken using digital earth tester in the seventh case.

Findings summary:

Although the readings were within limits, but it is considered inadequate and non-ideal, some devices are very sensitive to electrical interference (such as electrical graphic devices in general).

Lack of geometric map for the system and relying on the testimony of employees only is unacceptable.

The existence of a single grounding point of a building of this size also considered unacceptable.

Table 5.1: description of the hospitals visual inspection for grounding system.

Q1: Is it proper or not

Q2: Is it enough for all hospital or not

Q3: Facing problem in measuring or not

G: Governmental

P: Private

N	Case No	Location	Type	Presence of Grounding System	Q1	Q2	Q3
1	**first case**	Khartoum-arkweet	G	Presence	Not	Not	Yes
2	**Second case**	Khartoum-alamarat	G	Presence	Not	Yes	Yes
3	**Third case**	Khartoum-Soba	G	presence but not active now	Not	Not	Yes
4	**Forth case**	Khartoum-Khartoum	G	Absence	Not	-	Yes
5	**fifth case**	Khartoum-Khartoum	P	Presence	Not	Not	Yes
6	**sixth case**	Bahri	P	Presence	Not	Not	Yes
7	**Seventh case**	Khartoum-Khartoum	P	Absence	Not	-	Yes

Stage two: the cross sectional hospital based-study (the interviews)

This is across sectional hospital-study, where a number of public hospitals (16) were selected, 3 hospitals from Khartoum state and the others from different states. A number of 16 biomedical engineers (one engineer for each hospital) were randomly selected to constitute the study subjects. All study subjects were personally interviewed. Also a data collection sheet (DCS) was used in the collection of the required data. After being properly reviewed, the collected data were then classified, interpreted and presented in the following sequence:

Classification of the eligible subjects according to their, showed that males and females are equal in number, when they were classified according to their ages, Figure 5.11 indicate:

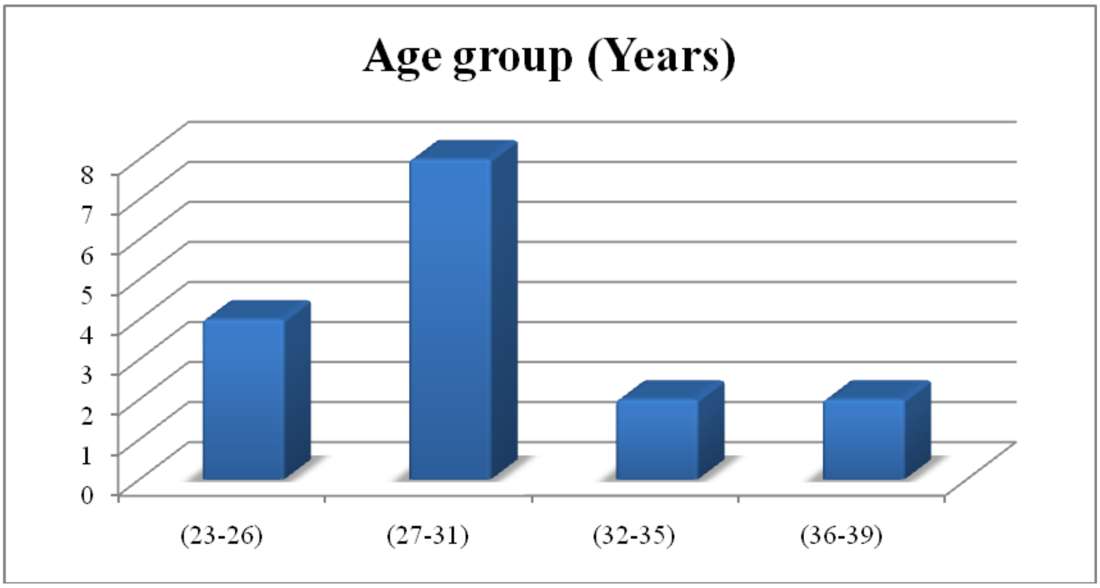


Figure 5.11: Distribution of study sample according to age.

When the participants were classified according to their years of experience, it was found that 8(50%) of them were found to have (1- 3) years of experience, whereas 4(25%) of them were found to have (4-5) years of experience, with an overall average number of years of experience of 4.38 years and standard deviation, as a measure of dispersion of 3 years, figure 5.12 classify more:

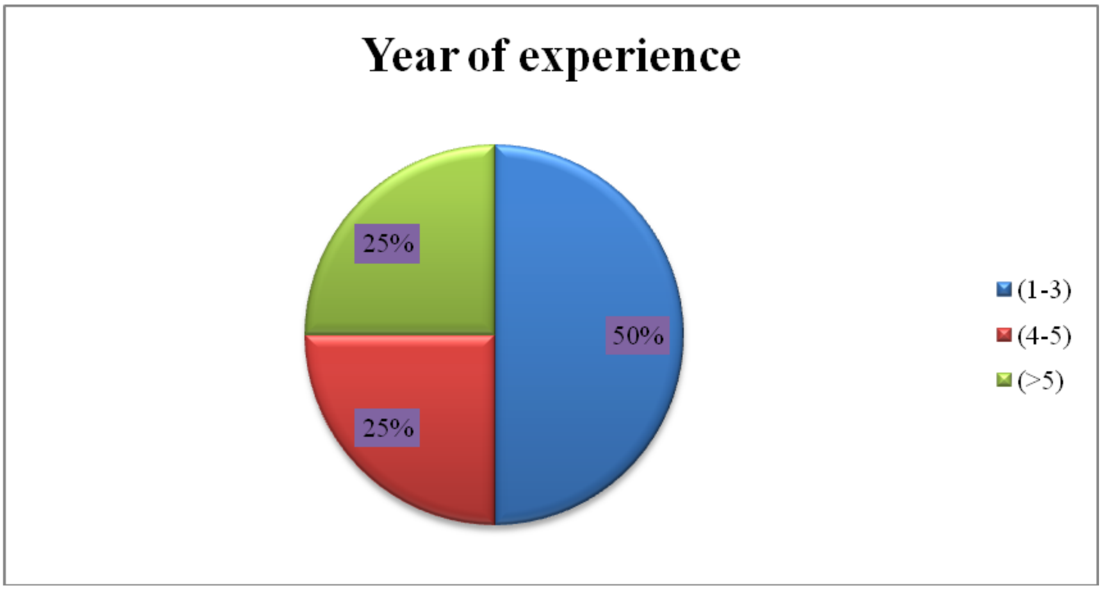


Figure5.12: Distribution of study sample according to Year of experience.

Classification of the hospitals according to the presence or absence of the earthing system, showed that 9(56.2%) of the hospitals were found to have earthing systems, as shown on figure 5.13:

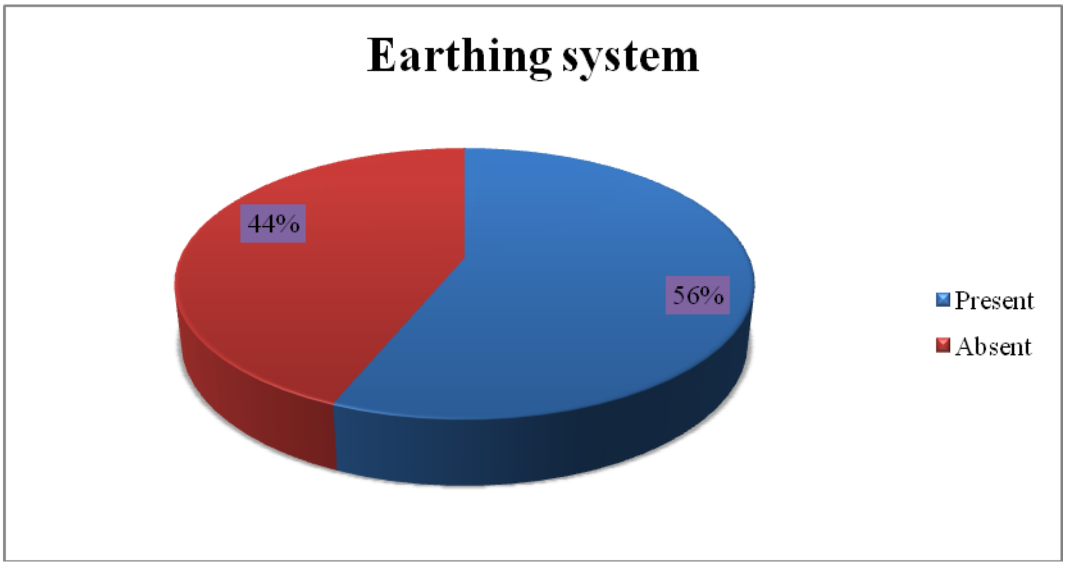


Figure 5.13: Distribution of study sample according to earthing system.

When the participants in the hospitals where earthing systems are available (9), were asked two dichotomous questions (Yes/No questions), their answers came as shown on Figure5.14:

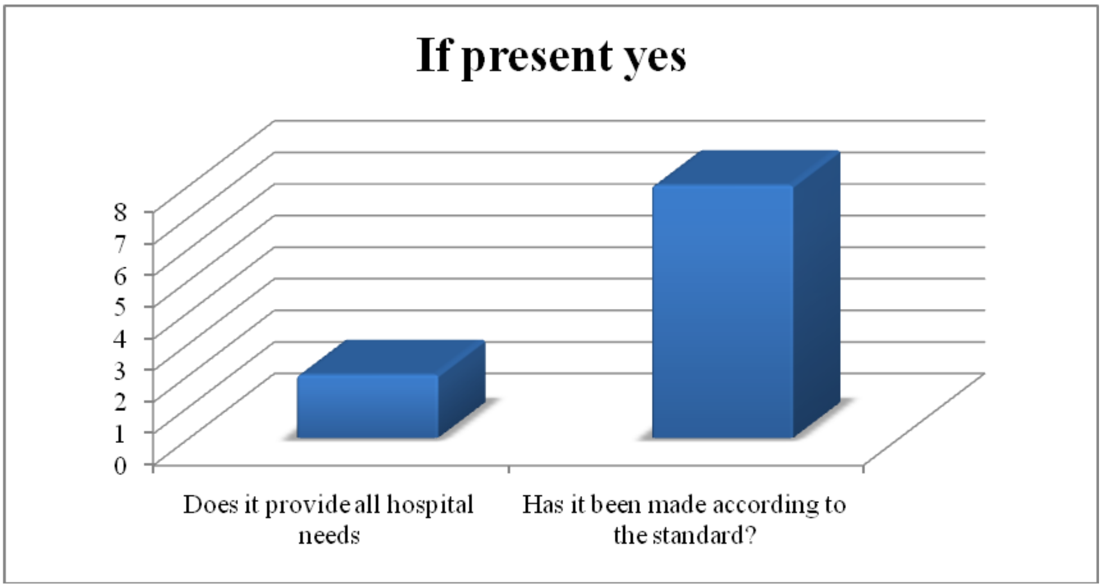


Figure5.14: Frequency of answering Q5 if present among study population.

Referring back to Figure5.14, the following results are obtained:

- 2 out of 9 hospitals (22.2%), with earthing systems, were found to have provided all hospital needs.
- 8 out of 9 hospitals (88.9%), with earthing systems, were found to have been made according to the standard.

When the respondents in those hospitals asked to mention the reasons of absence or improper of these earthing systems in those hospitals, their answers shown on figure 5.15:

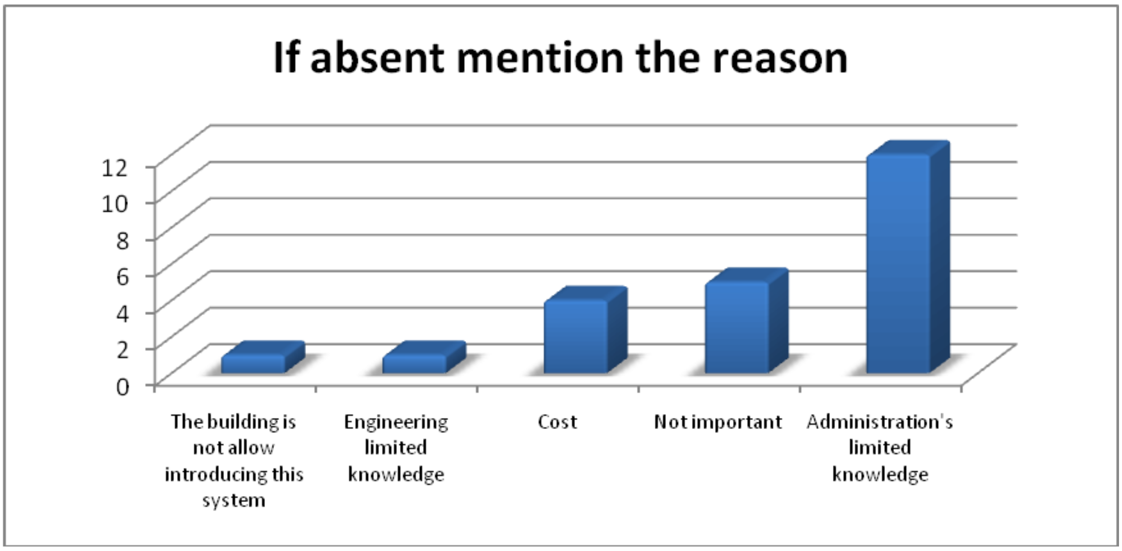


Figure 5.15: Frequency of answering Q5 if absent among study population.

Referring back to answers (reasons) given by the respondent as justification of not have those systems, one could inter that all reasons given were quite convincing and rather justifiable. When they were asked (n=16) if anyone in the hospital happened to have a suggestion of having it before, 10(62.5%) of them said (Yes) and 6(37.5%) of them said (NO), figure 5.16 bellow indicates:

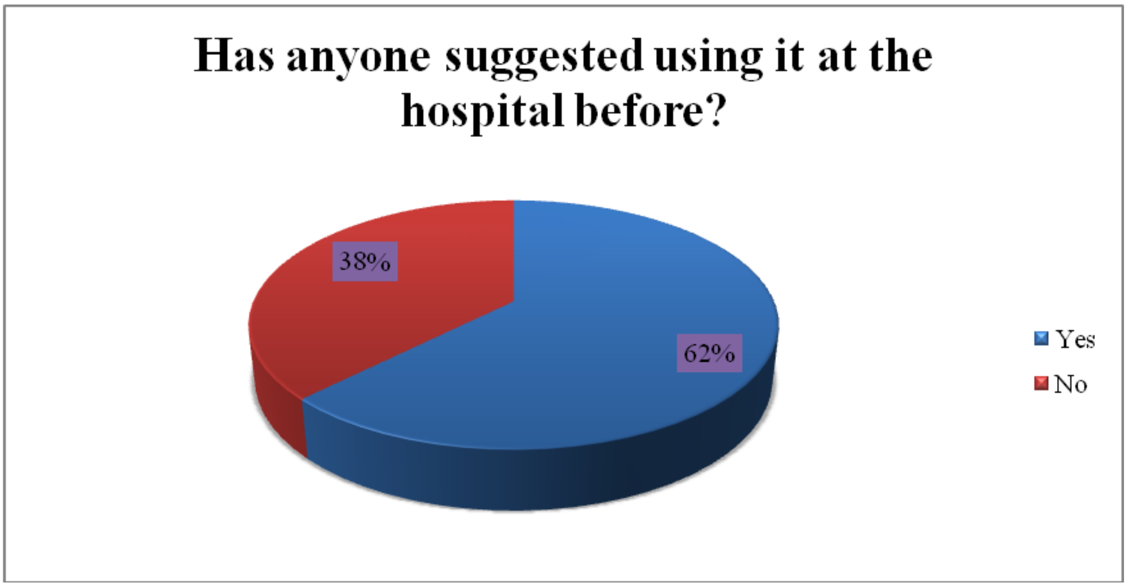


Figure 5.16: Frequency of answering Q6 among study population.

Two direct questions were given to respondent about their opinions in earthing systems were established in those hospitals. The questions came as follows with their answers:

- Do you think that they are critically important, 100% of them said yes.
- What are the benefits of having the system in use, 100% of them said: equipment accuracy and safety, patient and operator safety.

When the participants were asked was there any in convince or damage caused by the absence of earthing system, 13(81.2%) of them said yes, as shown on figure 5.17:

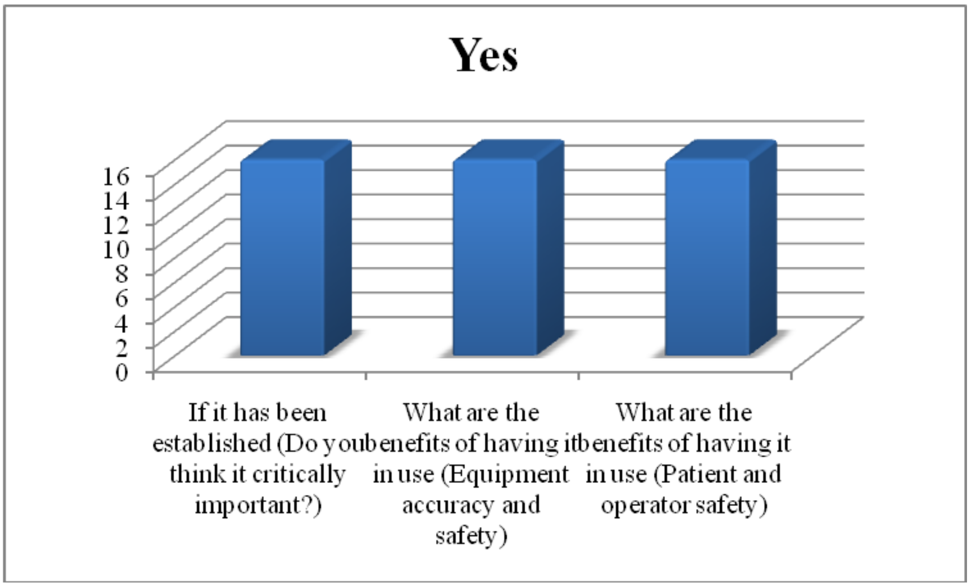


Figure 5.17: Frequency of answering Q7 among study population.

Table 5.2: Frequency of answering Q7 among study population.

Q7-Others
All human been
To avoid artifact in signals
Reduce quantity of instrument healing and shocks
Reduce engineer electrical equipment repairing problems

When those who said that absence of earthing system may cause in convince or damage(13), were asked again what type of in convinces or damages, all of them said equipment related damage, whereas 5(38.5%) of them said it causes type of fires accidents. Table 5.2 and figure 5.18 clarify more:

Table 5.3: Frequency of answering Q8 among study population.

Q8-Have there been any in convinces or damage case by the absence of it?	**Frequency**	**Percent of yes**
Yes	13	81.2%
No	3	18.8%
Total	16	100

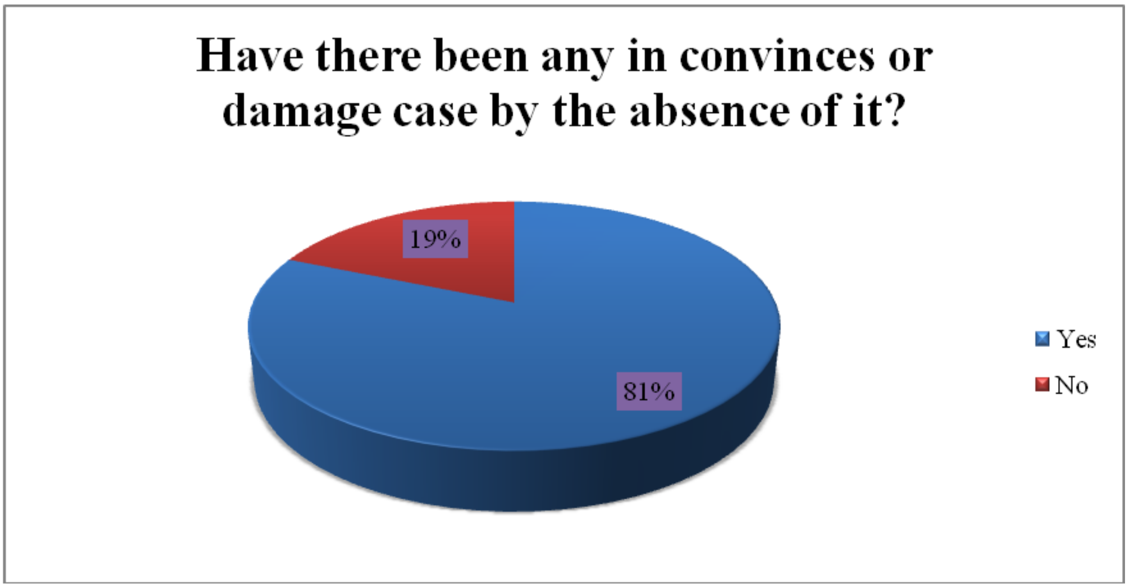


Figure 5.18: Frequency of answering Q8 among study population.

In addition to the answers given by the respondent to the questions of possible in convinces or damage(13), another in convinces were given by respondent, such as problems in the earthing system, electrical shock in equipment, plus many other hazards as shown on figure 5.19:

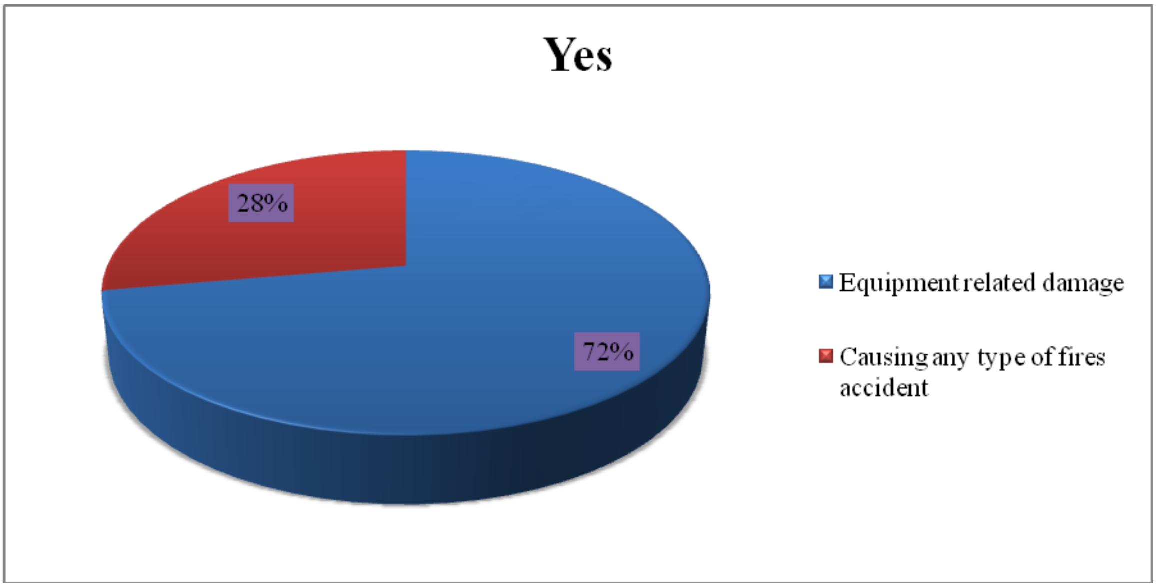


Figure 5.19: Frequency of answering Q8 among study population.

Table 5.4: Frequency of answering Q8 among study population.

Q8-others
problem in the earth system
electrical shock in equipment
all problems till now is fuse damage
may be earth itself bring electrical shock
all the accident in equipment and signals
general electrical problem in all equipment
autoclave equipment in hospital and surgery section were burned

When the respondents were asked if they have suggestion (n=16), 13(81.2%) of them said yes, as represented on figure 5.20:

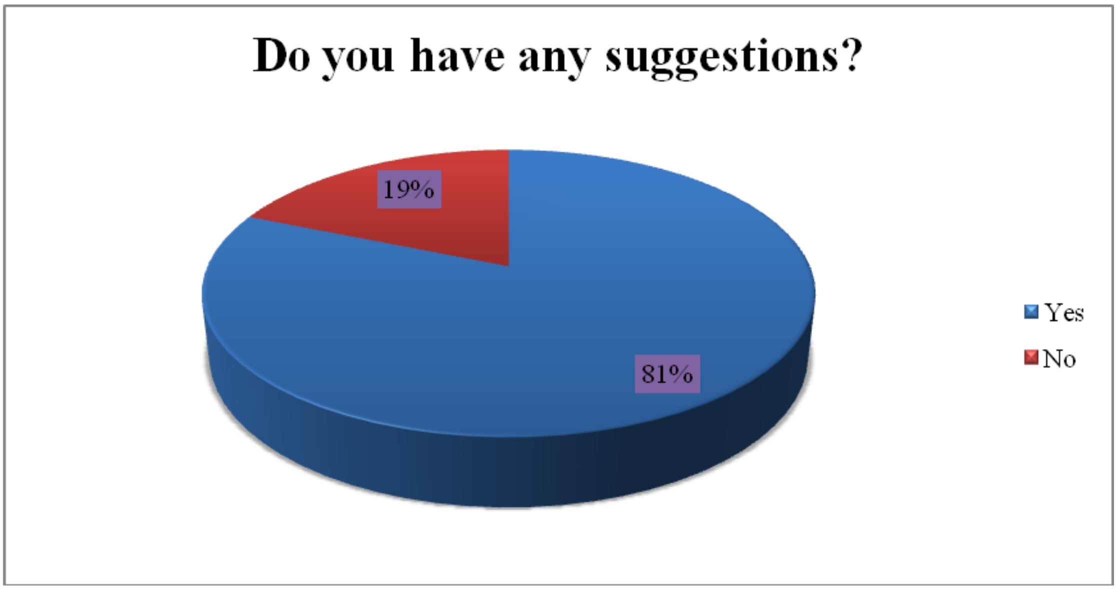


Figure 5.20: Distribution of study sample according to suggestions.

Those who said that they have suggestions (13) were asked to mention those suggestions where they gave a variety of suggestions as shown below:

Table 5.5: Q9 a variety of suggestions

Q9- Suggestions
It must be used stabilizer
It must be entering earth system
Entering earth system just in case of harmful
Complete earthing system in all hospital department
Earthing system most important in all hospital department
Demand of entering earth system in all hospitals department
Must be introducing to each hospitals because of its important
Entering earth system in most important department and generalized to others
It must be stabilized in all hospitals all equipment are expensive than earthing system
I recommend spreading all technician for reappearing electrical problem in all hospital department
Must be introducing earth system since beginning , I suggest to engineer install instrument after installing earth system
I hope it will be percent in all hospitals, tell all people in this filed by the importance of it (engineering and administration)
Generalized earth system in all hospitals because important of earth preventing burn like lead which preventing radiation

The results assembled from this study have given a general idea of the presence and usage of earthing system in some of our hospitals. The required data were collected from responsible relevant personnel of the hospitals under investigation (n=16), the participants were relatively young, varying between 23 to less than 40 years, 56.2% of the hospitals were found to have earthing systems, only 22.2% of the systems were found to have provided all hospital needs, 88.9% of the available earthing systems were found to be made according to the standard. Varieties of reasons were given for the absence earthing systems by the respondents in the 7 hospitals. These reasons revolved around: cost, importance, and the buildings conditions.

Prior suggestions were made for establishing earthing systems by 10(62.5%) of the hospitals. All respondents were found to be aware about the high importance of the systems if they are established. They were also aware of the benefits that will be gained if the systems are established, such as equipment accuracy and safety, patient and operator safety. 13 out of 16 (81.2%) were found to be aware that in the absence of the earthing systems the probability of the occurrence of in convinces or damages is not un expected, such as equipment related damages, fires accidents and patient or operator related damages, plus many other hazards.

Many suggestions were made by more than 80%respondents in regard to the necessary and importance of introducing stabilizer, establishment of earthing systems in all hospitals.

5.2 Stage three: The alternating material which can used instead of the copper

As illustrated in the appendixes, the first Page: Page from British standard special to grounding number BS 7430 determines that the material is it made of grounding rod does not have any effect on the value of the rod's resistance if it is made of copper or aluminium or iron because the resistance is the same.The resistance is very important factor for the selection of the grounding rod material and the other factors remain, the most important of which is the material resistance for corrosion and this has been treated by painting the steel chemically with cooper.

The second page :earthing theory

Shows that the selection of steel column (steel) chemically painted with copper is best suited for the following reasons:

- Excellent resistance to corrosion
- High bearing strength to high electrical currents resulting from electrical faults
- Very low cost compared to the rod is made of copper
  Note: (price of copper rod 150 cm diameter and a length of 16 ml is 800 pounds, while the price of the same rod made of steel and chemically painted with copper is 50 pounds).
- Very high stiffness to bear chiming in solid floors to far depths into the ground, compared with copper, which often do not bear the chiming and can bend.

CHAPTER SIX

6. Conclusions and Recommendations

6.1 Conclusions

Every electrical equipment or appliance must be ‘Earthed’ or ‘Grounded’ for the safety of equipment, network as a whole and operating personnel.

Fault in Grounding directly impacts human safety. Major accidents happen due to improper Earthing. Leakage of current passes through human body and fatality occurs.

Purpose of Earthing in an electric power system is to limit, with respect to the general mass of earth, the potential of current carrying conductors, which are part of the equipment, non-current carrying metal works, associated with the equipment, apparatus and appliances connected to the system.

Earthing plays an important role in Generation, Transmission & Distribution for safe and proper operation of electric system.

Every Earthing should be tested and checked at regular interval so as resistance of Earth connection is minimized. The records should be maintained if Results are poor, action should be taken to improve.

Major Application of Measuring Earth Resistance and Leakage Current:

Earthing wire of Transformer should be properly grounded as the most difficulties occur from the contact between the soil & the stack. If this is poor the flow of electricity is restricted

6.2 Recommendations

Apart from has been achieved from this study, the researcher would like to take this opportunity to submit the following recommendations:

- Important information must be provided about how healthcare facilities and

Medical clinics view power quality problems, how such problems can be recognized by Facility and medical staffs, definitions of the sources of electrical disturbances that can Impact healthcare facilities and medical clinics, and how power quality challenges Might be met in a complex environment where patient safety must prevail above Power quality.

- Recognizing and correcting wiring and grounding errors and the Commingling of loads are paramount in resolving power quality problems in Healthcare facilities and medical clinics, and establishing partnerships between electric Supply companies, facility designers, medical equipment manufacturers, and the Facility and medical staffs is also critical.

- Diagnostic medical imaging systems are ultrasensitive to voltage Disturbances, and many times these systems are not compatible with a UPS or cannot be placed on a power conditioner due to cost and space limitations in imaging suites. The Cost of resolving underlying wiring and grounding errors and separating Disturbance-causing loads from sensitive medical equipment is typically much less than the cost of placing an entire department or facility on conditioned power.

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Appendices

EARTHING

Earthing Theory

Earthing Principles

The correct design and installation of a quality Earthing System will ensure the safety of both people and equipment.

A good earth should have:

- Low electrical resistance (ohms)
- Good corrosion resistance
- Ability to carry high currents repeatedly
- A reliable life of at least 30 years

Soil resistivity is a crucial factor in obtaining a 'good earth.'

Factors Affecting Soil Resistivity

(a) Physical Composition

Different soil compositions give different average resistivities:

Soil	Resistivity Ohm.m
Marshy Ground	2 – 2.7
Loam and Clay	4 – 150
Chalk	60 – 400
Sand	90 – 8000
Peat	200 Upwards
Sandy Gravel	300 – 500
Rock	1000 Upwards

Wherever possible, dry, sandy, rocky ground should be avoided: however, in many installations no choice is available.

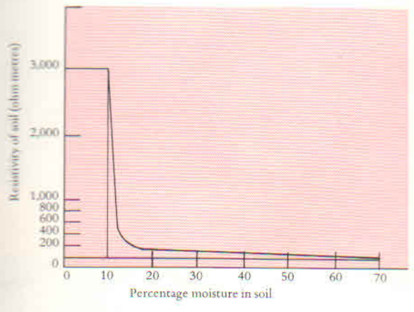
(b) Moisture

Increased moisture content of the ground can rapidly decrease its resistance.

It is especially important to consider moisture content in areas of high seasonal variation in rainfall.

This graph shows how, below 20% moisture content, the resistance of red clay soars. Wherever possible the earth electrode should be installed deep enough to reach the "water table" or "permanent moisture level."

Variation of Soil Resistivity with Moisture Content Red Clay Soil



(c) Chemical Composition

Certain minerals and salts can affect soil resistivity. Their levels can vary with time due to rainfall or flowing water.

Effect of Salt on Resistivity (Sandy loam, Moisture Content 15%)

This table shows the effect of adding salt to sandy loam.

Added Salt (Percentage by weight of moisture)	Resistivity (ohm. m)
0.0	107.0
0.1	18.0
1.0	4.6
5.0	1.9
10.0	1.3
20.0	1.0

(d) Temperature

When the ground becomes frozen, its resistivity rises dramatically. An earth that may be effective during temperate weather may become ineffective in winter.

Earth electrodes should be installed below the frost line to ensure year long performance.

Effect of Temperature on Resistivity (For Sandy Loam, 15.2% moisture)

Temperature C	F	Resistivity Ohm m
20	68	72
10	50	99
0	32 (Water)	138
0	32 (Ice)	300
−5	23	790
−15	14	3,300

Note that if your soil temperature decreases from +20°C to −5°C, the resistivity increases more than ten times.

Selecting the Correct Earth Electrode

We have already shown that by reaching permanent moisture and frost free soil levels, low resistance should be achieved. Often these levels are some metres below the surface and the most economical way of reaching them is by extensible deep driven earth rod electrodes.

Furse recommend the use of deep driven earth rod electrodes wherever conditions allow.

Where rocks lie just below the surface and deep driving is not possible, parallel driven shorter rods, plates, mats or buried conductors, or a combination of these can be used. However, these should still be buried as deep as possible to avoid seasonal variations and damage from agricultural machinery etc.

Often parallel rods are driven too close together; this decreases their effectiveness. The distance between rods should be greater than the rod length, L (see diagram below).

Earth Rod Electrodes

Earth rods are commonly made from the following materials:

- Copper clad steel (including copper bond and sheathed rods)
- Solid copper
- Galvanised steel
- Stainless steel

Furse can supply all four types, but the copper bonded steel cored rod is by far the most popular.

It offers the installer:

- Excellent corrosion resistance
- Ability to carry high fault currents for many years
- Much lower cost than solid copper
- A high strength rigid rod essential for deep driving

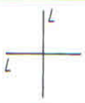
Current Carrying Capacity of Furse Copperbond Rods

Nominal Diameter (inches)	Actual Diameter (mm)	Fusing Current (Amperes) ¼ sec	½ sec	1 sec	Equiv. Copper Conductor (mm sq.)
⅜	8.9	15,200	10,700	7,600	25
½	12.7	31,200	22,000	15,600	53.4
⅝	14.2	38,800	27,400	19,400	70
¾	17.3	57,400	40,500	28,700	95
1	23.2	109,800	77,600	54,900	177.3

11

Care should be taken in positioning these electrodes, especially to avoid damage by agricultural operations.

Table 5 — Coefficients for strip or round conductor electrodes

Electrode arrangement		Coefficient		
		P	*Q*	
			Strip	Round
Single length[a]		2	− 1	− 1.3
Two lengths at 90°		4	0.5	0.9
Three lengths at 120°		6	1.8	2.2
Four lengths at 90°		8	3.6	4.1

[a] Where two or more straight lengths, each of length L in metres (m) and of separation s in metres (m), are laid parallel to each other and connected together the combined resistance can be calculated from the following equation:

$$R_n = FR_1$$

where

R_n is the resistance of n straight conductors in parallel, in Ω;

R_1 is the resistance of one straight conductor in isolation calculated from the equation and coefficients given above, in Ω.

F has the following value:

for two lengths, $F = 0.5 + 0.078(s/L)^{-0.307}$

for three lengths, $F = 0.33 + 0.071(s/L)^{-0.408}$

for four lengths, $F = 0.25 + 0.067(s/L)^{-0.451}$ provided that $0.02 \le (s/L) \le 0.3$.

11 Selection of a material for an earth electrode or a buried uninsulated earthing conductor

11.1 General

Although the material does not affect the earth resistance of an electrode, care should be taken to select a material that is resistant to corrosion in the type of soil in which it will be used. Some recommended materials for the manufacture of earthing components are listed in Table 6.

There are two aspects which should be considered regarding the corrosion resistance of an earth electrode or an earthing conductor, compatibility with the soil itself and possible galvanic effects when it is connected electrically to neighbouring metalwork. The latter is most likely to come about when the earthing system is bonded to exposed metal structural components.

11.2 Corrosion and type of soil

The factors associated with the corrosion of metals in contact with soil are the chemical nature of the soil, in particular acidity and salt content, differential aeration, and the presence of anaerobic bacteria.

A general picture of the aggressiveness of soils is given by the following list, which places various types of soil in increasing order of aggressiveness:

- — gravelly soils;
- — sandy soils;
- — silty soils (loam);
- — clays;
- — peat and other organic soils;
- — made up soils containing cinders.

Calcium carbonate in a soil will reduce the rate of corrosion. Non-cohesive soils, made from mixtures of the first three items above, are generally the least aggressive providing they are well drained and contain little or no dissolved salts. Location of electrodes should be chosen to avoid the drainage of fertilizer and other materials into the area. Top soil should not be mixed with the backfill around an electrode. The least aggressive soils tend to be those having a high resistivity.

More detail can be obtained by measuring the electrical resistivity of the soil, which provides an indication of corrosivity under aerated conditions, and the redox potential, which indicates the risk of corrosion due to the presence of anaerobic bacteria. These tests are described in BS 1377.