Surge protector technology in biomedical equipment and its impact on equipment stability

Abstract: Surge, as a major cause of safety in the use of biomedical equipment, increases the frequency of biomedical equipment failures, reduces service life and damages medical equipment. The core technology of surge protection includes the first, second and third level of protection, with each level working together at different levels to achieve efficient surge suppression. In addition, in conjunction with the application needs of biomedical equipment, this paper discusses the specific applications of surge protectors, including internal equipment protection measures such as uninterruptible power supplies and varistors as well as the design and installation of external surge protectors. Effective surge protection not only prevents equipment damage, but also improves system reliability and extends equipment life. In order to further optimize the effectiveness of surge protection, this paper proposes a multilevel protection scheme, the optimal choice of grounding materials, and suggestions for improving the lightning and surge protection system. Through the reasonable surge protection strategy, can significantly improve the stability and safety of biomedical equipment, for the medical system to provide more reliable operation guarantee.

Keywords: Biomedical equipment, surge protection, surge suppression, equipment stability, medical system.

1. Introduction

With the progress of society and development and science and technology, biomedical equipment is widely used in clinical diagnosis and treatment, and has become an important material basis for clinical research and teaching [1]. Biomedical equipment plays an increasingly important role in improving the level of diagnosis and treatment, carrying out new technology and new business, enhancing the social and economic benefits of hospitals, hauling guarantee and supporting the development of disciplines, and building hospital brands [2]. If the quality and safety of biomedical equipment is not emphasized, it will directly affect the level of diagnosis and treatment, and even cause medical accidents, endangering the health and life safety of patients, biomedical equipment safety and quality control has been the concern of more and more people [3]. The safe and reliable operation of biological equipment is related to the overall operational safety of the power system, but surge is the main cause of the impact of the safe operation of the equipment [4]. In particular, the impact of overvoltage on biological equipment due to lightning, especially on the secondary system is more serious. In order to ensure the safe operation of biological equipment, it is necessary to study the surge protection technology, so as to improve the safety and reliability of the equipment [5].

In the context of today's biomedical equipment and its widespread use in clinical diagnosis and treatment, the health of the equipment used is of paramount importance, as mentioned in the study of Amin, A. A et al. Surge protection devices are able to protect the medical equipment by testing the electrical lightning protection and installing surge protectors [6]. In the study of Pająk, P et al, it was mentioned that surge protectors can be very blocky when aging in outdoor humid environments, and it is important to follow external surge protectors in accordance with the requirements of the code [7]. Hwang, S. W et al. suggested that the installation of surge protectors can reduce the energy storage converter (pcs) and battery direct (CMV) to prevent insulation failures of the energy storage system and safeguard the normal operation of the energy storage system [8]. Tsovilis, T. E. mentions that surge protection devices can reduce the hazards of surges to equipment and improve the reliability of power systems [9]. Zhao, Z et al. suggested that when studying surge protection technology, it was found that if the installation is not done according to the standardized installation requirements, it can lead to a reduction in the suppression of surge protectors as well as shorten the service life, creating a hidden danger for biomedical equipment [10]. In the study of PÎSLARU-DĂNESCU, L et al. it was suggested that the protection of biomedical equipment is very important to ensure the proper functioning of the entire hospital and to safeguard the lives of patients [11]. In a study by Lee, Y et al. a low-cost surge current detection sensor (SCDS) for maintaining surge protectors (SPDs) was proposed, which measures high-current surges using a low-current toroidal coil and is capable of displaying the predicted lifetime of SPDs based on the magnitude and number of surge currents. In addition, the SCDS has been tested to meet the international standard IEC62561- 6 lightning strike counter test conditions and is expected to be used for SPD and lightning protection system maintenance [12].

The relationship between surge protectors and the normal operation and safety and security of biomedical equipment is explored through the analysis of several scholars from different perspectives on the protective effect of surge protectors on equipment and installation specifications, the impact on energy storage systems in different environments and the hazards of non-standardized installation. Despite a number of discussions on surge protector technology, the role of surge protection in biomedicine is still to be in-depth. Among the many factors affecting the safe operation of biomedical equipment, the harm of surge is particularly prominent, especially the overvoltage generated by lightning has a serious impact on the secondary system of the equipment. In order to ensure the safe and stable operation of equipment, the study of surge protection technology is of great significance, this paper centers on the impact of surge on biomedical equipment, surge protector technology and its application to carry out research, aimed at providing effective strategies for surge protection of biomedical equipment.

2. Impact of surges on biological equipment

2.1 Surge characteristics

When biological equipment and circuits are struck by lightning, very high transient overvoltages are generated in microsecond time, and such transient overvoltages or overcurrents are called surge voltages or surge currents [13]. In fact, there are differences in the voltage pulse waveforms and current pulse waveforms appearing in biological equipment due to the differences in the internal structure of biological equipment and the lightning environment in which they are located. However, based on a large number of observations and analyses, a series of standards have been developed for lightning surge waveforms, amplitudes, and other metrics in order to conduct lightning surge immunity tests and other related studies on electronic equipment and systems.

Figure 1 shows the surge simulation waveform, open circuit output voltage peak range of 0.5-4kV, short-circuit output current peak range of 0.25-2kA. surge waveform spectral analysis can be found that the surge waveform is mainly distributed in the low-frequency portion, that is, the main energy is concentrated in the lower frequency band. But in the surge waveform contained in the high frequency energy even if the proportion is small, but also enough to affect the normal operation of electronic equipment. The steeper the head of the surge waveform, the wider the frequency band it contains, the richer the high harmonics, and the longer the tail of the wave, the richer the low-frequency part. For biological equipment, high frequency is the main cause of radiated interference, low frequency energy can be eliminated by varistors, silicon diodes and grounding, while high frequency energy must be suppressed by filtering and shielding techniques, and generally low-pass filters can be used for high frequency filtering [14].

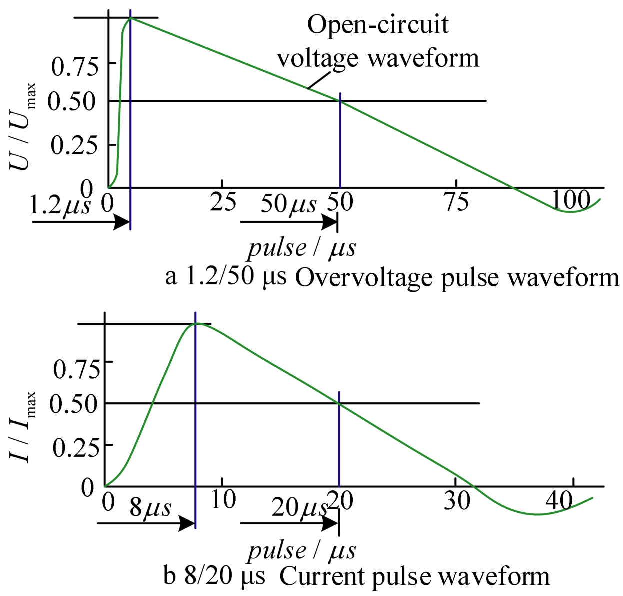

Figure 1 Surge simulation waveform

2.2 Hazards of surges on biomedical equipment

A surge, also known as a power surge, is a transient overvoltage in a circuit that lasts for about milliseconds. As the name implies, it is an instantaneous overvoltage and overcurrent that exceeds the normal operating voltage and current. Surge is mainly generated by lightning or load switching on power lines.

Biomedical equipment integrated wiring system is designed according to the standard, unified and simple structured way, medical equipment in the voice, data, image and multimedia services integrated network of lines. Connected to the medical equipment management system in a large number of electronic devices, such as computers, program-controlled switches, routers, switches, etc., these electronic devices have a large number of internal over-voltage, over-current is very sensitive to the components [15]. When lightning is close to a variety of communication cables, the induction of high-voltage shock waves generated by the formation of surge, and along the communication cables invade the building, directly on the overvoltage, overcurrent is very sensitive to the element, the device produces a great deal of damage. Lightning surge is far beyond the level of biological equipment can withstand. If the biomedical equipment frequently fails, it will shorten the service life of the equipment. The occurrence of large-scale surges may affect the stability of the entire power system, and even trigger the failure of the entire hospital system.

3. Principles and techniques of surge protectors

Medical device surge immunity tests are similar to and different from overvoltage, mainly because the surge waveform contains both voltage transients and current transients [16]. Therefore, surge disturbance suppression methods for biomedical equipment are different from common overvoltage protection methods. Overvoltage protection guarantees intact electrical equipment insulation, such as line insulation and electronics insulation. Whereas, surge interference suppression is necessary for the normal operation of active medical devices, i.e., all Class II and Class III active medical devices have to pass the surge immunity test.

3.1 Principle of Surge Immunity Suppression

Surge Protection Device (SPD) the main technical indicators are response speed limiting voltage level, current withstand maximum peak current and service life. Response speed is the most important technical indicators, reflecting the surge suppression protector SPD for rapid response to interference pulses, surge suppression protector SPD response time is smaller, the faster the speed of the suppression of surge transient interference voltage, an effective surge suppression protector SPD response time must be faster than the speed of the surge interference voltage. Typically, the response time of a surge suppression protector SPD should be within 10ms. Limit voltage level is the design of surge suppression protector SPD must consider the technical indicators, it refers to a certain pulse current under the residual voltage of the high and low, the residual voltage is too high, the need for the next level of surge suppression protector to continue to limit the voltage. Throughput tolerance maximum peak current reflects the surge suppression protector SPD impact resistance, i.e., the ability to withstand the rated number of interference pulse current without being destroyed. Surge suppression protector service life is limited, such as varistors, in a certain peak current of the surge interference signal repeated impact, the number of actions is limited, and with each action, its protective performance will decline. As can be seen from GB/T17626.5-2019 Surge Impact Immunity, surge interference signals are continuously, repeatedly and at different voltage levels injected into the active medical device power port. Therefore, when selecting surge protection components, active medical device manufacturers must check the life curve diagram of the relevant devices, select components with sufficient through-current withstand, maximum peak current margin, and ensure the number of actions to ensure protection [17].

Commonly used surge suppression protectors SPDs are varistors, transient voltage suppressors, gas discharge tubes, semiconductor discharge tubes and so on. These components have similar volt-ampere characteristics, i.e., when the voltage at both ends is below a certain value, the current flowing is small, and when the voltage at both ends is above a certain value, the current flowing grows, and grows with an exponential law. The reason why it has become a common electronic device for surge suppressors is that this volt-ampere characteristic can well meet the surge waveform suppression lagging and limiting requirements. Varistors are one of the most frequently used surge suppression protectors (SPDs), possessing the good characteristics of low limiting voltage, high through-current, a wide range of rated voltages, and an economical price, and have become the surge suppression protection device of choice for many biomedical equipment manufacturers.

Take the nonlinear characteristics of the varistor as an example, its work in the current of 0.1mA-1000Am, the nonlinear region of the varistor power is approximated as $a \equiv 1$, also applies to linear resistance. The range of the varistor is $20 \le a \le 30$, the larger the value of α, the better the varistor varistor performance.

3.2 Surge three-level protection technology

Lightning energy is very great, it is difficult to realize the first time to discharge, the reasonable practice is through the sequential order of graded discharge, and ultimately the energy into the earth, so the surge protection must be graded. According to the intensity of lightning electromagnetic pulse in the space is different, the partition of the building is lightning protection zoning. Among them, for the possibility of a direct lightning strike, the intensity of the electromagnetic pulse does not attenuate the region, set for the LPZ_0 zone, LPZ_0 zone is usually on the outside. Completely exposed unprotected area is LPZ_{oa} zone, and small chance of direct lightning strike, but medical equipment itself EMP intensity did not attenuate the area is LPZ_{ob} [18].

3.2.1 Level 1 protection

The role of the first level of protection for the discharge of direct lightning current, the level of protection mainly to prevent surge voltage directly from LPZ_0, zone conduction into the LPZ_1 zone, mainly installed in the hospital power supply system inlet into the various phases of the earth between the earth, such as the low voltage side of the power transformer into the home to install a three-phase switching power supply SPDs. 1 level of protection after the residual voltage still exists, and only the second level of protection can not be realized completely protected. The

3.2.2 Level 2 protection

Level 2 protection is for the discharge of residual voltages and for induced lightning strikes in the area. Transmission lines passing through level 1 SPDs also induce lightning strike EMP radiation, and when the lines are long enough, the induced lightning energy becomes large enough to require level 2 SPDs to further discharge the lightning strike energy. This level of protection is mainly for LPZ_1-LPZ_2 implementation of equipotential connection. Level 2 SPD is mainly installed at the power supply of important or sensitive biomedical equipment, such as in the distribution cabinet line output power supply.

3.2.3 Level 3 protection

Level 3 protection is the last line of defense against residual lightning strike energy, and can generally be installed inside particularly important or sensitive medical equipment and electrical systems to achieve complete elimination of smaller transient voltages. It also prevents the effects of transient overvoltages generated within the equipment.

4. Surge Protectors in Biomedical Equipment

Often the value of biomedical equipment is higher than the cost of a surge protector, which is installed to protect the equipment or system from damage by lightning or other power disturbances, thus avoiding the cost of repair or replacement.

4.1 Surge Protection Requirements for Typical Biological Equipment

Transient dramatic changes in voltage or current can generate electromagnetic waves, which can cause electromagnetic interference to electrical equipment on electrical lines and affect the normal operation of the equipment. Many medical electrical devices require high precision and reliability, and EMI generated by surges may significantly affect their lifespan or performance. Cardiac pacemakers are very sensitive to EMI, which can affect their normal operation, cause heart rate instability or cause malfunctions that can affect their lifespan. Implantable defibrillators rely on precise electrical signals to monitor heart rhythm and perform defibrillation. Electromagnetic interference may cause the device to detect errors or emit unwanted electrical shocks, affecting the proper function and life of the device. The accuracy of ventilators is critical for patient respiratory support. Electromagnetic interference may cause the ventilator to operate erratically or transmit data incorrectly, affecting its reliability and longevity. Monitors are used for real-time monitoring of patients' physiological parameters, such as heart rate blood pressure, oxygen saturation, etc. Electromagnetic interference may lead to inaccurate monitoring data, affecting the performance and life of the equipment. Imaging equipment is very sensitive to electromagnetic interference [19]. Many medical electrical devices are in direct contact with patients or play an important life-supporting role, and electromagnetic interference not only affects the performance and life of the equipment, but often may also lead to serious medical safety accidents. Compared with visible risks, such silent risks are more difficult to predict and prevent, and the protection of typical biomedical equipment is a challenge for hospitals.

4.2 Surge protection measures within the equipment

4.2.1 Uninterruptible power supply

For hospitals such as special places, uninterruptible power supply (UPS) should have a higher surge protection capability, the use of multiple varistors in parallel between the lines can provide higher energy absorption capacity to cope with greater over-voltage and current shocks, thereby improving surge protection. Surge protection circuit shown in Figure 2, increase the varistor power, three-terminal gas discharge tube in series with the varistor, LN line between a number of varistors in parallel with the UPS surge protection circuit, can greatly improve the surge protection capability of the UPS.

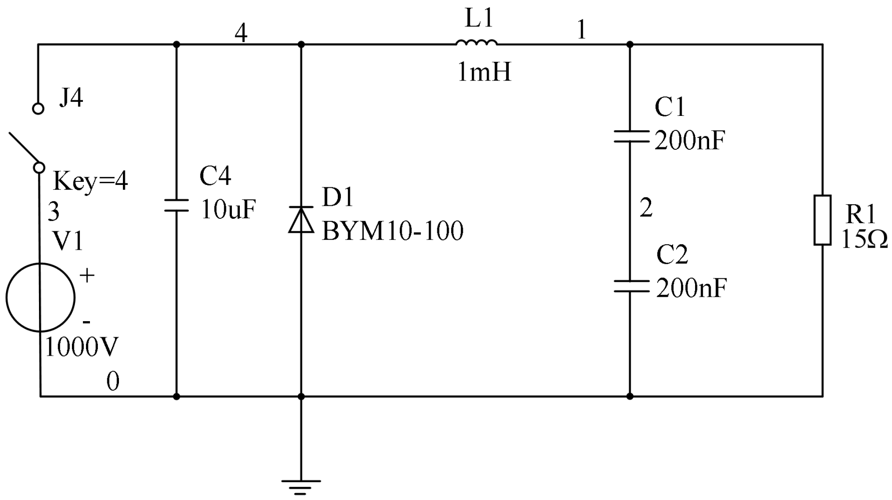

Figure 2 Surge protection circuit

4.2.2 Varistors

Voltage-sensitive resistors are widely used as voltage-limiting protection devices. Figure 3 shows the volt-ampere characteristics of a voltage-sensitive resistor. When the voltage applied to it is lower than the threshold, the current flowing through the voltage-sensitive resistor is extremely small, equivalent to a resistor with an infinite resistance value. When the voltage exceeds the threshold, the current flowing through the varistor increases rapidly, which is equivalent to a resistor with a very small resistance value. By making full use of the nonlinear characteristics of the varistor, when the voltage exceeds the threshold value between the two poles of the varistor, the voltage can be stabilized at a relatively fixed value, so as to realize the effective protection of the back stage circuit.

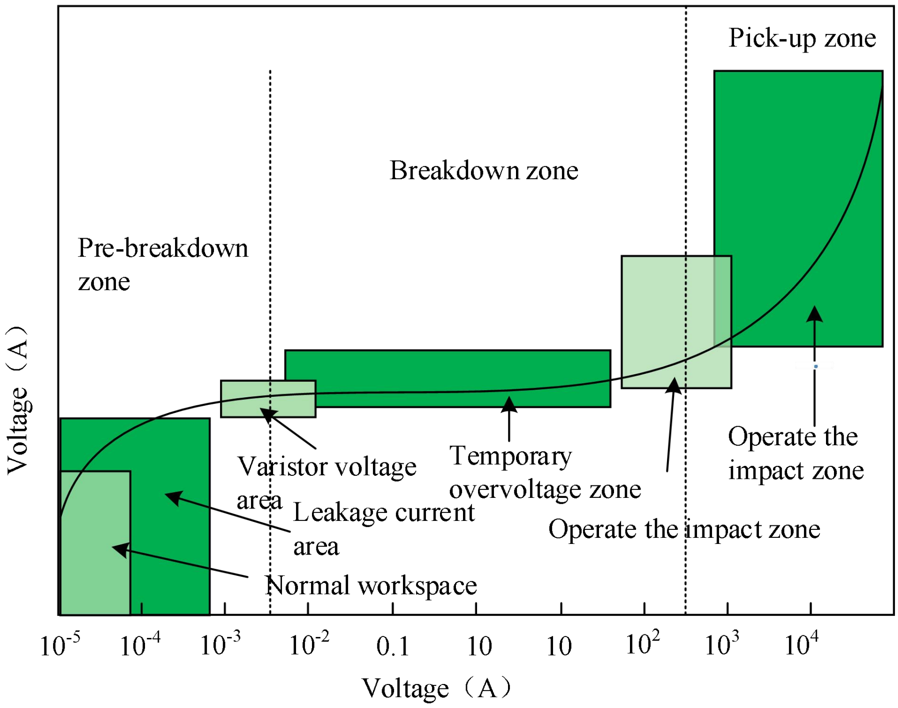

Figure 3 Volt ampere characteristics of varistor

Varistors as anti-surge components have many advantages such as low residual voltage, fast response time, no renewal current, and large through-current capacity. However, varistors have an obvious drawback, namely leakage current. Varistors are usually connected in parallel in the electrical circuit, under the influence of the circuit voltage will produce a very small leakage current. The performance of the varistor deteriorates after a long period of operation, which is manifested by a decrease in the threshold voltage and an increasing leakage current.

4.3 Design and Installation of External Surge Protectors4.3 Design and Installation of External Surge Protectors

External surge protectors can be selected from voltage switching model surge protectors, a comparison of the advantages and disadvantages of surge protectors is shown in Table 1. Usually use discharge gaps, inflatable discharge tubes, transistors and so on. Voltage-limiting type surge protectors use varistors, suppression diodes, etc. Combination type surge protectors are divided into combination type in series and parallel. The combination of switching type and voltage-limiting type, first switching type start, then voltage-limiting type start.

Table 1 Comparison of advantages and disadvantages of surge protective devices

Type	Characteristics					
	Response time	Movement stability	Afterflow	Leakage current	Voltage protection level	Aging
Voltage limiting type	Faster ≤25ms	Stable	Minimum	Yes	Lower	Yes
Voltage switching type	Slower≤100ms	Stable	Great	Basically none	High, but can trigger lowering	No
Combined type (in series)	Slower≤100ms	Relatively stable	Less	Basically none	High, but can trigger lowering	No
Combined type (parallel connection)	Mov≤25ms	First stable and then sudden change	Great	Yes	High, but can trigger lowering	Yes

External surge protector installation through the building's main steel, the upper end and the flashover, the lower end and the ground network connection, the middle and the various layers of equalization network or ring equalization belt connection, the implementation of equalization of various metal pipelines into the building equipotential connection, with special requirements of a variety of different ground for equipotential treatment. Requirements for biomedical equipment network system in the building building wiring and grounding method, as far as possible, concentrated in the middle of the building. Communication cable trunking as well as ground line trunking should be placed as far as possible to avoid close to the building columns or beams, and keep a long distance from it, communication cable trunking as well as ground line trunking design, should be located as far as possible from the building columns or beams. According to the requirements of the lightning protection zone, the outside of the building is the direct lightning strike area. The interior of the building and the computer room are located in the non-exposed area, and the further inside, the lower the degree of danger. Lightning overvoltage damage to the internal electronic equipment is introduced along the lines, and the interface of the protection zone is formed by the external lightning protection system, the reinforced concrete of the building, and the metal shell of the screen layer. Electrical pathways and metallic structures such as metal pipes must be equipotentialized at each crossing point when they pass through the various levels of lightning protection zones. Installation of SPDs is an effective means of protecting biomedical equipment from the hazards of conducted surge overvoltages caused by lightning strikes and other disturbances. Power and communication lines entering the building should be at the junction of LPZ0 and LPZ1, LP/1, and LP/2 zones and at the front of terminal equipment.

5. Impact of Surge Protectors on the Stability of Biomedical Equipment

5.1 Preventing damage to equipment

A lot of medical equipment are used on the surge protector, in the power supply box panel window can be clearly seen on the aging of the surge protector and damage to the prompt, while the protector with the aging warning function, the window using red and white color, the role is to remind the staff to replace the aging in a timely manner. Generally speaking, its security is relatively high, but also easy for staff to replace, surge protector is an important protective barrier for medical equipment accidents, its role is obvious and effective. But if you can not correctly select and install the device, may not play a protective function of the equipment will also appear to damage medical equipment, and even cause casualties such as irreparable accidents.

5.2 Improve system reliability

Surge protectors are widely used in biomedicine, primarily to protect biomedical equipment from damage caused by surge voltages. Biomedical equipment usually has a large number of electrical devices, including pacemakers, implantable defibrillators, ventilators, etc. These devices are very sensitive to electrical surge voltages. These devices are very sensitive to electrical surge voltages, and the introduction of surge protectors in biomedical installations can effectively prevent surge voltage damage due to lightning, power fluctuations, and other causes. Hospitals also need a large amount of power to maintain the equipment in use and to ensure the stability and reliability of medical equipment [20].

5.3 Extension of equipment life

Surge is a higher overvoltage generated within the power line when lightning strikes electrical equipment, which negatively affects the internal structure of electricity and is not conducive to the stable operation of biomedical equipment. High-voltage surge is an important reason for jeopardizing the safety of electronic components and electrical equipment within medical equipment, which can lead to a highly integrated internal structure of circuits, which can easily cause electronic equipment to misbehave, and also reduce, the service life of the equipment, and negatively affect the safety of the equipment in use. The surge voltage it forms may follow the power line, signal line, etc. into the equipment inside, jeopardizing the safety of electronic equipment, affecting the building of a variety of microelectronic equipment, intelligent equipment, the orderly operation of the building. With the continuous improvement of medical equipment, high-voltage surge caused by the degree of harm also increased, the service life is gradually reduced, surge protector can effectively avoid high-frequency power shock, play a protective role for medical equipment to increase its service life.

5.4 Surge Protector Optimization Measures

5.4.1 Multi-level protection

Determine the level of protection according to the importance, performance and value of the electrical and electronic systems, and classify them into A, B, C and D. The SPD of the power supply system shall adopt different protection measures according to the protection level of the electrical and electronic system:

(1) Level A shall be protected by 4-level SPDs, and the last level shall be multi-level integrated SPDs.

(2) Level B shall be protected by 3-level SPDs, and the last level shall be multi-level integrated SPDs.

(3) Level C shall be protected by a 2-stage SPD.

(4) Level D should use 1~2 level SPD for protection of power supply.

Power system at all levels of SPD selection depends on the SPD, SPD and the energy between the protected equipment with the line length between all levels of voltage-limiting SPD is not less than 5m, switching type and voltage-limiting type between the line length is not less than 10m, otherwise it should be decoupled between the device.

5.4.2 Selection of materials for grounding devices

The grounding materials for biomedical equipment often utilize the building's own pile foundation reinforcement or foundation floor beam reinforcement, but the materials of the steel structure in both pile foundation reinforcement and foundation floor beam reinforcement are relatively common. Although it has certain conductive properties, its corrosion resistance is poor. Therefore, in the selection of pile foundation reinforcement as well as foundation ground beam reinforcement, steel reinforcement with high corrosion resistance should be used as much as possible. In addition, in the site of high soil resistivity, copper, aluminum, graphite and other materials with excellent conductivity can be used as the main material of the grounding body to reduce the grounding resistance.

5.4.3 Increase the corresponding lightning and surge protection system, inspection frequency

Improve the instrument lightning and anti-static management rules and regulations, account records, and increase the records of anti-surge protector replacement. In accordance with the requirements, the metal casing of on-site instruments, instrument protection boxes, junction boxes and cabinets should be grounded nearby or connected to a grounded metal body. Whether the on-site lightning and anti-static facilities, including lightning and anti-static grounding, static cross-connection, working grounding of instrumentation equipment, protective grounding and information grounding facilities are in good condition, and the instrument static grounding device is regularly tested. Rectify the unqualified and unsafe grounding, and do the corresponding testing after completion. Carry out periodic inspections of the increased anti-surge equipment, and increase the frequency of inspections before and after thunderstorms; immediately organize the replacement of equipment with alarms. In accordance with the corresponding norms, the explosion-proof area of all the instrumentation of the protective ground to improve and check the loose, corrosion of the ground wire for fastening and rust removal.

6. Discussion

Accompanied by the rapid development of surge protector technology, the safe operation of biomedical equipment systems is increasingly important, a large number of surge protectors (SPD) widely used. In view of the uneven quality of SPD products, in order to meet the needs of the biomedical system of lightning safety protection, as well as standardize the low-voltage power distribution system, AC 220/380V system with SPD technical requirements and test methods for the manufacture of SPDs, production, inspection, selection, installation and use of the corresponding technology to provide the basis [21]. To date, with the progress of SPD technology, the reliability of its renewable current breaking capacity is constantly improving, and its own thermal stability and fire safety performance has also been significantly improved. In addition, at this stage, a number of testing organizations have switching SPD current renewal capacity test verification conditions. At the same time, the current standard IEC61643 series and standards GB/T18802.11-2020, etc., have been on the switching SPD technical requirements, safety performance and test methods have been developed exhaustive and strict regulations. For the validation and inspection of the relevant technical standards of the switching SPD, the application of biomedical equipment circuits in the application of whether it is necessary to limit the scope of its application, or whether it can be used in accordance with the actual scenarios and needs, is still the focus of future research to be discussed and researched.

7. Conclusion

Surge, as a major cause of safety in the use of equipment, poses many challenges for biomedicine, and this paper examines the characteristics and hazards of surge, as well as the principles and operational techniques of surge protectors to ensure the critical role of surge protectors in biomedical equipment. Whether the equipment is protected internally using varistors, or external surge protection is reasonably installed to safeguard medical equipment from the hazards of surges. At the same time, surge protectors have been significantly improved in preventing equipment damage, improving system reliability, and extending service life. Combined with the application characteristics of biomedical equipment, a systematic protection scheme is proposed. The multi-level protection system can effectively reduce the impact of the surge and enhance the anti-interference ability of the equipment. In addition, reasonable selection of grounding device materials, optimize the layout of the surge protector, and strengthen the lightning and surge management can further improve the reliability of the equipment. In the future, the gradual improvement of biomedical equipment at the same time should also strengthen the research on surge protectors to achieve better development of biomedical equipment.

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