TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

HEIDI PIRTTIMÄKI

SAFETY IN ELECTRICAL WORK

Master of Science Thesis

Examiner: Professor Teuvo Suntio
Examinor and topic approved in the Computing and Electrical Engineering Faculty Council meeting on 14 August 2013

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
Master's Degree Programme in Electrical Engineering
PIRTTIMÄKI, HEIDI: Safety in electrical work
Master of Science Thesis, 45 pages
October 2013
Major: Power Electronics of Electrical Drives
Examiner: Professor Teuvo Suntio
Keywords: Electrical work, safety, testing

Working with electricity causes injuries and deaths around the world every year. At the same time, the employers are more interested in their employee's safety at work. The purpose of this thesis is to create a base to electrical safety in work instruction leaning strongly on existing standards. This electrical safety instruction is made to reduce injuries and possible deaths, as well as to improve overall electrical safety in all Motors and Generators business units around the world. In this thesis electrical work is thought to mean electrical work and testing related to manufacturing of motors and generators.

This thesis discusses the path of electrical work from need to do electrical work to completion of the work. This chain begins with a risk assessment, which is used to identify potential hazards associated with the work. By using this information it is possible to create work instructions and measurement plans. Needed tools and work place can be found with the help of these instructions. Electrical work cannot be carried out without working people, so organization around electrical work is reviewed from employee level to management level not forgetting responsibilities and tasks including to every level. All the levels have their own significances and all of these levels should work conveniently together to ensure safety in work.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Sähkötekniikan koulutusohjelma
HEIDI PIRTTIMÄKI: Sähkötyöturvallisuus
Diplomityö, 45 sivua
Lokakuu 2013
Pääaine: Sähkökäyttöjen tehoelektroniikka
Tarkastaja: professori Teuvo Suntio
Avainsanat: Sähkötyö, turvallisuus, testaaminen

Sähkötyöt aiheuttavat vuosittain tapaturmia ja kuolemia ympäri maailmaa. Samaan aikaan työnantajat ovat entistä kiinnostuneempia työntekijöidensä työturvallisuudesta. Tämän työn tarkoituksena on luoda pohja sähkötyöturvallisuusohjeelle tukeutuen olemassa oleviin alan standardeihin. Sähkötyöturvallisuusohjeen tarkoituksena on vähentää tapaturmia ja mahdollisia kuolemia sekä parantaa yleisesti sähkötyöturvallisuutta ABB Oy:n moottorit ja generaattorit yksiköissä ympäri maailmaa. Sähkötöillä tämän työn tapauksessa on ajateltu moottorien ja generaattorien valmistukseen liittyviä sähkötöitä ja testauksia.

Työssä käsitellään sähkötyön kulkua aina tarpeesta tehdä sähkötyötä työn lopetusvaiheeseen asti. Ketju alkaa riskianalyysillä, jonka avulla kartoitetaan mahdolliset vaaratilanteet. Näiden tietojen avulla pystytään luomaan työ- ja mittausohjeita. Ohjeiden perusteella pystytään taas hankkimaan tarvittavat työvälineet sekä paikka työn suorittamiselle. Sähkötöitä ei kuitenkaan voida tehdä ilman henkilöstöä, joten sähkötyöturvallisuuden organisaatiota käsitellään myös aina työntekijästä johtotasolle asti unohtamatta kunkin tason vastuita ja tehtäviä. Kaikilla tasoilla on oma merkityksensä ja kaikkien pitäisi toimia, jotta työnteko olisi turvallista.

PREFACE

This Master of Science Thesis was made to create electrical safety instruction for Motors and Generators business unit at ABB. This electrical safety instruction should be a minimum requirement all around the world in these business units.

First of all, I would like to thank Prof. Teuvo Suntio for been so reachable and clear, when I had any questions. I would like to also thank my instructor Juha Huhtinen, who has been very helpful and understanding throughout this project. I would like to thank Kari Pärssinen and Tero Väisänen for all constructive comments and as well as all other people at ABB.

My last gratitude goes to Marko Lyden, who has helped me in many ways, when I was doing this Thesis.

September 18th, 20113

Heidi Pirttimäki

TABLE OF CONTENTS

1 INTRODUCTION

Electricity has caused many accidents and deaths to working people over time. Nowadays safety is more important than ever before and importance of safe working is rising all the time. Electrical safety in work has many variables from worker to used equipment to management and all of these should work correctly to avoid accidents.

Electrical safety systems are trying to save human lives. Human live is priceless and it cannot be recovered unlike destroyed property or lost money. To secure safe work environment, the whole system around the people should work right. This system includes organization of electrical safety, suitable training, energized equipment, different safety measures, maintenance and performance monitoring.

Organization of electrical safety consists of different levels and each level has its own responsibilities and tasks. Everyone should know their place in the organization and responsibilities, which comes with it. All these people should be competent to do their job.

Different equipment and installations are usually targets of electrical work. Carrying out electrical work is not just carrying out the work, it is much more. Possible hazards should be identified and the work itself should be planned and prepared well before starting any work.

The main goal for this thesis is to introduce basic measures to improve safety in electrical work leaning strongly on standards. Chapter 2 introduces how electricity is dangerous to human and what effects does it have. The next chapter introduces organization around electrical work, important persons and their responsibilities in it. Chapter also takes a look to competence of people inside the organization and communication between them.

Chapter 4 shows different test stations and their requirements in the industry today. The next chapter introduces more closely what preparations are need to be done before starting electrical work in test stations. Chapter 6 introduces different working methods in electrical work. In the last chapter are conclusions of safety in electrical work.

2 IDENTIFICATION AND CONTROL OF RISKS AND HAZARDS

When there is electricity, there is a possibility of danger. It is widely known that when working near high voltage systems, there is a chance of a flashover. Flashover generates arcs, which may be fatal. Arc-flash is determined as released energy caused by an electric arc. The arc creates a bright light, heat and a loud noise. Ionized gases, molten metal drops, metal vapors and fragments showering to the vicinity are results of arc flash. When working near low voltage systems, there is also a chance of flashover. Sometimes only high voltage is perceived dangerous, even though low voltage has the same dangers. [1; 2]

Usually the primary hazards related to electricity are electric shocks and burns. When the human becomes a part of a circuit and electrons can flow through the body, it is called electric shock. Electrical shock occurs usually when a person comes in contact with both wires of an electrical circuit or one energized wire of an electrical circuit and the ground. Arc flash is also a source of electric shock. [1]

Burns are usually result of heating due to resistance in a body. Burns create a notable portion of injuries from electrical malfunctions. Burns may be extensive and deep, depending of the heat and current flowing through a body. For example, the high temperatures of the arc-flash can cause fatal and major burns from a few meter distances. Therefore protecting employees from all arc-flash hazards should be taken seriously. [1; 2; 3]

Secondary hazards caused by electricity are fires, explosions and falls. Other possible hazards concerning electrical work are entanglement due rotating machinery, slips due liquids on the floor and being hit by overhead cranes. Everything should be done to prevent these hazards from occurring. That is why risk assessments, work permits and work instructions are made. [3, 4]

Three different areas are important, when speaking of electrical system safety: protection of human life, protection of property and protection of production output. The protection of human life is the most important thing. Property can be replaced and lost production can be made up, but human life cannot be recovered. When improving safety of personnel, different matters should be considered. Organization of electrical safety, proper training, competence, energized equipment, maintenance and performance monitoring are important pieces of safe work environment.

Nowadays most electrical companies have safety requirements and programs used in the workplace. These programs usually include training and performance monitoring. Most safety programs follow safety rules and practices, national and local codes and standards and federal laws. Personnel should always be aware of these requirements and rules that apply to their work and workplace, which can be accomplished with proper training. Electrical safety standards and requirements vary, because some standards and requirements are voluntary while others are mandatory.

2.1 Human and electricity

As a part of a circuit, human can be perceived as impedance. Because value of the voltage is often the same, magnitude of the current going through a human depends on impedance of a human. Different parts of a human body create specific impedance for electrical current, which consists of resistive and capacitive components. The values of these impedances are dependent on different factors, such as current path, frequency, touch voltage, touch area, temperature and age. [1]

Physiological effects of electricity have to be considered, when building protection from electrical shocks. Current goes through a human, when he or she touches two different parts with different electric potentials at the same time. The nerve system of a human body is so sensitive that even a small amount of current can cause disturbances to the system.

Figure 1 shows how the total impedance of the human body is formed. [1]

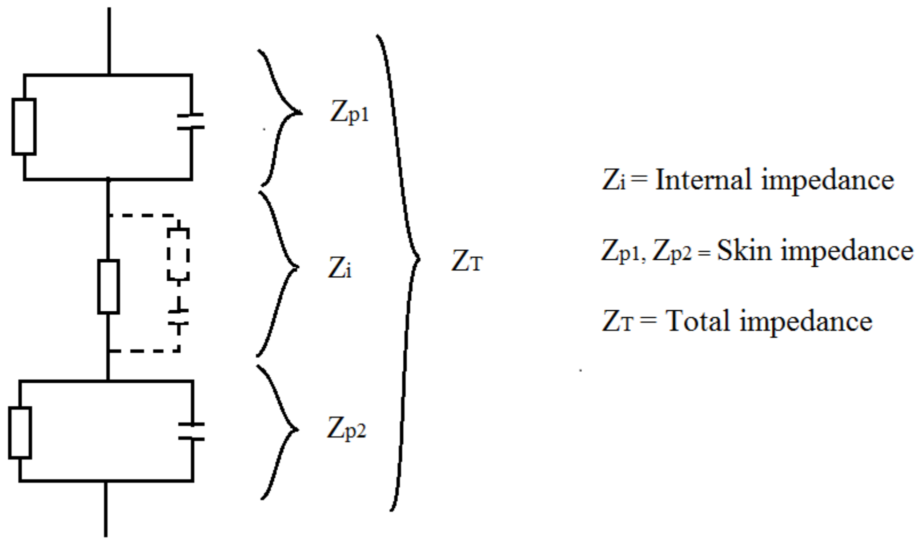

Figure 1. *Total impedance of a human body [1].*

Internal impedance of the human body is mostly resistive and its value is dependent mainly on current path and touch area. [1]

Total impedance is dependent on touch voltage. In small touch voltage values skin impedance is most significant. When touch voltage rises, skin impedance starts to behave like short circuit. This means that total impedance reduces and internal impedance becomes more ruling. At high touch voltage values, only affecting impedance is internal impedance. Human body impedance is about 1,7 kΩ from hand to hand and about 1 kΩ from hand to leg when the voltage is 230 V. Figure 2 shows the total impedance in function of touch voltage. Total impedance values are valid, when current path is hand – hand or hand – leg. [1]

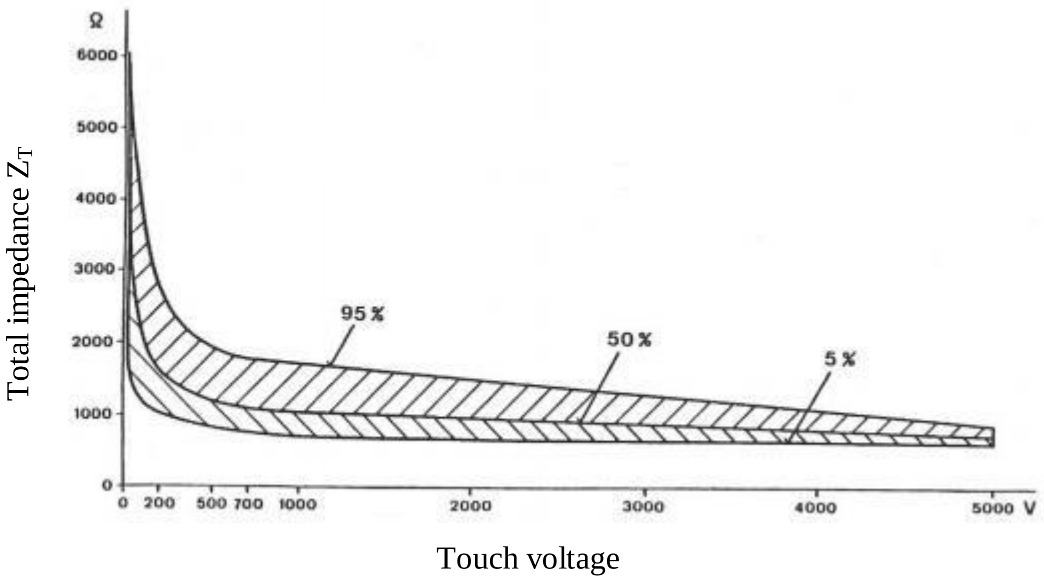

Figure 2. *Total impedance of a human body in function of touch voltage. [1]*

Different parts of a human body have different impedances. Blood and interstitial fluid lead well electricity, when bones do have more impedance. Under dry conditions human skin is very resistant and the total impedance is usually high. Wet conditions can dramatically drop the total impedance of the body as well as broken skin at the point of contact.

The severity of injury from electrical shock depends on amount of the alternative current and the length of time the current flows through the body. Table 1 shows effects caused by different amount of current flowing through the body.

Table 1. *Physiological effects caused by different amount of current. [1]*

Current range mA	Duration	Physiological effect
>1000	Long time	Usually immediate death
> 1000	Short time	Serious internal burns Serious external burns
> 500	Greater than a cardiac cycle	Cardiac arrest Unconsciousness Burned tissue
>500	Smaller than a cardiac cycle	Ventricular fibrillation Unconsciousness Burned tissue
50… 500	Greater than a cardiac cycle	Ventricular fibrillation Unconsciousness Burned tissue
50… 500	Smaller than a cardiac cycle	No ventricular fibrillation Intense shock effect
30… 50	Seconds to minutes	Possible ventricular fibrillation Unconsciousness Intense seizures Risen blood pressure Irregular heart functions
15… 30	Minutes	Risen blood pressure Breathing problems Seizures
2… 15	Duration is irrelevant	Muscles freeze, person is not able to let go Intense pain in fingers and hands
0.5…2	Duration is irrelevant	Threshold of feeling

If a person is unable to let go of the tool or wire and the current continues flowing through the body, it can result in respiratory paralysis. Respiratory paralysis means that a person stops breathing for a period of time, because muscles controlling breathing are not able to move. Often it takes about 30 mA to cause respiratory paralysis. [1]

When current is greater than 30 mA, there is a chance for ventricular fibrillation. In this condition the heart is not able to pump blood and because of this circulation becomes disturbed. When brains do not get enough oxygen, they will damage only in few minutes. In that kind of situation defibrillator can be used to save the victim. Defibrillator is a special device, which delivers an electric shock to the heart and allows its normal rhythm to be continued. Alternative current can cause ventricular fibrillation, so it is more dangerous than direct current. [1]

If the amount of the current is greater than 500 mA, heart paralysis, burned tissue and death can be results for that. The longer the time the current flows through the body, the greater damages to the body is made. [1]

2.2 Risk assessment

Risk is the likelihood and consequence of harm or injury occurring. The degree of the risk is dependent on exposure to the electrical risk. Exposure can be determined in many ways, like how much electrical equipment is present and how much and how regularly people use electrical equipment. The risks from every part of the work, installation, use, maintenance, testing, should be assessed. The goal is to eliminate risks when working and carry out work by dead working. If that is not possible, the risk level shall be made so low, that work can be carried out safely. Preventing is always the preference and personal protective equipment is the last resort. [5; 6; 7]

The main purpose for risk assessment is to find out the most effective way to control possible hazards. The risk assessment should be done to all work stations and activities and it involves continuously the operators, maintenance staff and supervisors. Assessment should be reviewed every year or when there is a change in the process. [5; 6]

The risk assessment process starts with identifying the jobs that needs to be done and the people who are involved and possibly affected by these actions. The next step is to identify risks and hazards. When identifying the risks and hazards, relevant documents and statistics need to be examined closely. Incident experience gives a lot of knowledge about different incidents and their consequences.[5; 6]

The severity of every hazard should be evaluated. It shall be determined which hazards are the most severe and prioritize them from most severe to least severe to health and safety. With this information is possible to evaluate potential severity of consequences to these hazards. Severity can be determined by different factors, like how much harm it could cause, how many people it could affect and whether the harm would be short or long term. For example, if used voltage is high, it is likely that the consequences severe too, compared to lower voltage. Also workers who work close to electrical equipment are more likely to accidentally touch live part than others who work further away. There are five categories for severity of consequences, as listed in Table 2. [5; 6]

***Table 2.** Severity of consequences. [6]*

Weight	Severity	Detail
1	Low	Superficial injury requiring first aid only and no lost time
2	Slight	Medical treatment required but no lost time
3	Moderate	Injury or disease that is likely to result in more than 1 day lost time
4	High	Serious injury only
5	Very high	Fatal injury

After the evaluation, it is possible to determine the likelihood by which those consequences happen. Likelihood of an event to occur is dependent on probability and frequency of exposure to a risk. When determining the likelihood of consequences, there are few factors to be considered. How, when and where people are exposed to the risk and varying exposure over time are some of those factors. Training and instruction are important factors and will affect the level of risk as do the environment, where people are working. People who are not trained and competent do their job will more likely be injured. [5; 6]

Attitude is also important factor and sometimes attitude towards safety is too casual or people are too used to do their work. Sometimes an electrically skilled person may In different countries attitude to risk taking is different and this has to be also considered. [5; 6]

There are also five categories for likelihood that consequences happen, as shown in Table 3.

***Table 3.** Likelihood for consequences to happen.[6]*

Weight	Likelihood	Detail
1	Not likely	The incident is not likely to occur
2	Possible	This incident could possibly occur.
3	Quite possible	The incident might occur based on existing control.
4	Likely	The incident is likely to occur given current control.
5	Very likely	There is an almost certainty that the incident will occur given current working practices. Regular occurrence.

When likelihood of occurrence and severity of consequences are determined, it is possible to determine the level of risk, which consists of both of these factors. The estimated levels of likelihood of occurrence and severity of consequences can be placed to risk priority table and the result is the risk score. The risk priority table is shown in Table 4. [5; 6]

Table 4. *The risk priority table. [6]*

Severity	5	Low	Medium	High	High	High
	4	Low	Medium	Medium	High	High
	3	Low	Low	Medium	Medium	High
	2	Low	Low	Low	Medium	Medium
	1	Low	Low	Low	Low	Low
		1	2	3	4	5
		Probability				

This helps prioritize risks in importance order from one to five, where five is the highest and most important risk score. After finding the risk score, the risk statement table can be used to see what actions need to be taken. The risk statement table can be found in Table 5. [5; 6]

Table 5. *The risk statement table. [6]*

(red)	High	Risks are intolerable and additional controls must be introduced to reduce risk further
(yellow)	Medium	Risks are tolerable, but only if additional control measures identified are not reasonably practicable to implement
(green)	Low	Risks are broadly acceptable and risks should be monitored to ensure the level does not change

By using this system it is possible to determine the risk score to every risk in the workplace and after that they can be compared. The result is ranking list telling which risks should be addressed firstly. [5; 6]

2.3 Permit to work

Once electrical tasks are known, the next step to strict control is a usage of permit to work. It is a document which tells the work that is to be done and what precautions should be taken. [7; 8]

This permit to work-system is used to control potentially hazardous work tasks and to help communication between everyone who is involved. System provides records that possible hazards have been considered and allows work to start only when procedures ensuring safety are made. [8]

The permit gives authority to start working with the electrical equipment under controlled conditions specified in it. Individual site conditions and requirements should be considered in every case. This includes details of the work, including all precautions and emergency procedures. Work area, equipment, any limits and possible hazards in the immediate area regarding the work should also be specified. [8]

The permit to work should also be signed by the working person before doing the work and after the work has been completed. Permitted time extensions and cancellation instructions should be included to the permit to work and if the limits of the working area changes during the work, new permits to work must be issued. [8]

A permit is created by trained, experienced and authorized person, who after assessing the hazards and risks will complete and sign the permit to work. That person is usually the nominated person in control of the work. [8]

2.4 Measurement plan

Measurement plan is made to clarify measurement to worker and to management. It is usually used when electrical testing is made somewhere else than in current employers site, for example in customers site. It states when and how measurement is done and gives all other important information about the measurement.

In the beginning of the measurement plan, there should be a jobsite, measurement team, task definition and a date of measurement stated clearly. Task definition is a short description of the job, not including any detailed information. These are the basic information in measurement plan.

Measurement plan should then include seven main topics and explanations about them. These topics are

- Justification of necessity
- Variables to be measured
- Work group
- Preparations and measurement equipment
- Measurement
- Risk analysis
- Safety precautions in work area and immediate vicinity of work area

Under these topics should be stated why this measurement is to be done, who is doing it and how. All persons who will be involved with this measurement should be stated and their responsibilities should be told. Training and competence of these people should also be stated.

A person responsible for maintaining electrical safety should be mentioned along with contact persons at the jobsite and other responsibilities regarding their actions.

Preparation of measurement equipment and their safe use should be stated clearly. Measurement itself should also be described and all preparations, possible hazards and other precautions should be stated. Risk analysis mentions these possible hazards, which can happen during the measurement. This helps workers to realize possible hazards before and during the measurement and instructs what should be done to avoid these hazards while working.

Working area should be mentioned and how to make it safe and noticeable. Access to the working area, equipment placing and unattended work area should be mentioned.

At the very end of the measurement plan should be a place for signatures to verify this document. Worker and management will sign this document before starting any work.

3 ORGANIZING ELECTRICAL WORK

A work in electrical industry has to be well organized to guarantee safe working environment. Employer and a nominated person in control of a work or an electrical installation take usually care that safety requirements and laws are followed when doing electrical work. A nominated person in control of a work or an electrical installation can do these tasks or take care that there is a system that is followed and by following it, all the requirements all fulfilled. [9]

There shall be a person in control of a work activity or an electrical installation for every task to be done, if a nominated person in control of a work activity or an electrical installation is not able to supervise or do the work. There should also be someone who is responsible for maintaining electrical safety. These people take care that an electrical work is carried out safely and requirements are followed. [9]

Figure 3 shows the organization structure and area of responsibility for all persons in organization. Wider responsibility area in the figure includes all responsibility areas inside it. For example, responsibility for a worker is only own work and its vicinity, when a nominated person in control of a work is responsible for electrical safety in the whole company. [9; 10; 11]

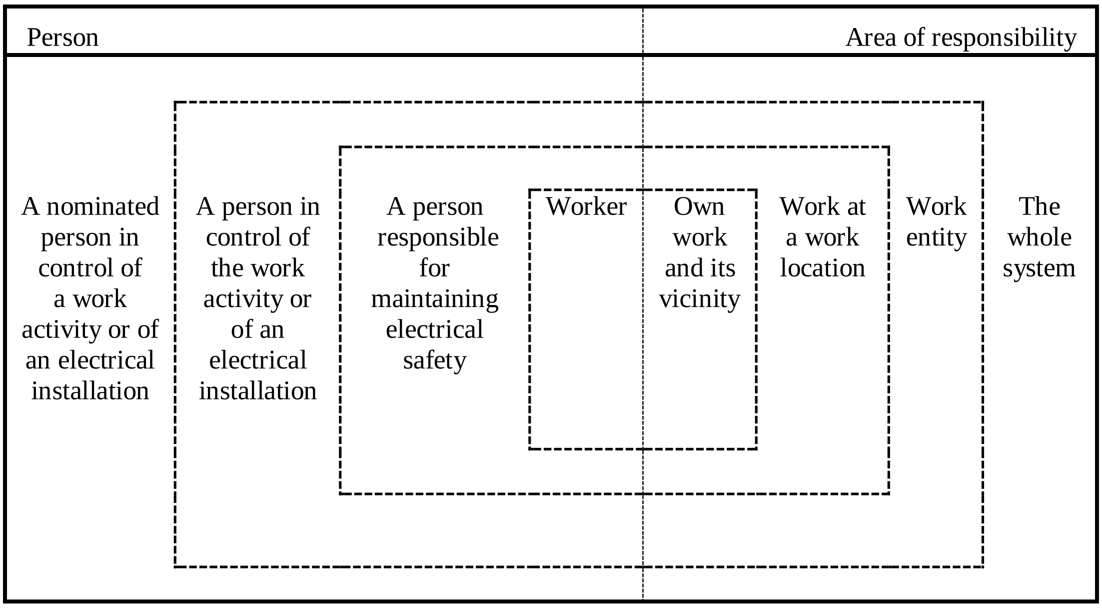

Figure 3. *Organization and area of responsibility [9]*

Supervising of electrical safety in the whole company is usually divided to different levels. Depending on the size and type of the company, there may be different number of levels. Big company may have all levels, when in one person company that one person handles all alone. [9]

3.1 A person responsible for maintaining electrical safety

A person responsible for maintaining electrical safety should be named to every work place to supervise electrical safety. This person should be able to do electrical work independently and be skilled in electrical engineering. A person responsible for maintaining electrical safety may take part of the work or do the whole work independently. If electrical work is done alone by electrically skilled person, this person is responsible for maintaining electrical safety. [9; 11]

A person responsible for maintaining electrical safety should have experience of used working methods, tools and equipment. Attitude towards safety, reliability and sense of responsibility are important qualities for this person. Main point is that a person responsible for maintaining electrical safety stays in the work place the whole time and is able to supervise electrical safety. If the person has to leave the work site, there must be a way to determine a new person responsible for maintaining electrical safety. [10; 11]

In work places, where different employers have people working, is extremely important to determine a person responsible for maintaining safety. In this kind of situations a person responsible for maintaining safety should be determined in writing. If organization of the work and tasks are clearly enough, supervising of electrical safety can be determined in speaking or following procedures set beforehand. [9; 11]

When there is a chance of electrical shock or arc, a person responsible for maintaining electrical safety should be named. All high voltage systems must also have a person responsible for maintaining electrical safety. When building electrical installation, supervisor of electrical safety should be named at least when electrical installation is in the state, when power can be turned on. If there is a possibility for electrical danger in earlier stages of building, supervisor should be named then. [9; 11]

3.2 A person in control of the electrical installation

For each electrical installation, there should be a person in control of the electrical installation. This person controls access to all the places where ordinary persons are exposed to electrical hazards and supervises and keeps electrical spaces locked. [11]

Because of the electrical hazards, all electrical spaces must have own separate locking systems. Keys to these locks are given only to electrically skilled or instructed person. A person in control of the electrical installation shall decide who is competent enough to be instructed. [11]

The person in control of the electrical installation and the person in control of the work activity can be the same person. The person in control of the work activity has to give information to the person in control of the electrical installation about the nature, place and influence to the electrical installation. One of these persons has to make sure that detailed instructions are given to the working personnel before starting and on completion of the work. The information shall be given in writing, if the work is complex. Before allowing any work activity, the nominated person in control of the electrical installation and the person in control of the work activity have to come to an agreement of a description of the work activity and arrangements that are needed before the work activity. [9]

Only the person in control of the electrical installation is authorized to give the permission to start working. This procedure applies also in the case of interruption or at the end of the work. [9]

3.3 A person in control of the work activity

Every organization must have a person in control of a work activity. This person is responsible for the whole work activity and its safety. If the work activity is subdivided, a person to be responsible for the safety of each subdivision may be nominated. A person in control of a work activity must be electrically skilled person who leads and supervises electrical work. Being in touch with the work and personnel belongs to this person. Guidance of the work, ensuring competence of the workers, taking care of tools, equipment and other external matters are responsibilities of a person in control of the work activity. [10; 11]

The nominated person in control of a work activity is responsible for supervising that valid regulations and standards are followed, when working. This means that the nominated person in control of the work must educate him/herself regularly. [9; 11]

Electrical devices and installations to be handed over to customer shall be electrically safe and in good condition before commissioning or delivering. These devices must not cause dangerous situations to people or property. This means that materials are chosen according the standards, visual inspection is performed through the making process and finished products are tested and documented before commissioning. Ensuring all this is belongs to person in control of a work activity. [11]

The nominated person in control of a work activity shall ensure that personnel are competent to do the work and are instructed well enough. That is ensured with school diplomas and references before recruiting. After recruitment new personnel must have suitable training and instructions to be able to do their work. The nominated person in control of a work has to also instruct all the persons working near the electrical installation of all the dangers that are not obvious to them. [9; 11]

3.4 Competence and training

People in the organization can be electrically skilled, instructed or ordinary persons. Electrically skilled person is someone who has relevant electrical education and/or work experience. The person is able to analyze risks, work independently and avoid possible electrical hazards. He or she is also able to supervise ordinary or guided people, when they are working. [9; 11]

Instructed person is someone who has electrical education and varying amount of electrical work experience. Instructed person can also be an ordinary person, who is instructed by skilled person to avoid possible dangers associated with electricity and to do the work. [11]

Ordinary person is someone who does not have electrical education or work experience and is not instructed to do the work. This person is not capable to realize all the dangers which electrical installation may cause. [9]

Managers, employees and third parties must be adequately trained. Competence criteria for different tasks should be set and safety training should support the criteria by being based on training needs analysis. Safety training should also be resourced and adapted to incidents and experience. The training should include following subjects:

- Use of personal protective equipment
- Operation of machinery
- Isolation
- Lifting operations
- Working at height
- First aid
- Fire and emergency. [12]

At the end of the training, there should be a test of learning, if it concerns safety critical activities. [12]

When work tasks include similar electrical devices or installations, two years of work experience of that kind of electrical work and basic electrical education is needed. Altogether, everyone shall be competent to do their job safely. This includes training and instructions on electrical safety and dangers of electricity and its applications. High voltage tasks and using of personal protective equipment shall be gone through. Emergency procedures in case of accidents must also be included to training. [11; 12]

When working in vicinity of electrical installation, there shall be enough people who have suitable knowledge of first aid and are able to help. All electrically skilled persons including management and assistants shall be given first aid training. First aid training skills shall be maintained continuously and that is why first aid training must be completed regularly. [9; 11]

3.5 Communication

When information is passed or exchanged between persons, it is called communication. There are many communication methods. You can exchange information in writing, spoken language or visually. Exchanging information visually includes lights, annunciator panels and display units, for example. Instructions shall be written down and repeated to the sender. [9]

The person in control of the electrical installation shall be informed before doing any electrical work to the installation. The information flow shall be reliable and clear. There shall be no misunderstanding possibilities or false signals in any circumstances. That concerns especially when are using other means of transmitting information, for example radio, lights, or computer. [9; 11]

When using spoken language as a communication method, misunderstandings will be avoided, if receiver repeats information back to the sender and sender verifies information to be rightfully received and understood.

All information associated with safe operation of the electrical installation will be transmitted by an accurate notification. The status of the switchgear, the position of safety devices and network arrangements are that kind of information. [9; 11]

Electrical work must not be started and electrical installation must not be re-energized after the work only relying on prearranged signals or time. Safety devices shall not be defeated or circumvented in any circumstances. [9]

Communication methods shall always be revised before starting to work. This way all new workers will know the right procedures for a specific work. Especially new workers shall be briefed carefully. [11]

3.6 Performance monitoring

Individual checks, planned audits and behavioral surveys shall be made to monitor compliance. These are for ensuring that good trade practices and safe working methods are being followed. Safety observational tours shall be arranged regularly to notice if something is wrong or unsafe. There should also be annual audit program to check compliance with current standard. [4; 13]

All accidents and near misses related to electrical safety should be reported, recorded and investigated. Reports shall be directed to Management and after that they will be investigated. Then it is possible to make records. Also minor accidents must be recorded, because records can help to make working environment safer. Reporting near misses should be encouraged by arranging regular meetings, where people can share thoughts and concerns about accidents. [4; 13]

All the records should be kept secured and they shall include annual calibration records of all equipment, records of training and safety inspection reports. These documents should be stored for five years. [4; 13]

All equipment, devices and spaces used in electrical testing should be maintained in good condition. This includes predictive, periodic and corrective maintenance according to the manufacturer’s recommendation. Also preventive maintenance should be used to help keep everything in good condition and it includes following things:

- All fixed guards are visually checked to ensure that guards are still safe to use and there are no damages.
- All equipment and tools are visually checked before use.
- All test equipment and safety devices shall be calibrated annually.
- Checking that the photoelectric light curtains and scanners are operational.
- Guards of the operator are in good shape and defect free. Interlock mechanism should be fully operational. [4]

Preventive maintenance should include at least the things above, but other measures may be performed as well.

2 REQUIREMENTS FOR TEST STATIONS

Electrical testing is usually performed in fixed or temporary test stations. Product to be tested defines what kind of test stations is used. Some products are electrically tested in fixed stationary test stations. There are fixed test stations for tests during the production and in the end of production, when the finished product is tested before sending it to customers. [14]

Tests during the production are done to ensure right functions before continuing the production. These products are usually similar and testing is performed the same way every time. Tests in the end of the production are made to ensure right function of the finished product. These tests may be different for every product and include many different tests.

There may be a need to electrically test products in the middle of production. Products may be large and difficult to move, so testing is performed in temporary test station. Temporary test stations will be built around the product and after testing is complete, it will be removed. [14]

4.1 Fixed test stations

As said before, fixed test stations can be divided to stations with to two different purposes. Testing is these stations may be different, but safety issues are quite the same. In general, all test stations should be designed and built to protect people from electrical hazards. Barriers can be used to prevent touching live parts. In addition live parts can also be shrouded or covered. Distance between live part and a person is enough, when the person is not able to touch live part with hands, legs or tools. [14]

Test area is divided to different sections, which are defined by testing voltage. Figure 4 demonstrates those different sections in different test stations.

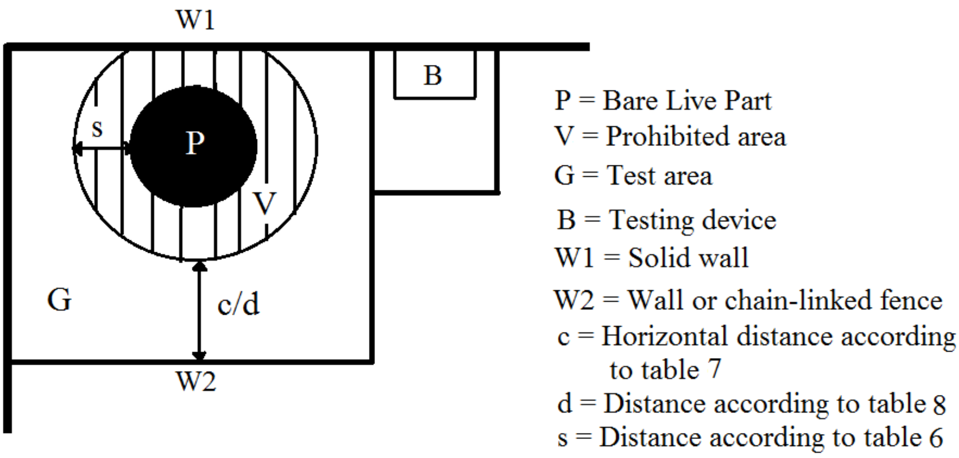

Figure 4. *Example of different areas of a test station [14]*

The center is always a live part, a device or installation to be tested. Around live part is a prohibited area, where shall be nothing, but the test piece. Reaching to this zone is considered equal to touching live part. In Figure 4 the distance *s* according to Table 6 is a width of prohibited area depending on testing voltage. In Table 6 is shown measurements for prohibited area with test voltages from 1 kV to 1000 kV. [14]

Table 6. *Measurements for prohibited area with different testing voltages. [14]*

AC testing voltage, 50/60 HZ RMS		AC testing voltage, 50/60 HZ RMS	
U (kV)	s (mm)	U (kV)	s (mm)
≤1	No touching	110	620
3	20	130	740
5	30	150	860
6	35	170	980
10	60	190	1100
15	85	210	1240
20	115	220	1300
25	140	260	1550
30	170	300	1850
35	195	340	2150
40	225	380	2450
45	250	420	2750
50	280	460	3100
55	305	500	3500
60	335	600	4500
70	390	700	5600
80	450	800	6900
90	510	900	8300
100	560	1000	9900

Surfaces of live part are limits of prohibited area, if testing voltage is not more than 1000 V. Around the prohibited area is restricted area, which is lined with barriers. Barriers, such as chain-linked fences and walls should ensure that only test personnel are able to go or reach to prohibited area. Walls or chain-linked fences should be 1.8 m high and possible width of opening should be 40 mm at maximum. In Figure 4 the distance *c* according Table 7 is a horizontal distance between prohibited area and the barrier. Figure 5 clarifies Table 7 and its dimensions. [14]

Table 7. *Distance between the barrier and danger point. [14]*

Distance of the danger point from the floor a mm	Height of the edge of the means of protection (barrier) b mm							
	1000	1200	1400	1600	1800	2000	2200	2400
	Horizontal distance between means of protection (barrier) and the danger point c mm							
2400	100	100	100	100	100	10	100	100
2200	600	600	500	500	400	350	250	
2000	1100	900	700	600	500	350		
1800	1100	1000	900	900	600			
1600	1300	1000	900	900	500			
1400	1300	1000	900	800	100			
1200	1400	1000	900	500				
1000	1400	1000	900	300				
800	1300	900	600					
600	1200	500						
400	1200	300						
200	1100	200						
Values below 1000 mm for edge b are not specified as this would not increase the arm's reach and in addition there would be a risk of falling into the test area.								

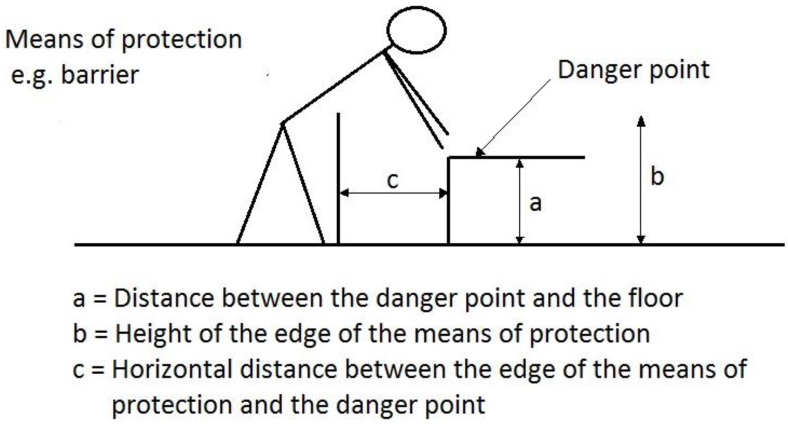

Figure 5. *Demonstration of the dimensions listed in Table 14. [14]*

Distance *d* according to Table 8 is used when barrier is chain-linked fence. It tells distance between prohibited area and chain-linked fence in relation to opening of the fence. [14]

Table 8. *Minimum distance between opening in the barrier [14]*

Width of opening (diameter or side length) mm	Minimum distance from the prohibition zone mm		
	Slot	Square	Circle
Over 4 to 6	10	5	5
Over 6 to 8	20	15	5
Over 8 to 10	80	25	20
Over 10 to 12	100	80	80
Over 12 to 20	120	120	120
Over 20 to 30	850	120	120
Over 30 to 40	850	200	120
Over 40 to 120	850	850	850

If barriers are made of conducting materials, they should be earthed properly. If that is not possible, other measures should be used to prevent indirect electric shocks in case of faults. Barriers should have suitable warnings signs, which are in the local language. [14]

Test station should be clearly recognizable and signal lights should be used to indicate the status of the test area. Red light is the most common warning light and it means that test is in progress and all access to test area is prohibited. If all lights are off, test station must be treated as potentially live. [4; 14]

In Figure 6 is a fixed test stations for electrical tests during production. Warning lights, different signs and emergency buttons can be seen in the figure. Products to be tested will be placed inside red markings on the floor. After that doors will be closed and other safety measures will be checked and verified. Test person carries out testing from test room with the help of testing device.

Figure 6. *Fixed test station in the middle of production.*

Test stations in the middle of production have often small test room only for one of a few persons. In Figure 7 a test person is performing a test in a small test room in a test station in the middle of production.

Figure 7. *Test person in a test room.*

Test stations, where finished products are to be tested are a bit different than test stations in the middle of production. They may have bigger test rooms for personnel and customers, who are following tests.

In Figure 8 is a test station for finished products. On the right you can see test room and its windows and it is significantly bigger than test room in Figure 7. In Figure 8 a product to be tested is being moved into its place.

Figure 8. *Fixed test station for finished products.*

In both type of test stations power can be turned on only if protection is fully operational and works right. Switching should be carried out remotely from test room and emergency stops should be located inside and outside the test area. Access ways and escape routes should always be kept free from obstacles and flammable materials. Also vicinity of electrical switchgear and control should be free from those. [4; 14]

4.2 Temporary test station

Temporary test installation is usually for short tests and single devices to be tested. Usually temporary test station is built when it is difficult or impossible to move the test piece to a test station. When building the test area, access to a prohibited area shall be prevented from others than testing personnel with barriers. Warning signs and lights should be used to indicate the status of the test installation and to make test area noticeable. [14]

Locations for barriers and measurements for prohibited area can be defined the same way as explained in Section 4.1. Width of the prohibited area can be found form Table 6. The location of the barriers can be defined by using Table 7 and Figure 8. If a barrier is a chain-linked fence, width of opening has to be considered when defining measures. Table 8 shows how width of the opening has an effect on the distance of the barrier.

The whole testing area shall be supervised during testing, if barriers are only chains, robes or belts. If one person cannot do that, there shall be at least an instructed person supervising test area and be prepared to action, if something happens. Temporary test station and personnel working is shown in Figure 9. [14]

Figure 9. *Temporary test station*

If there are objects next to an object to be tested, it shall be ensured that those objects do not become live. Figure 10 shows how a smaller rotor is included to a test area, because it is so close to a rotor to be tested. All other conducting objects in the test area should be earthed too.

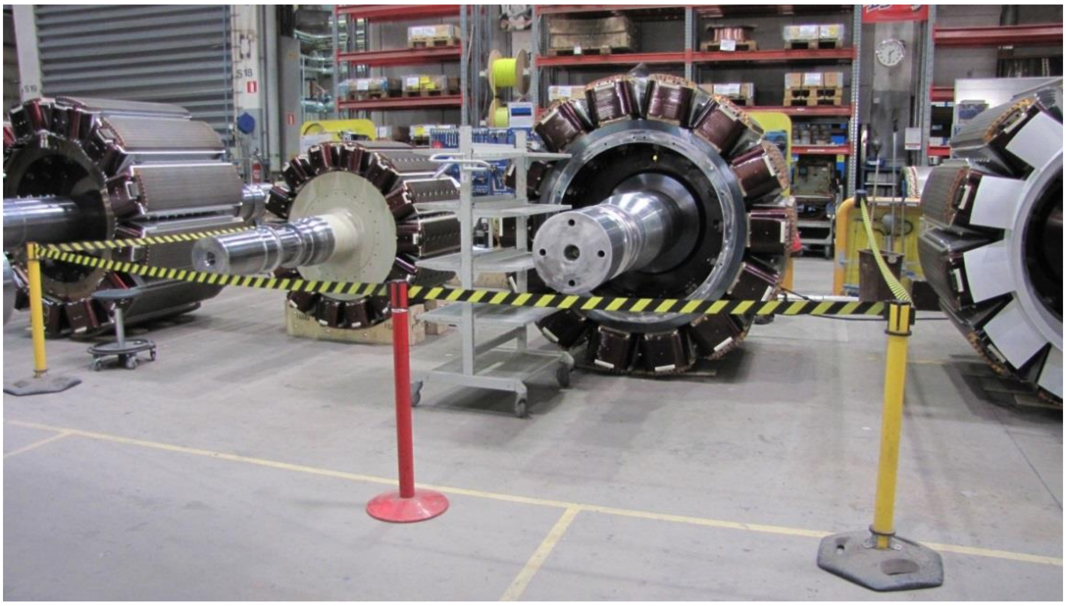

Figure 10. *Two objects inside the temporary test station*

In this case, smaller rotor is not moved away, because there is not enough space for it elsewhere. Distance from bigger rotor to smaller rotor is smaller than prohibited area and test area together, so the rotor is included the test area. Distances can be determined with the help of Tables 6 and 7. The smaller rotor is earthed properly to ensure that voltage does not transfer from bigger rotor to smaller rotor.

5 BEFORE ELECTRICAL TESTING

Before carrying out electrical testing, there are many things that should be considered. It all starts with planning the test and doing risk analysis. People who are associated with the test should be nominated and they should be trained and competent to do their job. All personnel should know what personal protective equipment should be worn and how to give first aid in case of emergency.

The test station and test piece itself need lots of preparations to ensure safety. The test station and its safety functions should be checked and test equipment and devices should function right. The test piece often needs to be moved, covered and connected.

When the test is completed, there is still a possibility of a danger. It is important to work safely until the test area and the test piece are proved to be dead again.

5.1 Preparation of test arrangement

Usually need for electrical testing arises when electric features or functions of a product are wanted to be checked. When it is clear what features and functions are wanted to be checked, next step is to think what results are wanted from the test. Knowing the target of the test helps planning the whole testing process forward towards safe actions.

It has to be thought in detail how it is possible to carry out a precise testing. Risk analysis must be made concerning the work and all possible hazards and other safety issues should be gone through. The goal is always to try to carry out the work dead, but other ways are possible too.

A person in control of a work activity should ensure that the person or persons who are doing the test are competent, trained and instructed to this particular work. Only electrically skilled persons or instructed persons are allowed to work with testing equipment. They should know how to do the work and what safety requirements and rules should be taken into account before, during and after the test. There should also be a person maintaining electrical safety at the work place to ensure all the safety requirements are fulfilled. [14]

Test place should be chosen and it should be valid for electrical tests. Fixed or temporary test stations are usually used. Test place should have test equipment and devices to carry out tests. These equipment and devices should be calibrated and maintained in good condition to ensure safe work and good test results. Test persons should also know how to use the equipment. [14]

When everything is set and ready, it is time to sign permit to work. It is one more safety measure in the process and it makes sure that all procedures to ensure safety are made before starting to work. If electrical testing is made in other employers work site, measurement plan should be made and signed.

5.2 Earthing requirements

Earthing is used to prevent dangerous voltages at the work location in case of faults. The electrical installation shall be ensured to be dead before doing any earthing. Before ensuring dead, the installation shall be treated as live. [9]

All parts to be worked on in high voltage installations and low voltage installations over 1000 A, should be short-circuited and earthed. Earthing and short-circuiting equipment or devices shall be connected to the common point and then to the components to be earthed. If possible, all earthing equipment should be visible. Earthing and short-circuiting should be set up as close to work location as possible. Usually earths should be found between possible high voltage sources and the work location. Figure 11 shows two examples of earthings in testing areas. [8; 11]

Figure 11. *Earthings in testing areas. [15]*

In Figure 12 is a portable earthing device in a test station. It is used to earth a piece to be tested. Portable earthing device provides a path for the short-circuit current away from a test person and allows short-circuit detection equipment to operate and disconnect supply. It also minimizes the voltage rise and decreases a possibility for electric shock from occurring.

Figure 12. *Portable earthing device*

There is a danger from potential differences on the installation, if conductors are to be broken or joined during the work. To ensure safety, earthing should be done at the work location before doing anything to conductors and they must remain secured during the work. If earthings are moved while testing, special precaution shall be taken to ensure safety. [9; 11]

5.3 Personal protective equipment

The main goal is to always keep all employees and contractors protected from an arc flash. All employees and contractors who carry out work at low or high voltage should be protected to a minimum standard in respect of arc flash the whole time. All or some of the following personal protective equipment are needed, depending on the situation:

- Whole body clothing
- Safety footwear
- Eye/face protection
- Hearing protection
- Voltage rated gloves
- Head protection
- Voltage rated tools. [2; 11]

If personal protective equipment is required, there should be a visible sign in the area in question. Local regulations and risk assessment determine what personal protective equipment shall be worn. Figure 13 shows an example of the sign, which tells what personal protective equipment should be used in a specific area. [11]

Figure 13. *A sign telling what personal protective equipment should be used.*

All persons who are doing electrical testing shall wear at least long sleeved shirt, long trousers and safety footwear, if there is a danger of arc flash. Shirts and jackets should not have pockets in the chest area, but if there are, there shall not be any items. This must be checked always at the start of every shift. [2]

Safety footwear and safety glasses must be used in all manufacturing areas. Safety footwear must also be used in other areas where may be a possibility to foot or ankle injuries and safety glasses in areas, which may have risk of eye injuries. When walking through safety footwear or safety glasses area, personal protective equipment in question must be used. Electrically-insulating gloves shall be worn, if there is a chance for an accidental contact to exposed conductors. [11]

Hearing protection must be used when the noise level reaches to or above 85 decibels on average. If walking through that kind of area, hearing protection must be used. All personal protective equipment shall be company approved. [11]

5.4 Other work safety issues

Work safety consists of many factors and these factors have to also be considered when doing electrical work. These factors are ergonomy, physical issues and organized and clean work place. [b]

Main goal of ergonomy is to match people's physical and mental condition with the work that is to be done. Ergonomy is used to increase safety, health and wellbeing. If a person is under- or overloaded physically or/and mentally, it can result in negative changes in a person. By removing inconvenient work load and increasing features that are suitable for a person, it is possible to make working more pleasant. Person can influence on personal load by developing preparedness and approach to the work. Work place should be designed to allow good working posture and movements. Electrical work is done often too difficult and tight places. [16]

Noise can cause hearing injury and disturbs communication. Other factors that are caused by noise are sleeping problems and declined performance. Machines and equipment are usual sources of noise. If noise exceeds 85 decibels, different measures should be taken to decrease exposure. Technical measures to block noise should be used firstly. After that noise should be blocked with hearing protection. [11; 16]

General cleanliness and organization should be considered before starting to work. Working place and places for equipment and other necessary items should be organized and planned before starting to work. When working, passage ways should be kept clear, waste should be put away and staff rooms should be kept clean. All persons should follow the instructions to keep working place clean to maintain safety. [9; 16]

5.5 Emergency situations

There should be a plan in case of an emergency. Emergency can be related to fire or medical emergency. [11]

5.5.1 Fire

In case of a fire there should be fire alarm system to warn working people inside the building. Smoke detection should be part of the system and smoke detectors should be installed on to different places, which are risk areas. The system should also have call points, which can be used to activate fire alarm. In Figure 14 can be seen a call point sign and below that is activation device and In case of power failure, there should be emergency lightning leading the way out. [12]

Figure 14. *Signs telling a place for a call point in case of a fire.*

To fight against the fire, there should be appropriate firefighting equipment provided. All equipment and systems should be inspected regularly and kept in good condition. In Figure 15 can be seen a firefighting equipment sign and below that there is equipment itself. [11]

Figure 15. *A sign telling place for firefighting equipment*

All personnel should be trained and instructed and they should know how to act in an emergency situation. The training should include the whole chain of events starting with how to act when spotting the fire and ending to getting in fire assembly point. The following areas should be covered:

- What to do when spotting a fire
- How to raise the fire alarm
- What to do when hearing the fire alarm
- Communication with the fire department
- Where to find and how to use firefighting equipment
- Fire escape routes
- Fire assembly point. [11]

Fire evacuation drills should be held at least annually and goal for every evacuation should be five minutes from alarm to headcount check. [11]

5.5.2 Medical emergency

In medical emergency first aid is the first step of helping. That is why there should be enough trained persons, who are able to help when working on site. There should also be appropriately stocked first aid kits available near work place. Frist aid kits should be marked visibly and be easily found, like in Figure 16. [9]

Figure 16. *First aid emergency kit in a visible place.*

First aid for electrical emergency sign should be visible in every work area. This should contain following steps:

1. Make a quick estimate about the situation
2. Shut down the power and release injured person from being part of a circuit without incurring damage to you. Power should be shut down with a switch or unplugging electrical equipment. If the power cannot be shut down quickly, the injured person should be released from being a part of a circuit with the help of dry wooden stick, a rope or a piece of clothing. Metal or wet object should not be used. When dealing with high voltage, rescue operation should not be started before skilled person has shut down the power.
3. Check the state of injured person. If injured person is unconscious or looks lifeless, it should be checked if there is a possibility to wake up the person by speaking or shaking him or her.
4. Call help. If the injured person does not wake up and does not react in any ways, shout out for help and ask someone nearby to make an emergency call. If you are alone, do it yourself. Follow instructions to be given by phone.
5. Give first aid. Open the respiratory passage and check the breathing by raising the chin with two fingers and bend the head back with another hand. Check if there is movement in the chest, sound of normal breathing or feeling of air flowing to your cheek.

   If the person is breathing normally, he or she should be turned to his or hers side to secure breathing.

   If breathing is not normal, begin press reflation. Press reflation consists of pressing the chest 30 times and then blowing in to the person's mouth 2 times. This should be continued until breathing starts again, professional person takes over the situation or you are not able to continue anymore. [16]

In electrical accident the injured person gets often burns. Burns can be seen on skin, but there are also internal burns. Internal burns can be difficult and are not visible to the eye. First aid to the burns is to cool the skin, but often securing vital functions are more important than taking care of burns. If reflation is needed, burns are not treated. [16]

Eyes can be also in danger in electrical accident. Arc flash can glare a person and first aid for easing the pain from glare is cold and wet bandage. [16]

First aid in case of shock should also be in electrical first aid sign. Shock can occur in electrical accidents where magnitude of current is over 50 milliamperes, but duration is shorter than a cardiac cycle. Symptoms of shock, like dizziness, pale and cold sweated skin, thirst and fast and decreasing pulse, can develop fast. Without first aid shock can be turned serious and lead to unconsciousness. This can be prevented with proper first aid, which includes following steps:

1. Help injured person to lay down
2. Lift the persons legs up
3. Keep the person warm with blanket or jacket. Shock causes injured person to be cold.

4. Behave calmly
5. Make sure that help is called out
6. Do not leave the injured person alone, unless it is necessary. [16]

If first aid is not enough and doctor is needed, there should be transportation available to local hospital.

5.6 Preparation of the test area and test piece

There are lots of things that need to be considered when preparing for an electrical test. Firstly, the test area needs preparation and inspection. The test area shall be free of any unnecessary items and all devices and tools shall be stacked and stored properly. All tools, devices and equipment shall be maintained in a good condition. That includes visual inspections and electrical testing, if necessary. [9]

Tools, devices and equipment shall fulfill the requirements of relevant European, National or International standards. Those shall be used and stored according the instructions from the manufacturer or supplier. Figure 17 shows an example how tools shall be stored. [9; 11]

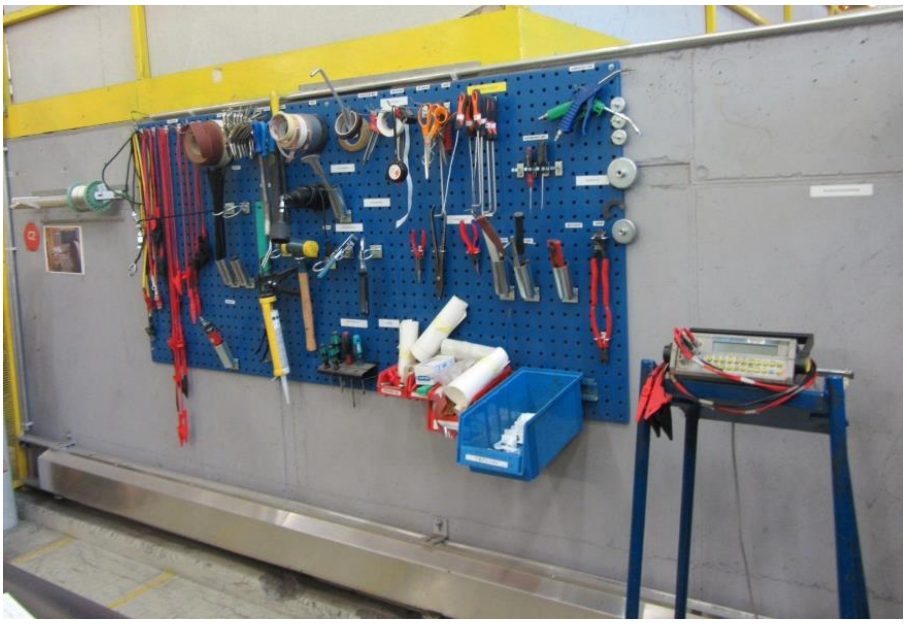

Figure 17. *Tools stored properly*

All cables shall be marked on both ends with right code. Cables that are not used must be earthed with bolt connection in the test area. Proper use of cables is shown in Figure 18. After using, cables shall be stacked properly for future use. [15]

Figure 18. *Unused cables earthed in test area.*

Condition of cables should be checked regularly. Protection insulation and integrity of the cable should also be checked and visually inspected prior using. When voltage is over 1000 V, only armored cables should be used. [15]

Before bringing the test piece to test area, it should be checked that test station shall have emergency buttons to turn off all power in the test area. The function of the emergency button shall be checked at the start of every shift. In case of an emergency, all access point must be kept clear. [14; 15]

Bringing the test piece to the test area can be done a couple of ways. Test piece shall be moved to the test area with hydraulic pallet truck, roller pallet, crane or conveyor system. In Figure 19, personnel are moving a test piece to the test station with a crane.

Figure 19. *Moving the test piece*

Overhead lifting is not recommended. If the only option is to lift the test piece to the test area, the following precautions shall be followed.

- There shall not be any overhead material movement above the test area.
- The test piece should be moved to the test area through the door. It is not allowed to lift the test piece over the test area fences. [15]

When the test piece is in its place, it should be ensured that the whole test area is visible to the test operator. If that is not the case, the test area should be equipped with cameras and there shall be video feed available. [4]

The test piece needs also preparing. First of all, the test piece should be earthed. In addition all moving parts, for example shafts, shall be covered. If rotors are not covered, there is a possibility to trip or be entangled to that. Testing terminals shall also be covered. Covering them is easy and economic and it prevents accidental touching to electrical connections. Voltage removal to objects next to tested object should be prevented. Other objects may be earthed or covered, for example. [14; 15]

Before carrying out any tests, testing personnel should ensure that test probes are visually fine and work right. Safety devices should be checked before each working shift and all defects should be reported to supervisor. Personal protective equipment should also be checked and worn. Possible arc flashes and other hazards, like noise and fire, should be taken into account with suitable personal protective equipment. [14; 15]

A person in control of a work should ensure that instructions are followed before test equipment is ready to be switched on. Electrical testing checklist should be used to all high voltage tests. Checklist is for ensuring that testing can be carried out safely. A person in control of a work activity shall ensure that connections and safety measures are checked prior energizing the test object. All persons, except test personnel shall leave test area before switching powers. [9,14]

A person in control of a work activity has to make sure that there is no lone working, when a test is being carried out at voltages bigger that 50 V Ac or 120 V. There shall always be two persons present, when carrying out high voltage testing. Only a person in control of a work can authorize switching. [4; 14; 15]

Testing equipment should be secured from inappropriate and meaningless voltage switching to test circuits. Test circuit should not become live automatically after blackout. [9; 14]

When test is done, there shall be appropriate equipment to discharge an object to be tested after switching power off, if it does not discharge by itself. [14]

6 WORKING METHODS

There are three different work methods when carrying out electrical work and those are dead working, working in the vicinity of live parts and live working. The aim is always to carry out electrical work by dead working, if possible. Live working should be the last method to be considered. All of these three methods are designed to ensure that there is no danger of electrical shock or arc for personnel, if all the rules and requirements are followed. [9]

6.1 Dead working

By using seven steps principles it is ensured that working area is and stays dead the whole working time. Work area must be determined clearly to avoid dangers. [9; 10]

A person in control of the electrical installation is authorized to give permission to start working. A person in control of electrical safety can give permission to start working only to an individual work. Permission is granted, when the electrical installation is made dead. If there are multiple works groups in the same area, only a person in control of the work, who supervises the whole working area, shall give permission to start working in the area. All working personnel shall be electrically skilled or instructed or supervised by either one. [9; 10]

Before switching the installation back on, it shall be ensured that all personnel have left the installation and all tools, devices and equipment are removed. Commissioning inspection shall be performed and all earthings and coverings shall be removed, proceeding towards outer limits of the installation. Cables heads shall not be left uncovered. [9; 10]

All locks shall be removed and shrouding shall be put back on. Finally it shall be ensured that nobody or nothing is in the danger zone, and remove all warning signs. [9]

6.1.1 Seven steps

The seven steps principle is the basis for safe working on low voltage and high voltage systems. With the help of seven steps it is possible to create a safe working area. The seven steps is the minimum standard and must be achieved always. If apparatus is rated over 1 kV, all seven steps shall always be applied. [9; 10]

- Step One: Clearly identify the work location.

There should be suitable labels, signs, schematics and plans to help identify the location. Suitable identification arrangements should be done, if the work target is not easily identified. Cables are sometimes not easily identified. Nearby live apparatus shall be marked as dangerous with warning labels. Identifying the work location may have to be repeated throughout the work. [9; 10]

- Step Two: Disconnect and secure against reconnection.

The apparatus must be made dead by disconnecting it from all possible supply points. Disconnection is determined carefully with the help of drawings and documents. An appropriate electrical gap should be made to every connection point. A reliable insulation, equivalent to electrical gap, can be also used. [9; 10]

The gap should be physically secured, so that it cannot accidentally re-connect. That is executed typically by barriers or locks, removing fuses, disconnecting stored mechanical energy devices or removing the apparatus from its normal position. The most secure way to prevent re-connection is to lock the gap open. Another secure way is to lock the whole electrical space. It should be impossible to reconnect the circuit by closing a switching device with remote control. [9; 10; 11]

Each disconnection point should have a warning sign and possible keys should be kept in secure place. Sign shall tell a date and a person's name, which has set the sign. It is also recommendable to put a phone number to the sign. [9; 11]

- Step three: Provide protection against other live parts.

Shrouding and screens can be used to protect persons from live parts. Warning signs shall be attached to all panels that are near. [9; 10; 11]

- Step four: Take special precautions when close to bare conductors.

When making the safe working area by installing safety barriers or screen, special precautions should be followed. Potentially live parts may be close enough to accidentally touch. The person making the safe working area shall wear insulated gloves, be with another person who can help and make sure there is no chance to accidental slips. [9; 10; 11]

The work can be done without barriers, if distances to live parts are big enough the whole working time. This method and its safety shall always be estimated before the work. [9]

- Step five: Verify the installation is dead.

Verifying should be done with an approved and proper tester at all of the working points. The tester should be tested before and after using it to make sure it works properly. When using the tester, a person should take care not to accidentally touch anywhere else than should. [9; 10]

- Step six: Carry out earthing and short circuiting.

Earthing is used to prevent dangerous voltages at the work location, in case of faults or other actions. It shall be ensured that the electrical installation is dead before doing any earthing. Before the installation is ensured dead, it shall be treated as live. [9; 11]

The apparatus to be worked on should be connected to earth. Those connections should be able to carry full short circuit current at that point. Earthing shall be visible in a test area, if possible. Earthing shall also be set up as close to working point as possible. [9; 11]

Earthing should be in place through the work. It may be possible to earth the apparatus with a rated switch. Earths should be found between possible high voltage sources and the work location. [9]

There should be equi-potential zone for all persons at the work location. That is made by connecting all earths at that point. Those earths may be moved when needed. [9]

- Step seven: Issue an electrical permit to work.

An electrical permit to work is a document, which specifies the apparatus to be worked on, the nature and extend of the work and the safety precautions. It is a summary of all the previous protective measures and possible hazards. A nominated person in control of an electrical installation can give permission to start working. The permission can be given, when all steps above are performed. [9;10]

6.2 Working in the vicinity of live parts

When worker is in the vicinity zone or reaches there with body parts, tools or devices, it is called working in the vicinity of live parts. Worker shall not enter or reach to live working zone. [9; 11]

Vicinity zone of live part is around live working zone. Its perimeter is determined from a live part. Figure 20 shows how vicinity zone is surrounding the live working zone. [9]

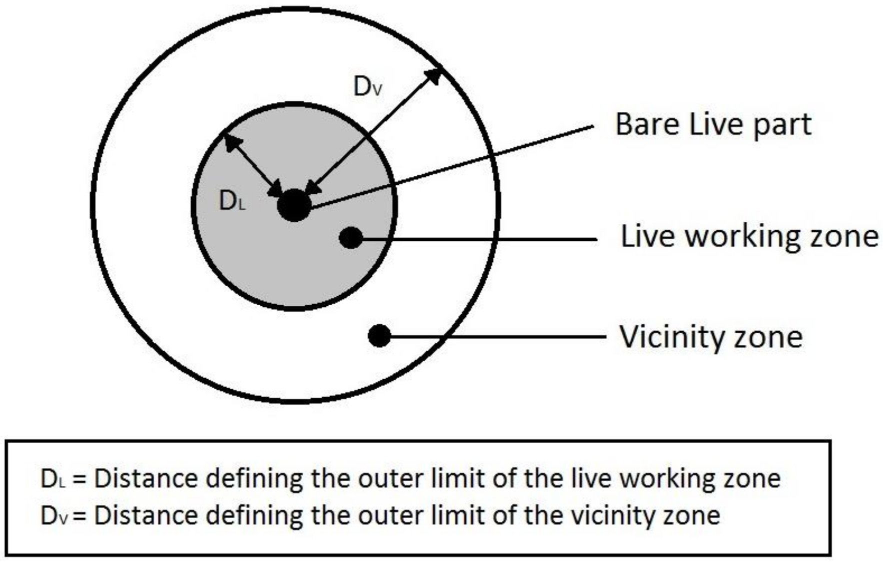

Figure 20. *Live working zone and vicinity zone [9]*

Different measures for outer limits of the vicinity zone are shown in Table 9. Width of the vicinity zone can be calculated from the same table by difference of minimum working clearance and live working zone. Outer limit of the vicinity zone is the boundary between the vicinity zone and the safe area. [9]

Table 9. *Measurements for live zone and vicinity zone in different voltages. [9]*

System Voltage kV	Outer limit of the vicinity zone m	Outer limit of the live zone M
< 1	0,7	0,2
3	1,2	0,22
6	1,2	0,23
10	1,4	0,35
20	1,4	0,4
30	1,6	0,56
45	1,6	0,63
110	2	1
220	3,6	1,6
400	4,5	2,5

The work location shall always be determined beforehand and be limited with robes and signs, if necessary. All live parts shall be marked clearly, when the whole installation is not dead. Accidental touching live parts or reaching to live working zone can be prevented by using removable shields, barriers boxes or insulating covers. Dead or live working procedures shall be used, when installing protective devices. [9; 11]

Before starting the work, it is encouraged to make sure if there is a chance to dead working instead of working in the vicinity zone. If there is a possibility to cover all live parts, all zones are removed and the work can be done safely. Figure 21 shows how insulated cover makes the zone smaller or even removes parts of it. This situation is equal to situation where all live parts are at least IP2X covered. [9]

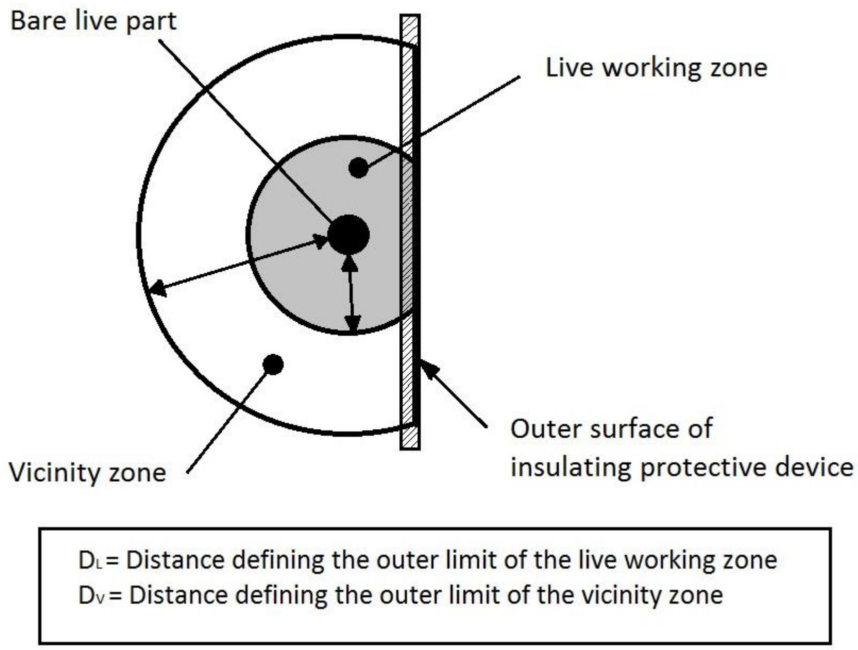

Figure 21. *Covering live and vicinity zones [9]*

Only electrically skilled person or instructed person with enough information is allowed to do electrical work in the vicinity of live parts. Ordinary persons are not allowed to do electrical work in the vicinity of live parts. [9]

There are requirements regarding personnel who work in the vicinity of live parts, but do not do electrical work. Instructed person or other personnel supervised by electrically skilled person can construct, paint or clean in the vicinity of live parts. They shall be familiar with the location and have enough experience working in electrical spaces. They shall also be informed about electrical hazards and how to act if something happens. [9; 11]

6.3 Live working

Electrical work is called live work, when worker touches bare live parts on purpose or reaches into the live working zone with part of the body, tools, equipment or devices. Live working may be changing components, for example. These situations apply on both low and high voltage. Bare live part shall never be touched only with insulated gloves. The worker shall have insulated tools, equipment and devices. [9; 11]

Live working zone is a three dimensional area surrounding live part. Perimeter of the live working zone is determined from bare live part. Figure 20 shows an example of a live working zone. A live working zone is formed around a bare live part only and around the live working zone is a vicinity zone. [9; 11]

. If low voltage is used or all live parts are IP2X-protected, these working zones do not exist. Table 9 shows how outer distance of live working zone changes along with the voltage. The bigger the used voltage, the wider is the live working zone. [11]

6.3.1 Work instruction

Work instruction must be used when doing live electrical work. Live work should be done only in situation, when shutting down the power is not an option due production causes. It must be in writing and the user of the work instruction can create it. Instruction should follow the standards and it should take into account how demanding the work is. It is recommendable to create the work instruction in co-operation with workers and a person in control of the work activity. The person in control of the work activity and if necessary, a person in control of the electrical installation, have to approve all new work instructions. [17]

Detailed work instruction includes nine different stages:

1. **General requirements of live work**

The necessity of the live work must be estimated and all permits regarding the work must be checked. All possible dangers and hazards shall be evaluated carefully and a person in control of electrical safety shall be nominated. [17]

2. **Restrictions caused by the structure of equipment**

The equipment to be worked on may be in difficult place or it may be hard to move it. The possibility of short circuit must be evaluated in case of accidental touch. [17]

3. **Personal protective equipment and tools**

Personal protective equipment and tool should always be inspected and stated to be in good condition before use. Measurement tools should be tested before use and other equipment and tools shall be at least visually inspected. Personal protective equipment and tool should be suitable for the work. [17]

4. **Specific parts are dead and remain that way**

All specific parts that need to be dead during the work shall be made dead. Assuring that they remain that way shall be done according to the seven steps principles. [17]

5. The installation can be done dead quickly, if necessary

When there is large short-circuit current and the work is done to installation with no shrouding, it may be possible to accidentally touch live parts. That is why it is necessary to have a possibility to make the installation dead quickly. [17]

6. Ensuring the electrical circuit has no load

This is essential, when adding or removing cables or doing temporary connection. [17]

7. Covering all live and earthed parts

All bare live parts shall be covered, if possible. If there are any bare live parts below the work location, they should be covered if there is danger of tools being dropped. [9; 17]

8. Step by step work instructions

It is very important to pay attention to the order of the work action. [17]

9. Actions to be done after completion or abort

The electrical installation will be left to safe condition and all temporary covers and warning signs shall be removed. Commissioning inspection shall be done if necessary. The person in control of the electrical installation shall be informed that the work is finished. [17]

In case of an abort, the electrical installation shall be left to safe and stable condition. The person in control of the electrical installation shall be informed after that. [17]

6.4 Functional checks

Measurement, testing and inspection are functional checks. These operations are not counted as actual live working even though they fulfill definitions of live working. [11]

6.4.1 Measuring

Measurement is defined as all actions to measure physical data from electrical installations. Measurements can be executed by electrically skilled persons or ordinary persons under supervision of the electrically skilled person. Measuring instruments should be accepted, suitable and safe. The instruments should be tested before and after using.

If there is a chance to accidentally touch live parts when measuring, personal protective equipment should be used. The personnel should also act against electric shocks and effects of arcs and short circuit. The rules for dead working, working near live parts or live working should be used if necessary. Main goal is always dead working. [9; 11]

6.4.2 Testing

Testing is checking the operation of an electrical installation. Testing can also include checking electrical, mechanical or thermal condition of an installation or proving electrical protective and safety circuits' effectiveness. If testing includes measurement activities, those should be executed as mentioned above.

Electrically skilled person or instructed person can carry out testing. Also an ordinary person under supervision of an electrically skilled person is allowed to carry out testing. When testing a dead installation, rules of dead working should be followed. It is important to prevent the installation being re-energized from any source of supply, if it is necessary to remove earthings. [9; 11]

When testing is made by using external source of supply, it is essential to ensure that installation is isolated from any normal source of supply and the installation can only be re-energized from external source of supply. Safety measurements should be followed to protect personnel from electrical hazards. The points of disconnection have to be strong enough to carry test voltage on one side and working voltage on the other side. [9; 11]

Only electrically skilled person with specialized training shall carry out special electrical testing, where bare live parts are exposed. [9]

6.4.3 Inspection

The main point of inspection is to ensure that electrical installation is in accordance with technical requirements and safety regulations of the standards. The normal state of the installation may be also stated. All new electrical installations and modifications or extensions of existing installations shall be inspected before operating. All electrical installations should be inspected regularly. These periodic inspections are made to find possible defects, which can disturb the operation and create hazards. [9; 11]

The inspection usually consists of visual examination and measuring/testing along with the requirements. Relevant electrical drawings should be used when inspecting and the result of an inspection should be recorded. [9; 11]

Only electrically skilled person with relevant experience is allowed to do inspections. Suitable equipment should be used to prevent danger, when doing the inspection. [9]

7 CONCLUSIONS

Safety in electrical work has improved along the years, but there are still lots to do. Risk assessments, permits to work and work instructions are a good way to eliminate accidents. Performance monitoring and records from training and accidents help to create new risk assessments and take in to account dangerous procedures and to improve them. All improvement suggestions should be taken in to account, because there will always be something to improve.

Test stations are places to carry out electrical testing safely. Test stations can be temporary stations or fixed stations. Temporary stations are for single tests and to ensure right functions before continuing the production. In the fixed test stations can be done functional tests during the production or final tests to finished product.

There are three possible working methods for electrical work, but the goal is always to carry out the work dead. Working in the vicinity of live parts and live work are used, if dead working is not possible. Sometimes it is not possible to shut down the power, because of production or other matters.

Attitude plays a major role in electrical safety along the organization. When something happens, something has usually gone wrong in every level of the organization. A good example of the attitude is, when skilled persons are so used to their work that they forget to follow safety rules or just do not care about them, because nothing may have ever happened. This way of thinking revenge itself and actions are usually not made until something happens. That is only first level of organization, but attitude could be better in other levels too.

The next level in organization is supervisors, who may also neglect their job. They may have not kept records of trainings and competence of workers and may not have supervised working at all. Management, the upper level of organization, should take all incidents into account and do something about them. They should think why something has gone wrong and what should be done to prevent that happening again. After all, they are usually the ones to blame when something happens.

REFERENCES

[1] SFS 6002 Käytännössä – Sähkön vaarallisuus. 16.4.2012, Sähköinfo Oy. Additional material related to book SFS 6002 Käytännössä. 15 s.

[2] Protection against the thermal hazards of Electric Arcs, Code of Practice for Personal Protective Equipment. 2008, ABB Group. 13 s.

[3] Reese, Charles D. Industrial Safety and Heath for People-Oriented Services. CRC Press 2008. Chapter 14.

[4] 1LAA000050. Health and Safety Requirements for Electrical Testing, BU Power Transformers. 2012, ABB. 18 s.

[5] Harms-Ringdahl, Lars. Principles and Practice in Occupational Safety. CRC Press 2001. s. 43-54

[6] 1LAA000062. Health and Safety Requirements for Risk Assessment. 2009, ABB Group. 11 s.

[7] GI/SA-01.05A24. OHS Permit to Work Guide – High Voltage tasks. 2006, ABB Group

[8] Permit-to-work systems. United Kingdom 2002, HSE. 8 s.

[9] SFS 6002. Safety at electrical work. 2005. Helsinki, Finnish Standards Association. 67 s.

[10] GI/SA-01.05A33. Electrical Safety Rules working with over 1 kV. 2007, ABB Group. 16 s.

[11] Mäkinen, P.A. SFS 6002 Käytännössä. 15. Edition. Espoo 2012, Sähkö- ja teleurakoitsijaliitto STUL ry. 88 s.

[12] GI/SA-01.05A31. ABB Facilities Safety Rules. 2007, ABB Group.

[13] Hyatt, Nigel. Incident Investigation and Accident Prevention in The Process and Allied Industries. CRC Press 2006. Chapter 22, s.1-22.

[14] SFS-EN 50191. Erection and operation of electrical test equipment. 2011. Helsinki, Finnish Standards Association. 23 s.

[15] Health and Safety Requirements for Electrical Testing, BU DMMG. 2.6.2012, ABB Group. Instruction. 20 s.

[16] Sähkötapaturmien ensiapu. TUKES, 14.2.2012 [WWW] [Referred 18.7.2013] Available: http://www.tukes.fi/fi/toimialat/sahko-ja-hissit/sahkolaitteistot/sahkotapaturmien-ensiapu/

[17] Knuutila, O. Pulkkinen J. Jännitetyöohjeet [WWW]. [Referred 17.7.2013]. Available: http://www.tut.fi/sahkotyoturvallisuus/tietosivusto/jännitetyöohjeet