Safety in HVDC converter stations

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SUMMARY

The increasing importance of health, safety and environment aspects puts more efforts towards reconsidering design aspects of electrical installations to improve safety for occupational personnel. There have been attempts at standard level to integrate insulation distances together with the safety distances in order to provide a specific value dependable on voltage levels.

The paper contributes to the vision on insulation and safety distances as two different aspects that should be treated separately: personnel safety cannot be associated and based on insulation distances as the risk of life-threatening due to occasional arc strokes is not the same as an acceptable risk of damage of electrical equipment due to breakdown at applicable voltage stresses and environment conditions.

Safety distances are defined considering the acceptable safety risks in certain workplace, based on risk assessment, work procedures to be applied, professional skills of personnel, work environment, ambient conditions, protective measures and equipment to be used, which are specific due to different possible combinations applied to every certain working scenario. These combinations may be specified in different ways by different utilities according to their own operation and maintenance practice.

Utilities around the globe define minimum safety distances in different ways based on their own practice, national regulations, own safety instructions and guidelines. Due to a wide variety of factors specific to every certain case and different practices, the safety distances shall not be completely stipulated and standardized. National standards and safety regulations define the recommendations of HVDC manufacturers as of the highest priority to follow for safe operation and maintenance of electrical installations.

The recommended safest way is to do maintenance when the system is de-energized. This practice is supported by IEC 63065:2017 proposed as the guideline collected best operation and maintenance practices for the last decades at HVDC converter stations for optimized operation and maintenance work.

Application of automated inspection and maintenance techniques is considered as an attractive solution improving personal safety, enhancing operation and maintenance efficiency.

KEYWORDS
HVDC, converter station, personnel safety, insulation, safety distance, maintenance.
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INTRODUCTION

Due to the increment of high voltage transmission levels, the size of the equipment to be installed in switchyards of HVDC converter stations has increased considerably. Insulation of installed apparatus should be dimensioned for installation in switchyards together with another equipment in a way to provide the acceptable level of operating reliability of HVDC stations at minimum costs. Based on the acceptable breakdown probability, the required insulation distances are defined considering the certain voltage stresses obtained from insulation coordination studies and converted to the environment conditions at site, among others. Instead, safety distances are defined by different standards [1-4] in different ways. These standards are mostly based on the well-proven experience obtained at AC system voltages below 550 kV AC and cannot be directly extended to EHV (≥345 kV) and UHV (≥800 kV) electrical installations where the instable behaviour of long arcs due to air insulation breakdowns in long gaps creates the risks for personnel to be injured even though the requirements to protective pedestals and fences are fulfilled in accordance with the standards.

In the paper safety risks associated with electrical hazards in HV areas are considered. Safety of personnel is connected to the recommended maintenance activities to be done in HVDC converter stations.

SAFETY DISTANCE IN STANDARDS

Electrical safety standards offer guidelines to provide safety of persons against danger which may arise in electrical installations. Electrical safety distances applicable for working activities in the vicinity of live parts are given in several standards which co-exist today and address the safety aspects for the design, operation and maintenance of electrical installations. Common standards specifying electrical safety distances are IEC 61936-1 [1], EN 50110-1 [2] and IEEE C2 [3]. It is to be noted that these standards give different safety distances due to introducing different ergonomic components as shown in Fig. 1 [5].

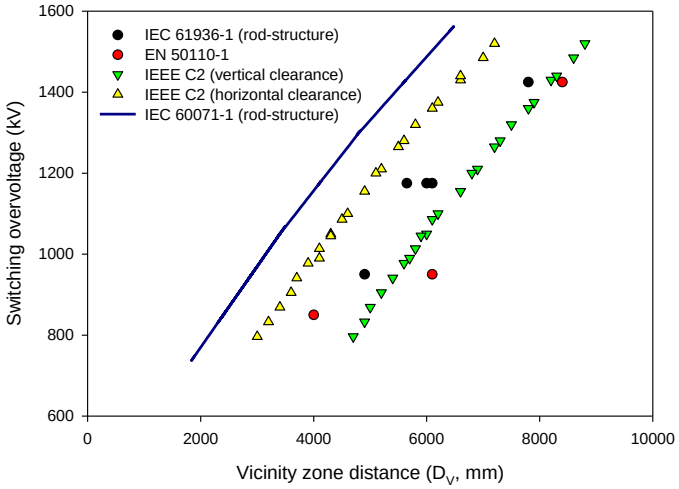

Figure 1. Safety distance in the vicinity zone acc. to standards

Various utilities have also defined standardised ergonomic components in order to plan work orders on a sound basis with fixed defined distances. The values are included into the own utilities' guidelines and instructions for operation of electrical installations and regulation for performing tasks by occupational personnel in the vicinity of electrical installations. In every certain case the safety distances are defined based on type of work activities, acceptable hazards and risks, work procedures to be applied, professional skills of occupational personnel, work environment, protective measures and equipment to be used as well as suitable maintenance methods to meet the requirements on acceptable risk [6-8]. Thereby, safety distances depend on a number of factors mostly related to the corresponding operation and maintenance procedures. Due to a wide variety of factors specific in

every case and different practices used by diverse utilities, the safety distances cannot be completely stipulated and standardized to cover all possible practical cases.

SAFETY ASPECTS IN UHVDC SWITCHYARDS

With the aim to minimize safety risks, the existing practice is to place HV apparatus at a certain height above the ground level by using the pedestals when no additional fencing or protective railings are required. International standards and different national standards consist of a guide for minimum height to insulators and minimum distances for a person approaching live metal parts of apparatus: pedestals are selected to be at least 2250 mm height for operating voltages of 1000 V and above [2, 6]. This practice is typically used in HVDC installations with operating voltages below 320 kV, when pedestals are higher than support insulators.

Meanwhile, based on the evidences from breakdown phenomena at higher voltages (≥ 800 kV) the risks of personnel being strike in case of overvoltage and the further breakdown from a live part are present even though the pedestals are used. It is related to the breakdown trajectories that do not follow the shortest path (towards pedestals), and instead, they propagate towards nearby grounded floor, walls or other grounded electrodes in surroundings. These conditions represent the environment typical for indoor DC switchyards (Fig. 2, a).

a) Indoor DC switchyards b) Outdoor DC switchyard

Figure 2. DC switchyards 800 kV in UHVDC converter stations [14]

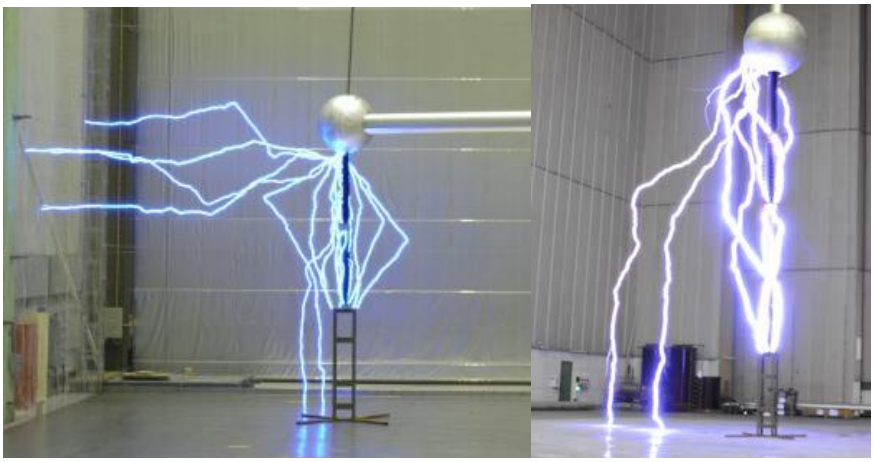

Figure 3. Breakdowns towards the wall and floor passing the pedestal in UHV arrangements [9].

In such cases, the arcs present the risks for occupational personnel at the ground level in the vicinity of live apparatus. Breakdown trajectories within the arrangement were recorded and shown in Fig. 3 where it is possible to recognize the different paths of discharges for tested configurations [9]. As it can be seen, the majority of breakdowns impacted the pedestal, however a number of breakdowns towards the wall and the floor were registered. It was concluded that even with the pedestal of 2.4 m

height there is a probability (between 7 to 16%) of breakdown that impacts the floor instead of the pedestal [9]. Probability of breakdowns towards a wall instead of the pedestal is between 3 to 20%. In the arrangement the size of electrodes, the surface conditions, flanges of the insulator's column may all have effects on the discharge. Based on the tests, the safe areas in indoor and outdoor UHV switchyards (Fig. 3) where discharge will not hit personnel in the vicinity of live equipment are undefined even though the pedestals or protective fences are installed. Safety distances based on the existing standards cannot guarantee the personnel safety in UHV arrangements. Another approach should be used to minimize safety risks for occupational personnel. The approach in the study is based on the review of certain recommended maintenance activities in UHVDC converter station based on the accumulated best practices and experience.

SAFE MAINTENANCE ACTIVITIES IN HVDC STATIONS: BEST PRACTICES

In converter stations to be able to minimize safety risks and health effects, it is necessary to identify in which areas and under which working conditions the occupational personnel shall be allowed. The presence of the personnel is dictated by periodical inspections and maintenance activities to keep the acceptable level of reliability and availability of power transmission.
During operation HVDC installations are energized and the personnel shall stay in the control and auxiliary service building. For access to the building the personnel use access roads within a station.
Occupational personnel shall only be allowed to stay inside valve/switchyard area when it is completely switched off, disconnected and properly grounded. Interlocks helps to avoid any unsafe access to installed energized equipment as the gates and doors are blocked. If all earth switches of valve hall and converter transformers are closed, then the doors are de-blocked to provide entrance. For visual inspections the valve and switchyard halls can be served with windows. Indoor installation makes possible to significantly reduce the scope of maintenance activities as well as its frequency/time interval. Advances in automation, monitoring and condition assessment result in more stations being unmanned. It helps to minimize the risks for personal to be injured due to electrical hazards.
Maintenance activities shall be done in a safe manner and included into maintenance programs that shall be prepared based on the recommendations from HVDC supplier, the maintenance instructions from equipment manufacturers, own utilities' working procedures and guidelines, national or regulatory requirements.

Maintenance programs include certain maintenance activities to be done on high voltage, low voltage and auxiliary equipment. Meanwhile, from all the activities, there are only those in the vicinity of live equipment which may expose the personnel to dangerous electrical hazards (risks of arc discharges due to breakdowns, electromagnetic emissions, etc.). Therefore, routine and preventive maintenance done during outages helps to make the working conditions for personnel free from these risks as an HVDC station is not in operation, i.e. de-energized.

Approaches to maintenance procedures may vary across utilities. With the goal to collect the best practices, IEC recommendations with principles of the safe maintenance of HVDC converter stations were prepared by IEC TC 115. The document IEC TR 60065:2017 [10] represents the guideline based on the existing operation and maintenance practices that have been successfully implemented during the last decades at HVDC converter stations all over the world. It is recommended to use the guideline as a reference to optimize operation and maintenance policy and assist utilities in performing the operation and maintenance work.

The document includes a limited list of maintenance activities that may be done during operation:

- Converter transformers: routine maintenance inspections for verification of oil/gas levels in transformers (typically done in the same proven and safe way as for HVAC oil filled transformers, trained and professional personnel required).
- Control and protection: maintenance activities on control and protection equipment including hardware and software upgrades.
- Valve cooling: routine maintenance for condition assessment of cooling pumps.

It is allowed for personnel to access the control building as well as low voltage and auxiliary systems for maintenance purposes as it poses no safety risks associated with HV areas. According to the recommendations, all maintenance activities on high voltage equipment installed in valve halls, AC and DC switchyards should be done during outage only, when the system is de-energized.

IEC 63065 [10] emphasizes and recommends the following:

- The maintenance program should be developed based on the recommendations from the HVDC supplier.
- The maintenance program should include all station equipment and should be based on risk, criticality and include coordinated scheduling.
- Diagnostic inspection is the maintenance work to be done during outage to visually inspect the appearance of a piece of equipment and its mechanical parts, for example checking the motor drive mechanism of a breaker.
- During the outage, detailed inspections and predictive tests for converter transformers, converter valves, AC/DC switchgears and arrestors are carried out, together with routine maintenance such as cleaning of the insulators (time-based maintenance).

AUTOMATED INSPECTION AND MAINTENANCE IN HVDC STATIONS

The main option to avoid safety risks associated electrical hazards in HV areas is to do maintenance activities when the system is de-energized as recommended by HVDC manufacturer. Nowadays more options are becoming available due to advances in online monitoring condition replacing physical readings from meters during personnel inspections.

The attractive option for minimizing both health and safety risks for personnel in HVDC converter stations is to implement automated inspection techniques which have also a high potential to improve the quality of maintenance procedures. Inspection robots have been put into full operation for patrol and inspection equipment in outdoor and indoor environments, as well as in valve halls, within transformers, etc. [11].

There are several key benefits from using automated inspection techniques:

- Robot- and drone-based inspection techniques has a potential to be used in areas associated with high safety risks for personnel. Deployment of automated inspection techniques provides an effective solution to the problems pertaining to safety, labour shortages, workplace hazards.
- Automated inspection can be done more frequently, even in daily manner, if needed, without personnel to be involved avoiding safety risks.
- High monitoring capability, mobility and accessibility. Spots with high position's accuracy may be approached for inspections which are either difficult to access or risky for personnel.
- Automated data collection from integrated sensors may detect leakages, hot spots, gas leaks and ageing processes at the very beginning stage.

Nowadays, progress in robotics resulted in systems that are becoming feasible for safe inspection and maintenance activities. The innovative automated robot-based technologies have been successfully implemented by different utilities at HVDC converter stations around the world [11-13].

CONCLUSIONS

There are following conclusions from the study:

1) Safety distances are related to the acceptable safety risks in the certain workplace defined by risk assessment, work procedures, professional skills of occupational personnel, work environment, ambient conditions, protective measures and equipment, which are specific due to different possible combinations applied to every certain working scenario. These combinations may be specified in different ways by different utilities according to their own practice of operation and maintenance.

2) Safety distances are defined in different ways based on national regulations, safety instructions and guidelines from utilities. Due to a wide variety of factors specific to every certain case and different practices, the safety distances shall not be stipulated and standardized.
3) National standards and safety regulations define the recommendations of manufacturer as of the highest priority to follow to be able to maintain and operate the installations in a safe way.
4) According to best practices, maintenance activities in HVDC stations shall be done in a completely safe way when the system is de-energized.
5) IEC 63065 provides general guidance on basic principles for the safe operation and maintenance of HVDC converter stations. The document supports the approach based on safe maintenance when the system is de-energized. It is recommended to use the guideline as a reference to optimize operation and maintenance policy and assist utilities in performing the operation and maintenance work
6) The latest achievements in digital technologies are attractive and promising for automated and unmanned maintenance in HVDC stations.

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