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Protection of safety installations for nuclear sites

Lightning currents greater than level of protection I as per IEC 62305

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***Abstract*— In 2011, the Fukushima nuclear plant accident in Japan was a major accident for the nuclear industry in the world. Following this event it became necessary to investigate if nuclear safety facilities were able to withstand natural stresses more severe than usual: earthquake, tidal wave, flood ... Obviously lightning is one of those natural stresses. Lightning impulses different from standardized lightning impulses must then be considered taking into account CIGRE distributions and experience feedback.**

Keywords—nuclear, lightning, CIGRE, testing

I. INTRODUCTION

For few facilities such as nuclear sites, it is important to take into account stresses that may exceed usual ones. As a matter of fact, Fukushima event has shown that natural stresses greater than average should be considered. Obviously this doesn't apply to all nuclear facilities and in a specific nuclear facility this will not apply to all structures and equipment but only to a few of them that are nuclear basic safety equipment (BSE) or basic safety structures (BSS). Such nuclear basic safety means (BSM) are defined by national authorities or by nuclear operators. Lightning is one of the stresses to be studied for these BSM. In nature, lightning current parameters may exceed values fixed for level of protection I. For example, level of protection I defines a magnitude of current between 3 kA and 200 kA. These values may be exceeded both ways: current can be as high as 300 kA and current can be as low as 2 kA. Then it is really necessary for such BSM to know what can be the influence of these currents either greater or lower than defined for level of protection I. The paper present an ongoing project preliminary applied to a real structure being a BSS in a nuclear site. It may apply to others in near future. It follows a previous theoretical study performed to determine what should be the key parameters to use for designing a lightning protection for such a building that should be able to operate in spite of very severe storms.

II. LIGHTNING CURRENTS

A. IEC 62305-1

Probabilities associated to currents as high as 300 kA are given in IEC 62305-1 [1]. In current Edition 2 of the IEC 62305-1 standard, values as high as 600 kA are even listed in Annex A (see Fig. 1). Lightning current above 300 kA have never been measured, and accordingly Edition 3 of the standard (not yet published) will not keep these values of current greater than 300 kA. Greater values than 300 kA are sometimes announced but they are not really measured. They are derived from Lightning Location System data. For the present study, a maximum current of 300 kA has been considered. Probability associated to 300 kA is 0,005. Other parameters associated to these low probabilities can be derived from curves and table given in IEC 62305-1. IEC 62305-1 is based on ELECTRA [2], [3] parameters that have been largely confirmed by a recent CIGRE report [4]. Parameters that are pertinent for lightning and surge protection are, in addition to the peak current, impulse charge and total charge, as well as di/dt. We need then to consider a first impulse with a 300 kA peak value followed by a continuous current and a subsequent impulse with high di/dt.

Probability of lightning current peak values according IEC 62305-1

Lightning current I [kA]	Probability P
200	0.01
300	0.005
400	0.002
600	0.001

Figure 1 : Probability of lightning current peak values according IEC 62305-1.

B. Fixed parameters

In order to cover the most severe stress a direct lightning current was fixed for that project: a first impulse (300 kA 10/350 wave shape) followed by a continuous current (500 A, 0,5 s) and a subsequent impulse (50 kA, with a front of 200 kA/µs). This will be named the Specific Lightning Current stress (SLC).

C. Reality check

Damages on Lightning Protection Systems have been observed in field on systems installed and tested according to standards. This means that current greater than 200 kA are occurring. As discussed above, current greater than 300 kA are sometimes announced to justify the failure of the Lightning

Protection System but the current magnitude is not measured but just derived from Lightning Location Systems. In any case, even if the current is not as high as announced, current between 200 kA and 300 kA are clearly occurring and damages observed accordingly.

In addition, multiples strikes are more and more involved in damages on Surge Protective Devices. Specific generators have been developed in China to cover such a case and investigations have shown that multiple surges were one of the main causes to explain SPD failures encountered in the field [5].

III. Application to a preliminary building

A. *Technical Study*

A rather simple building, dedicated to the site rescue team, which is classified as BSS, has been used as a preliminary step for applying such a high SLC stress. Due to the specificities of this project, all the details of the study cannot be provided.

This building is made of concrete and has a rather simple shape. The building has to meet the esthetics rules of the nuclear site and is designed to withstand the severe stresses coming from wind and earthquake. This building is presently at the construction stage.

Figure 2 : BSS building used as a preliminary step for the study

Even if the whole structure needs to be protected at level I, only a few points on the roof can be impacted by the extreme lightning current considered for that project. Regarding extreme current in the range 200 kA up to 300 kA the rolling sphere model has been used to determine the point of the structure (roof) that could be impacted. This rolling sphere should cover lightning current between 200 kA and 300 kA and is then determined for the magnitude of 200 kA. At the end of this process, lightning rods were located on the roof to protect the building locally against huge lightning currents. Then the rolling sphere model was used again to check that the structure was well protected at this level of current.

Additionally, a rolling sphere corresponding to level I of protection was also used to determine how to protect the building with regular protection means at level I of protection. Locations on the roof that need protection at level I, have been identified. Protection is then provided by a mix of striking roof and mesh system.

At the end, a third rolling sphere was used corresponding to the minimum current of 2 kA to check that no external equipment could be impacted by lightning (light, vents, sensors …). Whenever needed a specific protection based on additional striking rods has been used to protect the external equipment that could have been impacted with this low current. Once again, purpose is to ensure that nothing will disturb the building operation in stormy periods.

Extreme wind pressure was a specific constraint to take into account for the rods design.

For the 200-300 kA range of current, the main target has been to split the extreme current as soon as possible such as the current flowing in downconductors be compatible with level I of protection (i.e. not greater than 200 kA). This was especially critical as the down-conductor needed to be embedded in the concrete. At least 3 paths of same length has been used to connect the lightning rods to down-conductors to ensure that current in down-conductors never exceed 200 kA.

As soon as the lightning protection on the roof was determined it was necessary to determine the location of down-conductors and the earthing system. Natural component were used inside the concrete walls as down-conductors. Inside the concrete, the equipotentiality between down-conductors, apron and wall iron framework was studied with precision. Penetration of the current inside the wall was specifically studied as well where current exits the wall to reach the ring earthing electrode. The rebars were soldered at different layers in order to form a mesh and in addition a copper conductor was also integrated inside the concrete.

All components used for the LPS (Lightning Protection System) either inside or outside of concrete are in accordance with the standard IEC 62561 series [6].

Where the current is not yet reduced by multiple sharing, this means near the 300 kA impact point, lightning rods, copper conductors and exothermic welds have been used. Purpose was to reduce the current enough before entering the concrete to meet level I characteristics. Of course, specific tests will be needed for these components located on the roof. This will be described later on.

At the grounding level the current 300 kA is also to be considered. Near injection point in the soil, in addition to the ring earthing electrode (Type B according to IEC 62305-3 [6]) around the building, additional earth electrodes (Type A as per IEC 62305-3) were used to facilitate the current flow in the rocky soil. To avoid problems for the people being in vicinity and for equipment inside the building, the earthing system must have the lowest possible impedance. This impedance will be considered for the rating of the Surge Protective Devices

Separation distance was calculated near the lightning protection system above the roof with the specific impulse current of 300 kA. The higher current leads to greater voltage and thus to greater separation distance. However, there were limited equipment on the roof and it was easy to keep them apart of the rods. At down-conductor level, there is no more separation distance to consider as down-conductor are equipotentially bonded to rebars.

Protection of people near the lightning protection earthing system has been also specifically addressed to take care of the 300 kA impulse current flowing in the earthing system.

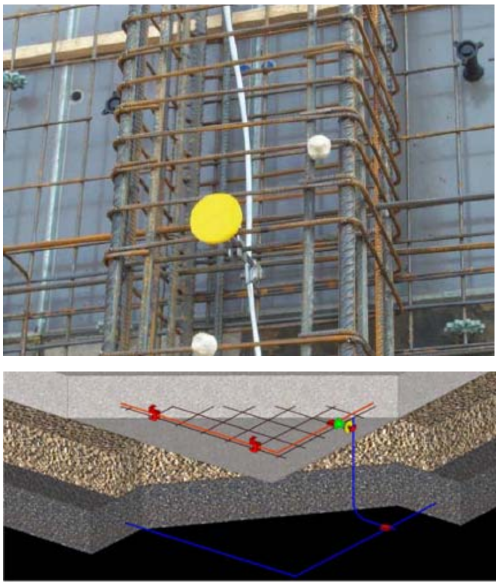

Figure 3 : Typical example of down-conductors inside the reinforced concrete [8].

Global equipotentiality was used at ground level for all metallic pipes entering the structure. The sharing of current between the pipes and the power lines was estimated to design the size of the bonding elements including Surge Protective Devices. SPDs Type 1 have been defined on all incoming lines (either power [9] or data lines [10]). The building is supplied by a power line and an external power generator. There are two telecom/data/signal lines connected to remote telecom switches allowing the rescue team to obtain data for the whole site from the BSS building. The power lines should be protected such as they don't leave big surges entering the structure. Regarding the telecom/data/signal line they should be operational all the time. The disconnector on power SPDs were determined to have the same surge withstand than the SPD itself. Rating for the SPD was defined by using the 300 kA impulse as well as the continuous current and taking care of the earthing system current dissipation. Only a partial current if flowing through SPDs.

Protective level provided by this SPD should be defined by taking into account a 200 kA/µs impulse: this have influence on the SPD itself that may have an inductive behavior and on the lead conductors (impacting the usual 50 cm rule). This means that specific tests need to be performed.

Of course, in such conditions, the effective voltage protection level will be quite high and it is difficult to provide adequate protection with a single SPD. Further SPDs will be necessary downstream to protect specific sensitive equipment. Coordination rules must then be checked with the SLC stress. This can be done by testing or by simulation based on raw data provided by the SPD manufacturer.

B. Specific products

Due to many down-conductors and meshes on the roof, the current is shared between many paths. Very quickly the current becomes lower than the usual stress defined for level of protection I. This means that except the part of the LPS above the roof and SPDs regular products designed for level of protection I may be used. However above the roof, specific tests need to be performed on few components. As said previously, SPDs need also to be specifically tested.

The specific risks for the down-conductors, connecting components and fixing components are electrodynamic forces and Joule effects. These may be pulled out and therefore the conductor can be destroyed. Lightning then can sparkover to an unplanned item. So it's necessary to use conductors and components able to hold electrodynamic stress and to fasten the conductors with fasteners located near to each other.

In the course of this ongoing project all thecomponent that need it will be tested with the SLC stress. They are regular components and it a few fail the tests, it will be necessary, in cooperation with a manufacturer, to develop specific components to hold the stress. Tests will be based on IEC 62561 series **Erreur ! Source du renvoi introuvable.**adapted to take into account the SLC stress.

At this stage, at least one European lab has been identified that allows to perform such tests and to qualify regular or specific products and components. Tests need to be performed with high magnitude (300 kA 10/350) followed by a continuous current that represents the greatest stress for such components.

For SPDs the same lab allows to perform a partial direct lightning current on SPDs followed by a partial continuous current. Furthermore tests with high front of wave can be performed to determine the protective level. Coordination tests can be performed to check that with such a SLC stress both coordination in energy and in protective level can be achieved between the Type 1 SPD and the Type 2 downstream SPDs located near sensitive equipment inside the structure. Another way is to obtain enough data from the test on Type 1 SPD and use simulation tools to demonstrate the coordination between SPDs. Two impulses must be considered:

- A 300 kA 10/350 impulse followed by continuous current rated 500 A with a duration of 0.5s,

- And a secondary impulse 50 kA associated with a front steepness of 200 kA/µs.

The first will define the energy stress on the Type 1 SPD and the second, the inductive stress (both voltage drop on lead length and inductive effect on the SPD itself), coordination rules and the level of protection.

To determine the peak current flowing in each of the conductive paths, the method described in the standard IEC 62305-1 is used based on the SLC injected current and the earth impedance.

C. Generator

A specific generator is necessary to test lightning protection components and SPDs Type 1.

An European laboratory is able to perform such tests. It is able to simulate an extreme high lightning currents peak of 300kA 10/350 followed by the needed long duration current. The generator is designed with a twin crowbar spark gap lightning current generator.

Figure 4 : Extreme high lightning currents generator.

Tests will be performed before the end of 2015 for all components that need such a tests. A few existing lightning protection components and SPDs should be able to withstand such a stress. If needed, specific products will be developed but this would result in the project delays.

IV. CONCLUSIONS

To study lightning risk for Nuclear Basic Safety Structures of nuclear facilities, a new methodology was developed to take care of extreme lightning currents based on IEC 62305-1 standard. This particular method takes into account a Specific Lightning Current stress which is more severe than the usual lightning protection I (first impulse of 300 kA 10/350 wave shape followed by a continuous current and a secondary impulse with a high di/dt). In standards lightning protection systems, highest current than defined for level I of protection are not considered. In the same way the effect of continuous current on equipment is not investigated. In addition, the fact that lower currents than defined for level I of protection can struck the building are ignored by definition of the level of protection. Damages coming from such low current on buildings are not expected to be high but they can interact with sensitive equipment that are necessary for the safety the installation.

This paper is based on a preliminary simple building on an ongoing project. The first step is to define what should be the parameters of the lightning current to consider. Even if very high values above 300 kA are sometimes mentioned and if IEC 62305-1 consider current probabilities up to 600 kA. We kept a maximum current of 300 kA. Other parameters were defined with same probability. After having defined which parameters could have influence on lightning protection system components including SPDs, the study concentrated on what could be the possible protection means to handle the defined stress on a specific building under construction. This preliminary building is still at the design stage.

To protect the building from direct strikes, the strategy is mainly based on natural components. Components used either in concrete structure or above the roof will be tested in an European laboratory with the defined Specific Lightning Current stress. Surge Protection Devises will be also tested and the coordination between the equipotential bonding SPDs at the entrance and the secondary SPDs to protect sensitive equipment will be demonstrated based on tests and simulations.

Once the availability of needed components will be demonstrated by tests with adequate testing procedures, the same method should be applied to more complex buildings. Testing of components and especially the SPDs is still at definition stage. A laboratory able to perform all the needed tests has been defined and program of test has been adapted with their testing engineers. Next step will be to perform such a test and if needed develop specific products.

REFERENCES

[1] IEC 62305-1 Ed. 2.0 : 2010-12, *Protection against lightning – Part 1 : General principles*

[2] Berger K., Anderson R.B., Kröninger H., Parameters of lightning flashes. CIGRE Electra No 41 (1975), p23-37.

[3] Anderson R.B., Eriksson A.J., Lightning parameters for engineering application. CIGRE Electra No 69 (1980), p.65 – 102.

[4] Working Group C4.407, Lightning parameters for engineering application. CIGRE Electra No 549 (August 2013)

[5] Rousseau A., Cruz. F, Zang, X; and Dongbo L., 2015 SIPDA, Degradation Analysis of MOV Type SPDs With Surge Superposing AC Operating Voltage, Birkl J., Zahlmann P., 2014 International Conference on Lightning Proctection (ICLP) Schangai, China. – Extreme high lightning currents : Testing requirements and pratical application.

[6] IEC 62561 series : 2012, Lightning protection system components (LPSC).

[7] IEC 62305-3 Ed. 2.0 : 2010-12, *Protection against lightning – Part 3 : Physical damage to structures and life hazard.*

[8] Reeb R., 2015 Forum Dehn - Protection contre la foudre d'un établissement recevant du public.

[9] IEC 61643-11 : 2011-03, *Low-voltage surge protective devices – Part 11 : Surge protective devices connected to low-voltage power systems – Requirments and test methods.*

[10] IEC 61643-21 : 2012-07, *Low-voltage surge protective devices – Part 21 : Surge protective devices connected to telecommunications and signalling networks – Performance requirments and testing methods.*