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Corona Shielding of Current Path Features of Air Insulated High Voltage Disconnectors and Earthing Switches

Mariusz Rohmann[1], Dirk Schräder[2]

[1]Research and Development Querétaro, Siemens Energy S. de R.L. de C.V., Querétaro, México

[2]Research and Development Mechanical Engineering and Testing, Siemens Energy Global GmbH & Co. KG, Berlin, Germany

Email address:
mariusz.rohmann@siemens-energy.com (M. Rohmann), dirk.schraeder@siemens-energy.com (D. Schräder)

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Abstract: The radio interference voltage occurring as so-called corona effects on current paths of air insulated high voltage disconnectors and earthing switches will be introduced and the need, the effect, and the realization of accordingly corona shielding of current path features of air insulated high voltage disconnectors and earthing switches will be discussed. Both is included, the requirements as per international standards and requirements by customers beyond international standards, as those are the principal motivation for investigating in the effects of radio interference voltage and its limitation. The reasons for corona effects and the shielding functionality for reduction of those effects will be elaborated. Challenges and limits of different types of shielding will be described, which covers the mounting and its items, and emphasizes not only mechanical stress risks, but also the possible complexity of potentially necessary shielding arrangements. Also, the type testing for the corona effects will be mentioned and includes aspects of the market or by customers beyond IEC standard needs, so that not only keeping limits is important, but also to understand inception and deception. Additionally, numerical methods to solve the necessary field calculations of corona effects and effects of shielding will be described. Finally practical examples will be given for different corona shielding applications on current paths of center break disconnectors, which includes details for additional functionality of corona shielding providing the possibility to cover additional product requirements and therefore increasing the product marketability without increasing material consumption of the product. In conclusion the benefit of sophisticated investigation is highlighted and intends to promote the same, overcoming cost and efforts hurdles and best practices based on application experiences only.

Keywords: Disconnector, Current Path, Contact System, Components Extremities, Corona, Corona Shielding, Radio Interference Voltage

1. Introduction

Air insulated high voltage disconnectors need not to exceed certain value limits for the radio interference voltage as per IEC 62271-102 [3], which is herein regulated with specific type testing for devices of 245kV and above. This limits the consequences of the corona effects, like light and sound emissions, which finally represent energy losses. Beside the important point of minimizing energy losses (unwanted electrical signals within the radio and high frequency ranges like television, microwave, or other transmission bands), minimizing sound effects is highly important for operators – specifically for substation locations in urban areas, where partially governmental regulations are not allowing facilities exceeding certain noise levels for protection of nearby living communities. Partially the limits according to the IEC 62271-102 [3] are still high for certain customers or their respective projects with highly noise regulated installation locations and specifications occur on the market with more severe limits as per IEC 62271-102 [3]. Generally, the likelihood for such specifications will be high for countries and regions with a high population density, huge space occupation by cities and low space remaining for countryside (or just not available due to nature protective restrictions and reservations).

By this it is important for the design of disconnector and earthing switches to understand the corona effects and the reasons for the same, as well as the possibilities to control or minimize them. Further, each current path optimization or feature introduction requires the re-evaluation of any existing corona effect controlling measure and eventually its adaptation to suit the new situation (by 'best practice' engineering any optimization shall respect existing corona effect situations improving them and not worsen them, but on new features this must be newly verified and considered) [7, 9, 10].

2. Corona Effect Reasons

Corona discharges occurs, when a high potential electrode ionizes the air in its direct proximity and the ionization phenomenon of building up streamers-leaders takes place. In the extreme case this leads not only to corona, but to lightning and flashover (sparking, partial discharges).

The electrode can be interpreted as field lines concentration point, where field lines will not anymore find a counter foot point and instead ionize the air, if not flash over for finding the counter foot point. The electrode will be found on the current path as sharp edge or extremity of different assembly items.

The general surface and atmospheric conditions influence the corona effects in its values, already basically. The surface conditions are controllable to an acceptable effect limitation without high production efforts (moderate surface requirements are enough) and the atmospheric conditions are surely not controllable in the case of outdoor equipment, so that the testing as per the IEC standards [3-5] is the main basis. However, e.g., pollution can have a significant negative effect on the corona effect values [8, 11-15].

2.1. Sharp Edges

A classical effect is observable with sharp edges, which are disadvantageous for corona effects, as the electromagnetic field will be squeezed in such corners and field lines will be interrupted so that the corona effect is getting increased (light appears to be sprayed out and the noise level is getting relatively high). The opposite foot point of the field line is not possible and appears somehow in the air only.

2.2. Extremities

Reaching out details, such as contact fingers already or specifically features like catching hooks or secondary contacts, are highly disadvantageous for corona effects. This for the same field details as mentioned for the sharp edges already. Such extremities need specific consideration for counter measures.

3. Corona Shielding

Based on the difficulties with sharp edges for the corona effects, a basic design rule is of course the avoidance of sharp edges. Also, safety requirements call for the avoidance of sharp edges in regards the handling and assembly activities. However, the corona effect avoidance is not only calling for avoidance of sharp edges, but for enough smooth surface transfers, so that minimum sizes of radiuses must be considered [8, 11-15].

Therefore, box profile current paths will always be seen with a minimum radius at the edges of the box profile, as a shielding over the length of a current path would simply be a waste of efforts and material – economically not feasible. The strict following of edges with radiuses can be observed commonly for the contact system items as well. Doesn't matter, if it is about holding/or counter plates, female contact fingers, male contact fists or blades. This minimizes the corona effects and still there is the challenge of the used screws for the assembly. In case of the corona effects with secondary importance about the material only. The focus is needed on the shape of screw heads and nuts, which cannot avoid sharp edges – rounded screw heads and nuts are just out of standard material and would not be achievable with economic feasibility. Consequently, shielding cannot be avoided for rated voltages of 245kV and above.

Shielding means to cover such unavoidable sharp edges in such a manner that the electromagnetic field will not be squeezed in such corners. This can be achieved by covering accordingly areas with sufficiently conductive material and necessary radiuses, so without sharp edges. With other words, the unavoidable sharp edges will be put or hidden within the electromagnetic field and not anymore situated at the material shape border or surface. Such shielding than, needs to be assembled and require specific care for brackets (holders/fasteners) and fixations, on the current path side and on the shielding side of the bracket.

There are different basic shielding solutions driven by manufacturing possibilities and material cost effectiveness and basically determined by necessary sizes.

The preferred material for shielding and its brackets is aluminum, basically because this will be a weight amendment to the current path. In order to avoid or minimize mechanical negative effects (like additional power need by the kinematics or worsened angle effect for the final contact system position – male against female contact) the additional weight shall be low. Aluminum serves this request beside matching the need for providing enough conductivity (avoidance field line foot points).

A basic rule – as bigger the radius, as lower the corona effect (distributing the energy over a surface and not concentrating it to a point/small surface).

3.1. Corona Spheres

Most preferable, but rarely feasible, is surely the spherical shape (regarding the energy distribution over the surface). Corona spheres are limited to application as finger or rod ending shields, so that the size is limited and the spherical shape is feasible, mechanically, and economically. The application of the corona spheres is consequently focused on current path features based on studs or rods or maybe finger extremities, which would increase unnecessarily the diameter of corona dishes or rings. Conveniently those are applied on threaded stud ends, which is often the case for features like secondary contact fingers or catching hooks. If it needs to be the assembled end, the operational end or both ends depend on the assembly situation and operational feasibility.

3.2. Corona Dishes

Corona dishes are round, flat aluminum sheets with a bended collar giving the necessary radius. The collar will appear as a half-sphere, so that the radius is big and determined by the collar height. The manufacturing possibilities are allowing diameters of the dish up to 400 to 500mm. This covers at least most applications of devices with voltage ratings of 245kV and 420kV. Those are a classical shielding solution for contact systems of the center break disconnectors and will be applied pair wise in opposite position, so that the collars are directed to the contact system – the electromagnetic field, where they are than covering or hiding the contact system extremities. Well, in case of the center break disconnector this is than necessary on male and female part and must not interfere with each other. This case requires a vertical and a horizontal pair of dishes, or twice horizontal pair of dishes on different height levels with appropriate brackets applications. Two times a horizontal pair of dishes will be mandatory in case of features to be shielded and the need to avoid interference with the features and the brackets of vertical dishes and/or the vertical dishes itself.

Another typical application is the shielding of the insulator flange directly below the current path. In such cases the dish is mounted between the insulator and the current path with its collar downwards for shielding the edge of the insulator top flange.

Corona dishes may have within certain applications, related to specific regions or installation sites, the disadvantage of providing a wind force surface. In dependency of the wind occurrence by force and frequency of the same, the dish fixation and bracket may suffer specific stress (like vibrations) leading to material failures (fatigue of material). Such situations are difficult to understand by specifications and order inputs, so that site correction activities would occur. Dishes under such influences can be foreseen with drilling holes on the flat service, so that the wind force attack surface is interrupted and minimized, and the stresses are sufficiently reduced. Other than this, the better choice may be corona rings.

3.3. Corona Sheets

Where appropriate, corona dishes may be replaced by just corona shields. Aluminum metal sheets with shielding request specific bending (for achieving radius needs) can provide the necessary corona effect limitation.

Those possibilities are limited, and a classical example would be the shielding of fixed contacts of add-on earthing switches, which are integral part of the disconnector current path. Further, accordingly shielding capacity is limited, so that such solutions are mostly limited to lower rated voltage ratings (e.g., 245kV) with limited corona effect stresses. Another limitation must be seen for the cases of requirements beyond the IEC, where this solution is again unlikely to be enough – but this needs of course validation based on the specific values.

3.4. Corona Rings

Corona rings may and can be applied similar or equal to dishes. However, as corona dishes are economically more effective up to the possible diameters, corona rings are out of question. Beyond those limits of the corona dishes, the corona rings are essential in order to provide the necessary corona shielding.

Corona rings are practically a bended aluminum tube, which than requests one or more cross bars in order to provide a fixation possibility with or without additional brackets. The corona rings have its application focus on the high voltage ratings, above 420kV, as here the required sizes will exceed the corona dishes feasibilities.

Corona rings have the advantage against the corona dishes, not to provide significant surfaces for wind force effects. As they consist mostly of tubes the effect of 'Karman vortex streets' occurring with certain wind situation may need to be considered (a vortex shedding, which is an oscillating flow, potentially resulting in tube vibrations and reducible or avoidable by helical strakes).

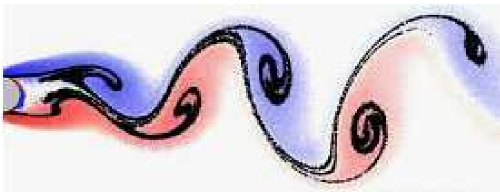

Figure 1. *Karman vortex street past a cylinder.*

Another advantage of the corona rings is, that those can be applied segmented, as well. This means, that the ring can have a cut-out in order to provide for example an entry possibility for a current path arm of an add-on earthing switch to reach its counter contact (fixed contact) within the shielded area. In such a case the fixed contact will not require separate shielding. The cut-out will require a shielding on the remaining ends of the segmented corona ring, which mostly can be a corona sphere (with a diameter as the tube diameter of the ring or bigger).

3.5. Corona Sphere-Segments

Nowadays rare, but less material intensive are corona sphere segments. As casting items optimized to minimum material consumption and specific applications. Random applications within a disconnector and earthing switches portfolio are very limited and variations require new casting dies, so that this kind of shielding is disappearing from the applications and/or market.

3.6. Mounting Brackets

Mounting brackets (and/or cross bars) need of course to be applied in such a way that those themselves are covered by the shielding as well.

Cross bars of corona rings are therefore placed within the ring towards the area to be shielded. This ensures in case of additional mounting brackets with the cross bar, that the screws for the fixation of bracket and cross bar will be relatively far away from the outer surface of the corona ring and within the shielded area.

Brackets fixed to corona dishes, must consider the effects of the screws for fixation. Usually, the screw head, which will be found on the outer surface of the corona dish. The side of the screw with the nut application will usually be found at the inner (shielded) side of the corona dish, as those would be more problematic for corona effects by the nature of sharp edges at the threaded screw end. The negative screw head effect for the corona stress must be tackled.

One possibility is given by a corona dish outer diameter big enough, so that screw heads approximately in the middle of the diameter will be shielded (field lines foot points would not reach any more or just in a very power weak manner with minimum corona effects). This possibility is useful for lower rated voltages, as the diameter need in regards of the extremities is providing diameters already with sizes big enough for minimum screw effects. For higher voltage ratings the corona dish sizes need to be increased beyond the need for covering extremities to be shielded, so that the screws are controlled, alternative possibilities are available (to avoid e.g., corona rings).

1) One alternative possibility is the use of screws with round heads (could be the nut, as well). However, this possibility is mostly not followed, as those kind of screws with than a very limited application (low quantity) within a disconnector and earthing switch portfolio could not be managed economically effective.
2) A second alternative possibility is the application of sinks, lowered areas, on the corona dish surface for the area of the screw application for the bracket fixation. This will position the screw head again below the outer surface of the corona shielding and within the shielded area. Where necessary, this is mostly the economically more efficient solution against the rounded screw heads and has even a positive effect for reducing the wind forces consequences, even though only minor. Further, this possibility gives a positive effect on the necessary lengths of brackets, again a minor effect only, but with advantages economically and mechanically.

4. Type Testing of Corona Effects

The IEC 62271-102 [3] is finally just referring to the IEC 62271-1 [4], which is considering specifically the radio interference test as an electromagnetic compatibility test (an EMC emission test). Permitted are 2500 µV.

4.1. Radio Interference Voltage

As per IEC 62271-1 [4] a voltage of 1,1×Ur×√3 shall be applied to the test object and maintained for at least 5 min, where Ur is the rated voltage of the device, the test object. The test is than considered as successfully passed if the radio interference level does not exceed 2500 µV (at an ambient humidity ≤ 80%).

In the most cases, customer requirements exceeding the IEC requirements, will only lower the value of 2500 µV. Observable in certain markets are standardized requests for 500 µV, which requires corona shielding for rated voltage applications below 245 kV despite the accordingly IEC request. Consequently, laboratories would execute a type test not as per IEC, but as per customer request following the IEC [3-5].

4.2. Corona Inception and Deception

In addition to the radio interference test as per IEC standards, specific market or customer requirements are calling for measuring and reporting the values for the inception and the deception of occurring corona. This requires observing carefully accordingly events, while increasing or decreasing the voltage to be applied. Nevertheless, the voltage to be applied is again the voltage for radio interference testing as per the mentioned relevant IEC standards [3-5].

The observation needs to be in the darkness, as the visual identification of corona is more reliable and usually earlier identifiable than the audible identification. Specific safety measure for this activity must be taken. Mostly for air-insulated high voltage applications, partial discharge instruments are not used and difficult to apply. Such instruments usually use a pulse train response for quantifying the largest repeatedly occurring partial discharge magnitudes (sophomoric weighting circuits simulate physiological noise responses of the human ear).

Measurements in the field of radio disturbance voltages (radio noise) in the vicinity of transmission lines is practiced and well-known since long time already with narrow-band partial discharge instruments and important to identify disturbances for radio transmission or radiotelephony. Nowadays with drone and camera applications, one example for visualizing and locating electrical discharges (corona and arcing) would be imaging systems based on high sensitivity ultraviolet (UV) cameras (corona cameras) [6, 10].

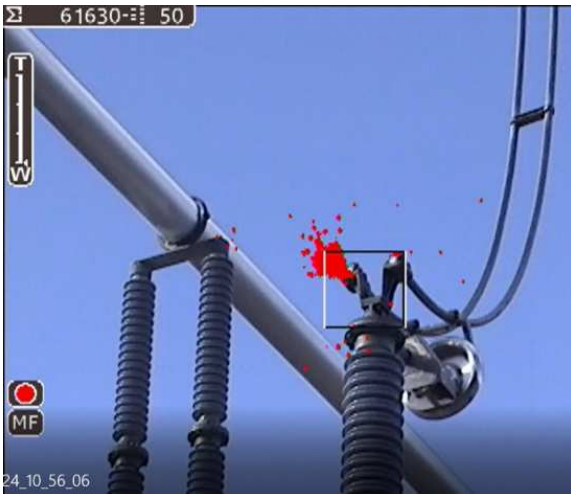

Figure 2. *Example of Corona Record with a Corona Camera Showing Corona Stress on the High Voltage Terminal Connection.*

However, this is not sufficient for the measurements required for the type testing of corona effects.

5. Simulation of Corona Effects

Basically, there are two numerical methods to solve the necessary field calculations, which are the boundary element method and the finite elements method. The latter one is the preferred one based on available three-dimensional models and its accuracy for electrostatic analysis.

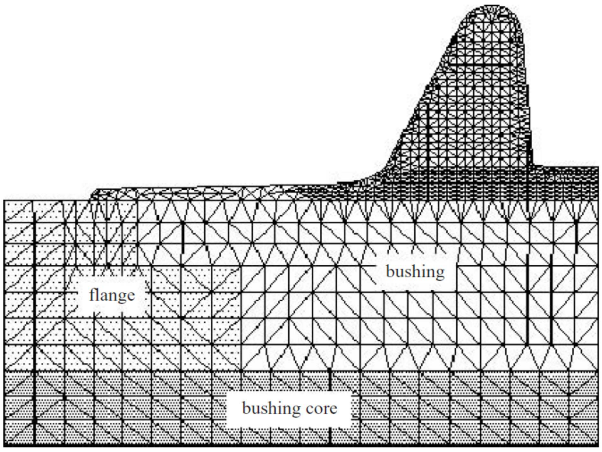

Figure 3. *Finite Elements Method.*

5.1. Simulation of an Extremity Without Shielding

The simulated example of an extremity by an add-on feature on the current path easily show the stressing points of the corona effects.

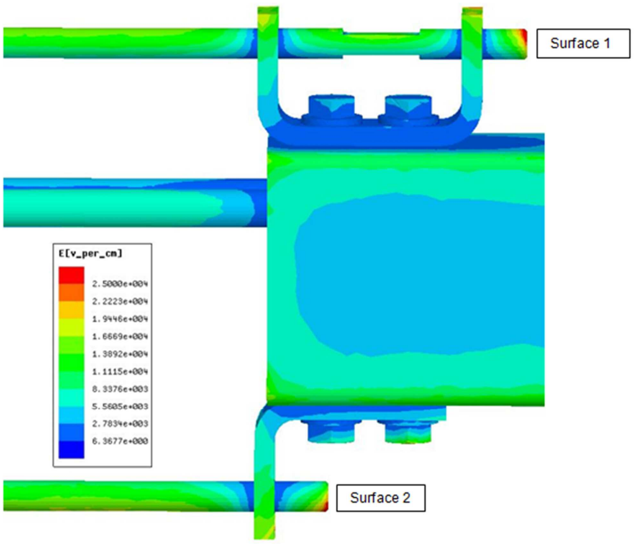

Figure 4. *Corona Effects by Extremity without Shielding by Corona Dishes.*

The definition of the used colors needs to be based on defined radio interference voltages, so that the visual identification of reaching or exceeding limits is possible accurately and quickly.

5.2. Simulation of an Extremity with Shielding

On the same example, easily the highly positive effects of an accordingly corona shielding is shown, which are in the given example dishes.

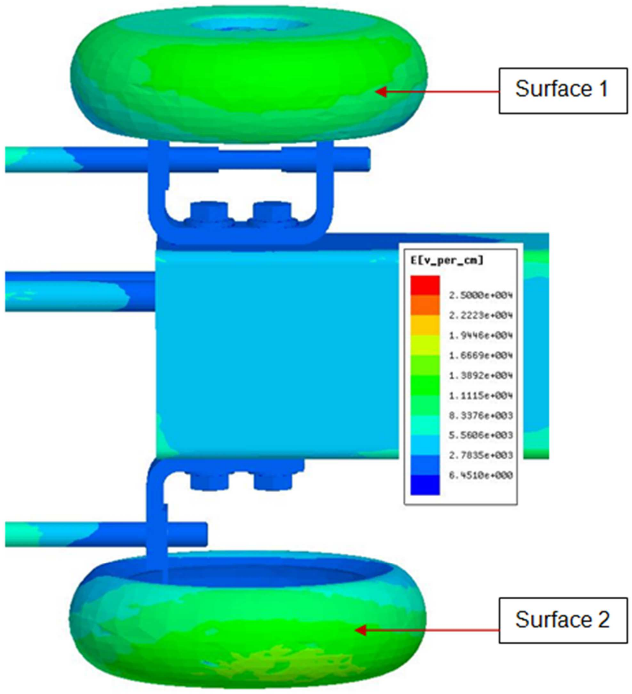

Figure 5. *Corona Effects by Extremity with Shielding by Corona Dishes.*

However, the simulation efforts are relatively high in comparison to the economic benefits achievable, so that such sophisticated analysis are still the exception for disconnector and earthing switches and not the norm. Consequently, the shielding application is driven by experience, best practices and available shielding based on the supplier base – considering its tool kits in regards of sizes and shapes (diameters and radiuses).

6. Shielding of a Center Break Disconnector

The varieties of the corona shielding within the disconnector and earthing switch portfolio are highly driven by the different type of devices and their accordingly current path solutions with its extremities to be shielded. The same shall be illustrated with the example of the horizontal center break disconnectors [1-2, 11-15].

6.1. Standard Shielding on a 245 kV Device

In accordance with IEC 62271-102 [3], testing and consequently shielding is necessary, latest with 245kV rated voltage applications.

On this voltage level it is usually sufficient to shield the contact system. At the opposite extreme end of the current path there are likely no problematic corona effect levels to be observed. Consequently, a common appearance of corona shielding are two pairs of horizontal dishes, having a limited complexity for the mounting and minimizing any risks for e.g., wind forces and providing additional protection e.g., against icing on the contact system for accordingly requirements or regions of application.

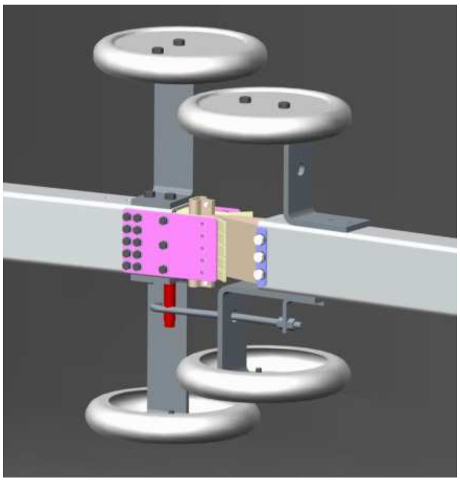

Figure 6. Common Contact System Shielding.

Interferences are controllable with minimum efforts, as addon features are limited (e.g., catching hook).

6.2. Secondary Contact Shielding on a 245 kV Device

In the case that the same current path (device) is equipped e.g., with a secondary contact system, the shielding application is more complex. The functionality of such an add-on device requires its own shielding solution, which would not be standardized, as such feature is not delivered with most of the current path deliveries [1, 2]. Here a common appearance of corona shielding are four horizontal dishes (shielding always for open and closed condition of the disconnector).

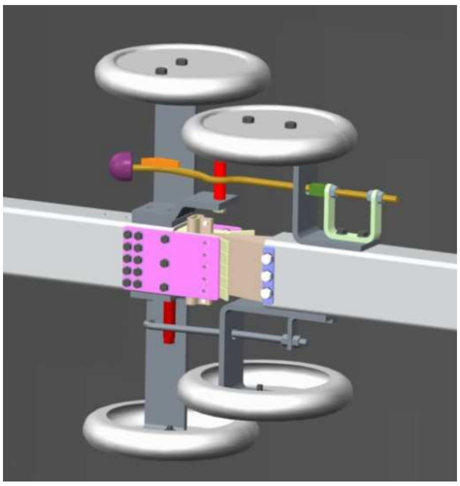

Figure 7. Shielding of a Contact System with Secondary Contact.

A general horizontal arrangement of corona dishes (shielding in general) will not be directly advantageous in regards of e.g., wind forces, as those do not generally blow only in the horizontal plain and even if this would be the case e.g., vortex shedding effects may still occur.

6.3. Standard Shielding on a 420 kV Device

The higher rated voltage will lead beside others to higher corona effects, so that the shielding will need to increase in principle for distributing the accordingly field on a bigger surface. Beside this, a high quantity of contact fingers and consequently current path size due to a high rated continuous current, it may be preferred in regards of the current path height, to use only horizontally arranged corona dishes. This to avoid, that vertically arranged dishes will become unreasonable big in diameter or need to be replaced by rings. The same considerations will be necessary for 245kV applications in the case of accordingly high rated continuous currents without the basic need for bigger size because of the rated voltage results on the corona effects [1-2, 11-15].

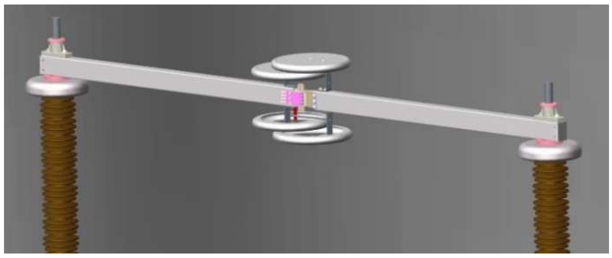

Figure 8. Insulator Top Flange Shielding (rectangular current path arm of a center break disconnector with only horizontal contact system shielding, 420 kV application).

Additionally, due to the rated voltage level, shielding for the insulator top flanges will be unavoidable. This shielding is realized by assembly of a dish or ring with accordingly fasteners between insulator top flange and current path.

For requirements beyond the IEC permissible values [3-5], shielding of insulator top flanges may also be necessary for 245kV applications [8, 11-15].

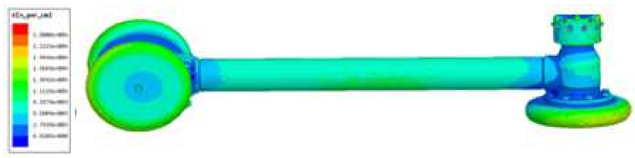

Figure 9. Insulator Top Flange Shielding (round current path arm of a center break disconnector with vertical contact system shielding, 420 kV application).

7. Conclusion

As the markets and customers tend to request values beyond the permitted ones as per the IEC standards [3-5], it is mandatory for the designers of disconnectors and earthing switches to consider shielding solutions from the beginning of current path designs. Even though that classically there cannot be identified significant economic benefits for a focus on corona effects analysis (accordingly investigations and simulations), it would result in comprehensive understanding of optimization potentials.

The impression is fostered, that based on investigations with suppliers for e.g., oval shaped corona dishes or effectiveness of rings against dishes, significant economic potential could be generated. This then needs of course, supporting results of accordingly theoretical simulations, which shall be underlined by accordingly test and field results.

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