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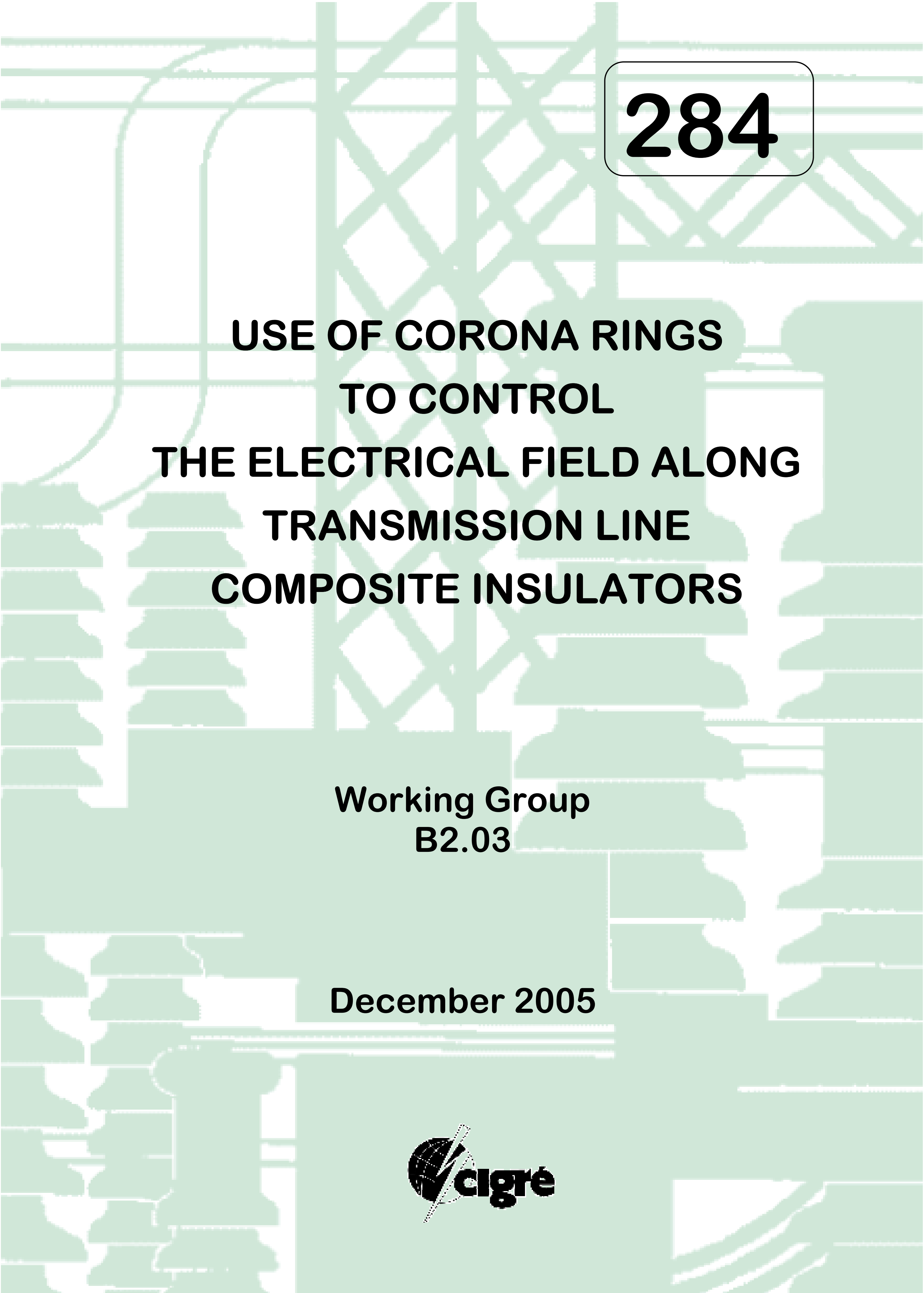

USE OF CORONA RINGS TO CONTROL THE ELECTRICAL FIELD ALONG TRANSMISSION LINE COMPOSITE INSULATORS

Working Group
B2.03

December 2005

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Working Group
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(Insulators)

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USE OF CORONA RINGS TO CONTROL THE ELECTRICAL FIELD ALONG TRANSMISSION LINE COMPOSITE INSULATORS

Working Group 03 (Insulators)
of Study Committee B2.

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1- Introduction

This document intends to make the reader aware of the complexities of the corona ring design and to give him a “feel” for good and bad design options. Its purpose is not to specify a specific corona ring for a given voltage and insulator design. This is the responsibility of the insulator manufacturer.

The voltage distribution along a glass or ceramic insulator string or along a composite insulator is not linear. Measurements performed in HV laboratories, and confirmed by software calculations, show a significant variation in the voltage distribution along the length of a glass or ceramic string or a long-rod porcelain or composite insulator. There is a large increase of the electrical field at the high voltage end of the insulator and a significant increase at the ground end. For example, in the case of a 400 kV glass or ceramic insulator string with 20 or more units (or a composite insulator) depending on the type of end fitting hardware and conductor bundle configuration, the last insulator at the HV end (or the last shed in case of a composite insulator) can be subjected to more than 10% of the phase to ground line voltage, while an intermediate insulator located in the middle of the string will support only 2% of this voltage. In dry conditions, the highest electrical field is always located near the high voltage end of the insulator and, if not controlled, can lead to the appearance of corona or electrical discharges in air if the 2200 V_{rms}/mm (or 3100 V_p/mm) threshold is exceeded. Corona and electrical discharges at the surface of the insulator must, as much as possible, be prevented because they generate radio interference (noise and RIV). In addition, in the case of composite insulators, the frequent or permanent presence of electrical discharges can accelerate the ageing of the housing material and reduce the lifetime of the insulator [1]. This is why, in the case of composite insulators used at transmission levels, it is most important to control the electrical field at the ends of the insulator [2]. This is done by using rings whose dimensions must be adjusted to each insulator type and whose location with respect to the end fitting is critical.

2- Field control at the surface of and inside the housing material

An excessively high electrical field at the end of a composite insulator can have three distinct consequences:

- Creation of partial discharges inside the materials in voids, around impurities or at the interfaces rod/housing/end-fitting of the insulator. These discharges can damage the interfaces and, if of sufficiently long duration, can lead to the insulator failure. The maximum admissible electrical field value at these interfaces depends on the material and technology used and can only be determined by the manufacturer of the insulator.

- Appearance of “water drop corona” at the surface of the insulator [3]. When the insulator is wet, water drops on the housing, because of their shape and location, can locally increase the electrical field to a level such that corona will appear around a water drop or between adjacent water drops. When the insulator is made with a silicone rubber housing, this corona can temporarily reduce the hydrophobicity of the housing surface. This effect does not significantly damage the insulator.

- Creation of electrical discharges in the air near the surface of the housing if the electrical field value is above 3100 V_p/mm. In addition to the radio (RIV) and TV interference problems, the frequent presence of electrical discharges at the surface of the housing can lead to the erosion of the housing material, and subsequent rod exposure [4].

To ensure the long-term performance of composite insulators, it is necessary to keep the electrical field anywhere along its surface to a sufficiently low value. The way to control the electrical field is well known and consists in using so called corona rings as field control devices on the HV end only or at both ends of the insulator. The dimensions of the corona ring are dictated by the type of insulator, the line and tower configurations and the system voltage. Know-how and experience are critical to determine when to use and how to design such grading rings.

The E-field distribution along the surface of a composite insulator can be calculated and subsequently verified in HV laboratory tests. Experience has shown that a good correlation exists between laboratory test results and calculations. However, the evaluation of the E-field distribution inside the materials cannot be verified by laboratory tests. Consequently, software calculations remain the only process that can lead to a global answer.

3- Software calculations

Different software programs are available today : general or specialised, 2D or 3D, using finite elements or boundary elements methods. Comparisons have shown that, if correctly used, these different programs give very similar results. A recent publication [5] has also shown that a simplified model of the insulator, i.e. a single phase representation and modelling only a few sheds near the end fittings, can give results that are very similar to those obtained using a three phase representation and a full model of the insulator. In service, the E-field along each insulator is a function of the system voltage and the number of circuits on the tower. Such cases can only be analysed through joint work between user and manufacturer of the insulators. For a given system voltage and complete tower configuration, the calculated electrical field near the HV end of the insulator obtained with the 3D program is slightly higher than that obtained with a single phase representation. These simplifications introduce some approximations but the results of this study remain acceptable and make it less time consuming.

In the present study, the field calculations have been performed with an axi-symmetric 2D-software program that was optimised by using a special electrode configuration located below the HV end fitting. It has been verified by laboratory tests that the use of this electrode, when it is suitably located, can effectively simulate the presence of the conductors. The field calculations have been performed with only a few sheds near the end fittings.

In every E-field evaluation, some insulator dimensions are most critical. They make the E-field distribution significantly different for different types of insulators. They are:

- Size and shape of the end fitting;
- Shed profile;
- Location of the shed nearest to the end fitting;
- Shape of the ring;
- Location of the ring;

The modelling of these elements must be performed with high precision.

3.1- Validation of the 3D calculation parameters by laboratory tests.

The validation of the use of the 3D software program was done by comparing the calculation results with corona tests performed on two types of 132 kV insulators.

Software :	Coulomb V6.1 developed by IES.
Procedure :	3D calculation
Permittivity :	Housing = 4; air = 1;
Insulator dimensions :	Insulator profile 1 (see Fig 1) : connecting length = 1384mm, arcing distance = 1151mm Insulator profile 2 (see Fig 2) : connecting length = 1270mm, arcing distance = 960mm
Applied voltage :	See Table 1.

Laboratory tests were performed to measure the corona inception and extinction voltages on the high voltage end-fittings of these insulators in order to validate the 3D numerical calculations. These tests were performed in two different laboratories (EGU in the Czech republic and Sediver CEB in France) on the two different insulator types. The test configuration was kept identical for each test : same conductor, same conductor clamp, same height above the ground, same distance to the supporting crossarm. This configuration was also used for the 3D E-field calculation. The voltage at which the electrical field at the free surface of the high voltage end fitting reached 3100 V_p/mm (or 2200 V_{rms}/mm) was called the "calculated corona threshold voltage".

When comparing this 3D calculated corona threshold voltage to the corona extinction voltage measured in the two laboratories, it can be seen that the difference between the measured and the 3D calculated values is lower than 10% of the minimum value for profile 2 and even much lower for profile 1. Detailed results are given in Table 1.

Table 1

STUDIED CONFIGURATION	E-FIELD CALCULATION (3D)	CORONA TESTS RESULTS			
	Calculated corona threshold voltage (kV_{rms})	EGU inception (kV_{rms})	EGU extinction (kV_{rms})	SEDIVER inception (kV_{rms})	SEDIVER extinction (kV_{rms})
Insulator profile 1	142	160	147	171	147
Insulator profile 2	78.6	87	85	/	/
Insulator profile 1 60 X 280 mm ring	262	275	258	267	269

3.2- 2D calculation on a 400 kV insulator.

For the 2D axi-symmetric calculation, the geometry and position of the auxiliary electrode was selected in order to obtain the same E-field results as those obtained with the 3D calculation.

Software :	Electro V5.1 developed by IES.
Procedure :	2D axi-symmetric with conductors simulated by a round plate and ring assembly placed under the HV end fitting.
Permittivity :	Housing = 4; air = 1
Insulator dimensions :	Insulator connecting length = 3232mm Arcing distance = 3000mm
Applied voltage :	243 kV_{rms} phase to ground.

3.3- Electrical field evaluations

A series of field plots have been generated using the given profiles of the two distinct types of composite insulators. Profile 1, shown in Figure 1, has the first shed located over the collar of the end fitting. Profile 2, shown on Figure 2, has the first shed located 53 mm above the end fitting. To emphasise the effect of the shape of the collar of the end fitting, one additional field distribution was calculated using the shape of the collar of profile 1 on the end fitting of profile 2.

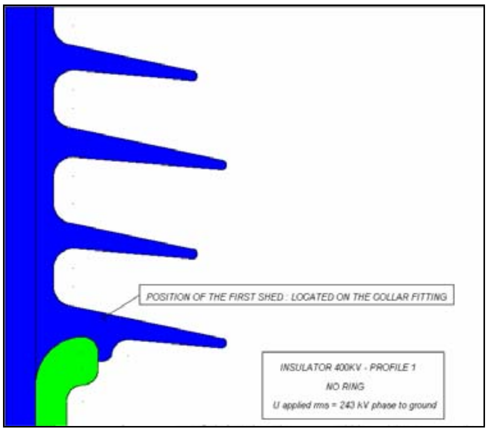

Figure 1 : Geometry of profile 1 design

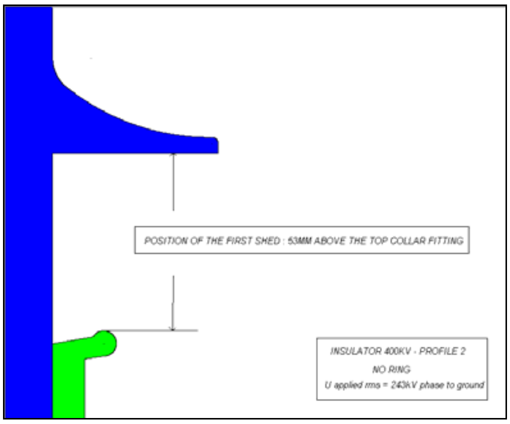

Figure 2 : Geometry of profile 2 design

Several ring configurations have been evaluated with both profile 1 and profile 2. The size of the corona ring is given by both the diameter of the tube making the ring and the external diameter of the ring. The ring can be placed at different locations with respect to the collar of the end fitting. The influence of the size and location of the corona ring on the electric field distribution along the insulator has been evaluated for several cases as shown on Table 2.

Table 2

Case	Comments	Results
1	Profile 1 and profile 2 insulators without ring	Appendix 1
2	Profile 2 insulator with modified collar and without ring	Appendix 2
3	Profiles 1 and 2 insulators, 60x280 mm ring. The upper plane of the ring is located 25 mm above the upper plane of the end fitting, position P1	Appendix 3
4	Profiles 1 and 2 insulators, 60x280 mm ring. The upper plane of the ring is located 50 mm above the upper plane of the end fitting, position P2	Appendix 4
5	Profiles 1 and 2 insulators, 60x280 mm ring. The upper plane of the ring is located 75 mm above the upper plane of the end fitting, position P3	Appendix 5
6	Profile 1 insulator with ring in position P2. The outer diameter of the ring is kept at 280 mm while the diameter of the tube is 20, 40 or 70 mm	Appendix 6
7	Profile 1 insulator with ring in position P2. The outer diameter of the ring is 390 mm while the diameter of the tube is 60 mm	Appendix 7

4- Results.

The field plots corresponding to Cases 1 to 7 are presented in Appendices 1 to 7. Details of the maximum field values at different locations are found in Table 3.

Table 3
Results of field calculation

Case	Profile	Corona ring	Max. E-field V_{rms}/mm	Location of maximum E-field
1	**Profile 1**	None	1670 1255 1800	- On the collar at the interface end fitting/air. - Inside the material (between 1st and 2nd shed on HV side). - On the surface of the housing (over the end fitting).
	Profile 2	None	3625 1400 1610	- On the collar at the interface end fitting/air. - Inside the material (junction sheath silicone gel) - On the surface of the housing (junction sheath silicone gel).
2	**Profile 2 modified**	None	3330 1500 2000	- On the collar at the interface end fitting/air - Inside the material (junction sheath silicone gel). - On the surface of the housing (surface of silicone gel).
3	**Profile 1**	60/280mm P1	1290 205 525 640	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (between 3rd and 4th shed on HV side). - On the surface of the housing (top surface of the 1st shed).
	Profile 2	60/280mm P1	1270 920 580 780	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (junction sheath silicone gel). - On the surface of the housing (tip of the 1st shed).
4	**Profile 1**	60/280mm P2	1370 165 510 810	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (between 4th and 5th shed on HV side). - On the surface of the housing (tip of the 3rd shed).
	Profile 2	60/280mm P2	1350 520 510 1100	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (between 1st and 2nd shed on HV side). - On the surface of the housing (tip of the 1st shed).
5	**Profile 1**	60/280mm P3	1440 215 500 615	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (between 5th and 6th shed on HV side). - On the surface of the housing (tip of the 3rd shed).
	Profile 2	60/280mm P3	1410 370 500 1560	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (between 1st and 2nd shed on HV side). - On the surface of the housing (tip of the 1st shed).

Table 3
Results of field calculation

Case	Profile	Corona ring	Max. E-field V_{rms}/mm	Location of maximum E-field
6	**Profile 1**	20/280mm P2	2280 590 540 710	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (between 1st and 2nd shed on HV side). - On the surface of the housing (top surface of the 1st shed).
	Profile 1	40/280mm P2	1620 340 490 680	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (between 4th and 5th shed on HV side). - On the surface of the housing (tip of the 3rd shed).
	Profile 1	70/280mm P2	1290 90 520 890	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (between 4th and 5th shed on HV side). - On the surface of the housing (tip of the 3rd shed)
7	**Profile 1**	60/390mm P2	1320 360 460 590	- On the ring surface. - On the collar at the interface end fitting/air. - Inside the material (between 1st and 2nd shed on HV side). - On the surface of the housing (top surface of the 1st shed).

5- Comments

For Cases 1 to 5 the field plots shown cover the entire length of the insulator. For Cases 6 and 7 only the most relevant part near the HV end fitting is shown.

- Cases 1 and 2 : The results obtained for Cases 1 and 2 show that in some cases, an installation without grading ring could induce permanent electrical discharge activity on the end fitting leading to a probable risk of housing erosion in this area. A comparison between Case 1 and Case 2 shows that the modification of the shape of the end fitting itself reduces slightly the E-field value on the collar, but the E-field value remains above the threshold corona level, and its value increases on the housing surface. This comparison shows clearly that the line voltage above which a corona ring has to be used critically depends on the type of insulator and that no general rule can be established for “composite insulators”. See Table 4 below.

Table 4
E-field (V_{rms}/mm)

Case	**Without ring**	Profile 1 Collar/air interface	Profile 2 Collar/air interface	Profile 1 Inside housing	Profile 2 Inside housing	Profile 1 Housing surface	Profile 2 Housing surface
1	**-**	1670	3625	1255	1400	1800	1610
2	**-**	-	3330	-	1500	-	2000

- A comparison between Cases 3, 4 and 5 shows that changing the position of the ring can modify significantly the E-field on the housing, particularly at the tip of the sheds, depending on the shed diameter and the internal diameter of the ring. See Table 5 below.

Table 5
E-field (V_{rms}/mm)

Case	**60/280 mm Ring Position**	Profile 1 Ring surface	Profile 2 Ring surface	Profile 1 Collar/air interface	Profile 2 Collar/air interface	Profile 1 Inside housing	Profile 2 Inside housing	Profile 1 Housing surface	Profile 2 Housing surface
3	**P1 (+25)**	1290	1270	205	920	525	580	640	780
4	**P2 (+50)**	1370	1350	165	520	510	510	810	1100
5	**P3 (+75)**	1440	1410	215	370	500	500	615	1560

- A comparison between Cases 4 and 6 shows that for a given external diameter and position of the grading ring, changing the toroïd diameter modifies significantly the electrical field at the surface of the ring and also modifies the electrical field along and inside the insulator housing. See Table 6 below.

Table 6
E-field (V_{rms}/mm)

Case	**Ring in Position P2**	Profile 1 Ring surface	Profile 1 Collar/air interface	Profile 1 Inside housing	Profile 1 Housing surface
6	**20/280mm**	2280	590	540	710
6	**40/280mm**	1620	340	490	680
4	**60/280mm**	1370	165	510	810
6	**70/280mm**	1290	90	520	890

- A comparison between Cases 4 and 7 shows that increasing the ring diameter improves the E-field conditions on the ring surface, inside and on the surface of the housing but increases the E-field on the collar-air interface. Provided that the E-field at that location remains well below the corona inception value, increasing the ring diameter is a good solution. However, it must be kept in mind that a large ring diameter must remain compatible with a double string arrangement. See Table 7 below.

Table 7
E-field (V_{rms}/mm)

Case	**Ring in Position P2**	Profile 1 Ring surface	Profile 1 Collar/air interface	Profile 1 Inside housing	Profile 1 Housing surface
4	**60/280mm**	1370	165	510	810
7	**60/390mm**	1320	360	460	590

6- Additional considerations

6.1 Polluted conditions

All the above field calculations have been made for dry and clean insulators. It is important to note that as soon as the insulators are polluted, the electrical field distribution is changed and critical field values can occur locally at lower voltage levels. In case of hydrophilic materials, or during temporary loss of hydrophobicity, with the wetting of the pollution layer a leakage current will appear and induce electrical discharges activity at the surface of the insulator (dry band arcing phenomenon). The E-field along the insulator is then changing continuously with the appearance of these dry bands. The E-field can no longer be evaluated by calculation. Therefore the level at which corona rings have to be used under polluted conditions has not been studied in this work, but should be considered to avoid over-stressing of the insulator surface.

6.2 Power arc protection.

In many cases, the insulator string must be equipped with arcing protection devices. The grading rings, which are designed by the insulator manufacturer for electrical field control, are fixed on the insulator end fitting and are often made of aluminium. In most cases, this makes them unable to provide the required protection against power arcs. As the arc protection devices might be supplied by a different manufacturer than that of the insulator, it means that the insulator could be equipped with both field grading rings and arcing devices. Their compatibility must therefore be verified.

When a one-piece hardware is used to provide both the field grading (electrical control at the ends of the insulator + RIV control for the whole insulator) AND the arcing protection functions, it is important that the insulator manufacturer approves such a device. This can be done based on calculations performed with the same software.

6.3 Corona rings at the ground end

The system voltage may be such that the critical field is also reached near the ground end of the insulator. In that case the use of a corona ring is also required on the ground end. The same calculation for its size and location can be used.

7- Conclusion

In order to protect composite insulators from the damaging effect of electrical discharges caused by excessive local electrical fields, it is necessary to equip them with electric field grading rings.

In this study most of the field calculations have been performed using a 2D axi-symmetric computer program with an optimisation HV electrode. Validation of the results has been done by comparing the 2D results with those obtained using a 3D program as well as laboratory tests done on 2 types of composite insulators.

It has been shown that the electrical field occurring near the HV end fitting both on the housing surface and inside the composite insulator is critically dependant on the size and location of the corona ring. Therefore, the design of the grading rings is clearly under the responsibility of the insulator manufacturer.

The exact voltage level that will generate the critical field at which corona rings are required is also dependent on the tower and string configuration. The utility should provide the different tower and string configurations to the corona ring designer. Usually, the single string tension configuration is likely to be the most severe case. A 3D calculation is required to determine precisely this critical voltage level. Although computer calculations are reliable and efficient, it is also recommended to perform laboratory tests that simulate the relevant tower configuration. In addition, to ensure long satisfactory service, it may be advisable to use a safety factor to cover changes such as that caused by corrosion of the corona rings.

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APPENDIX 1 - PAGE 1/2

CASE 1

INSULATOR PROFILE 1 WITHOUT RING

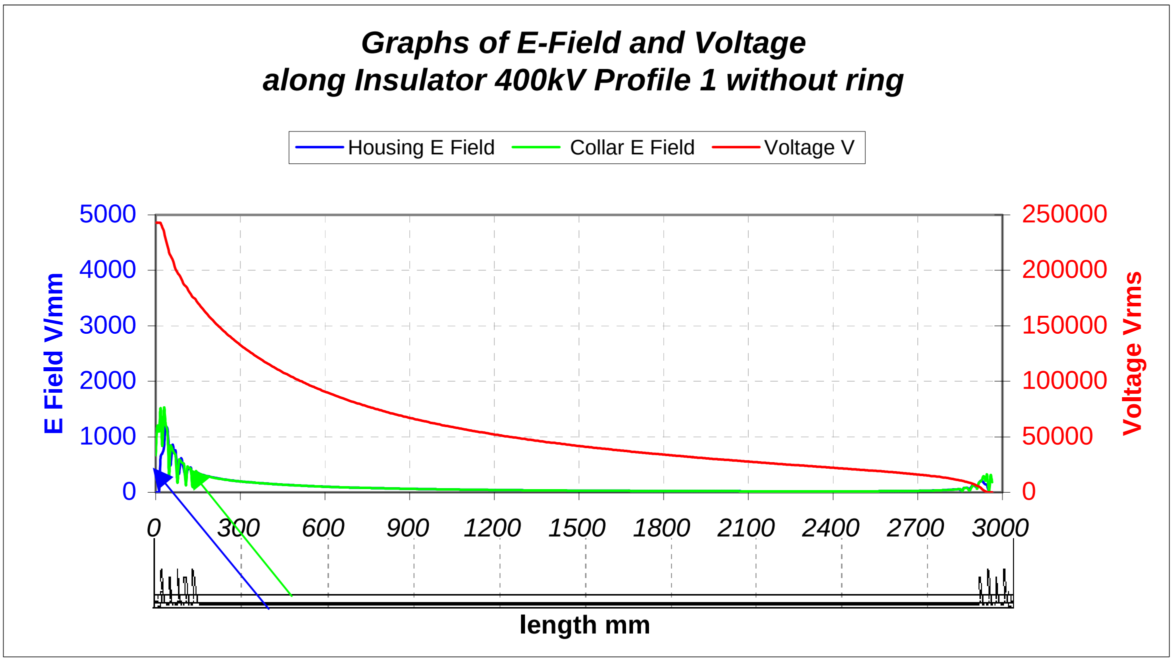

Figure 1

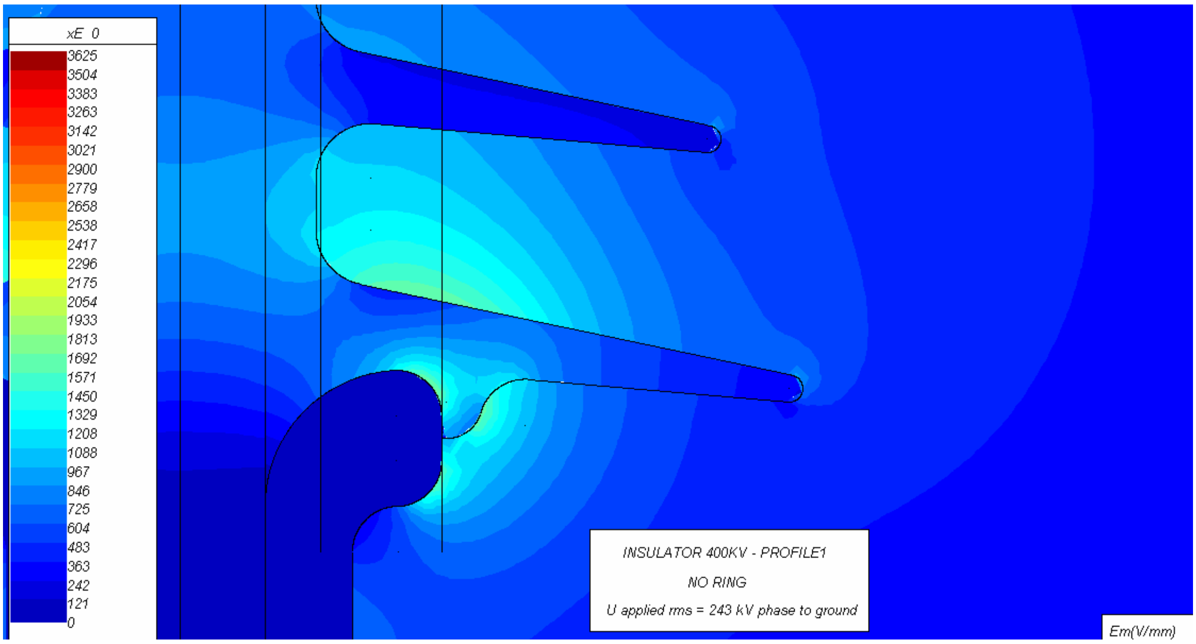

Figure 2 : Insulator profile 1 with no ring. Contours field details

APPENDIX 1 - PAGE 2/2

CASE 1

INSULATOR PROFILE 2 WITHOUT RING

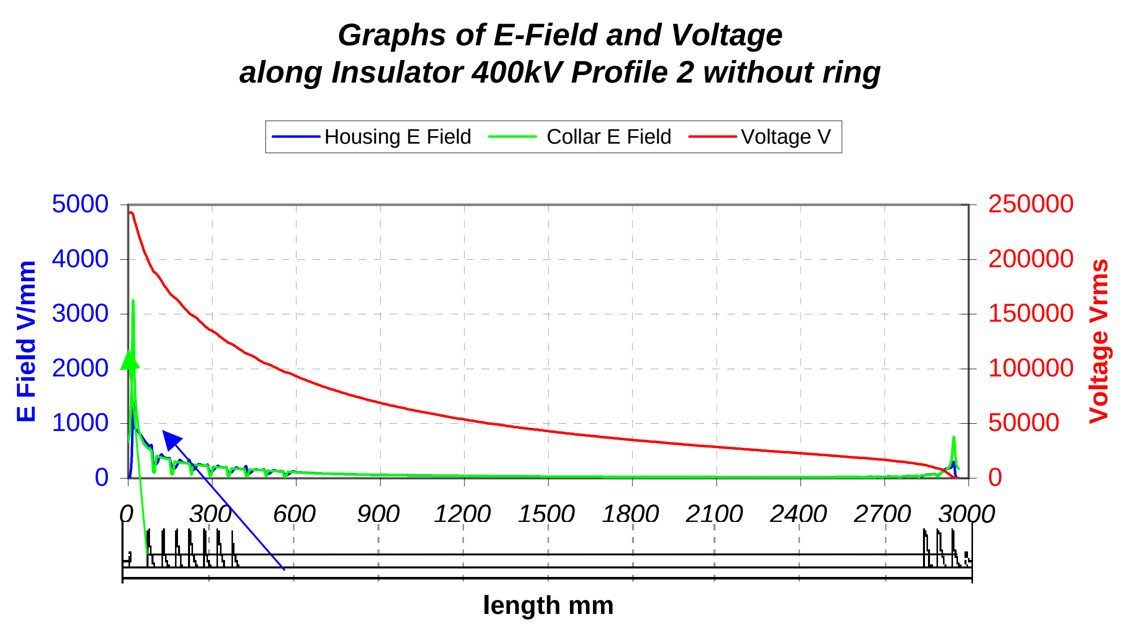

Figure 3

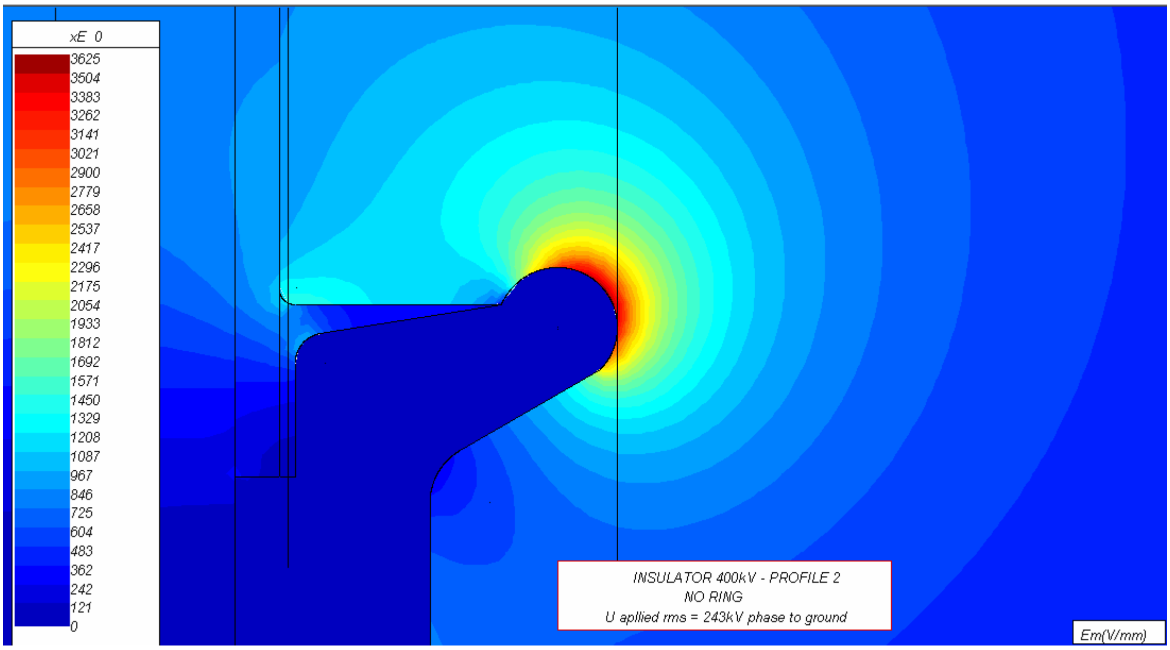

Figure 4 : Insulator profile 2 with no ring. Contours field details

APPENDIX 2

CASE 2

INSULATOR PROFILE 2 WITH MODIFIED COLLAR

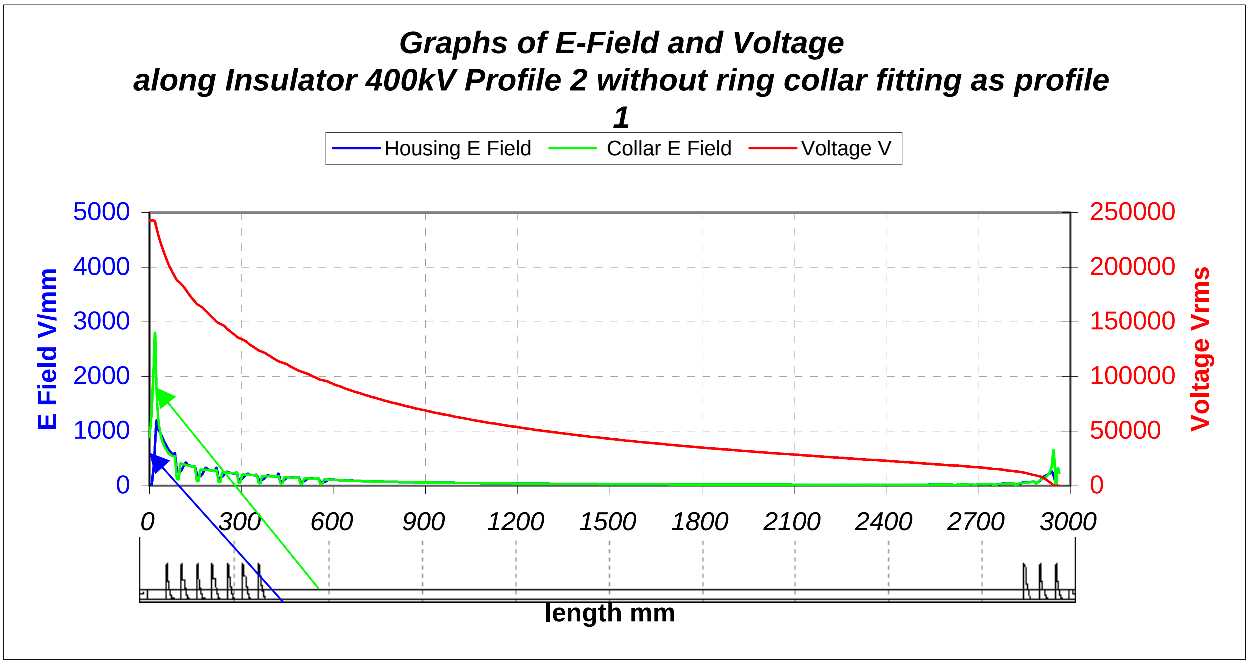

Figure 5

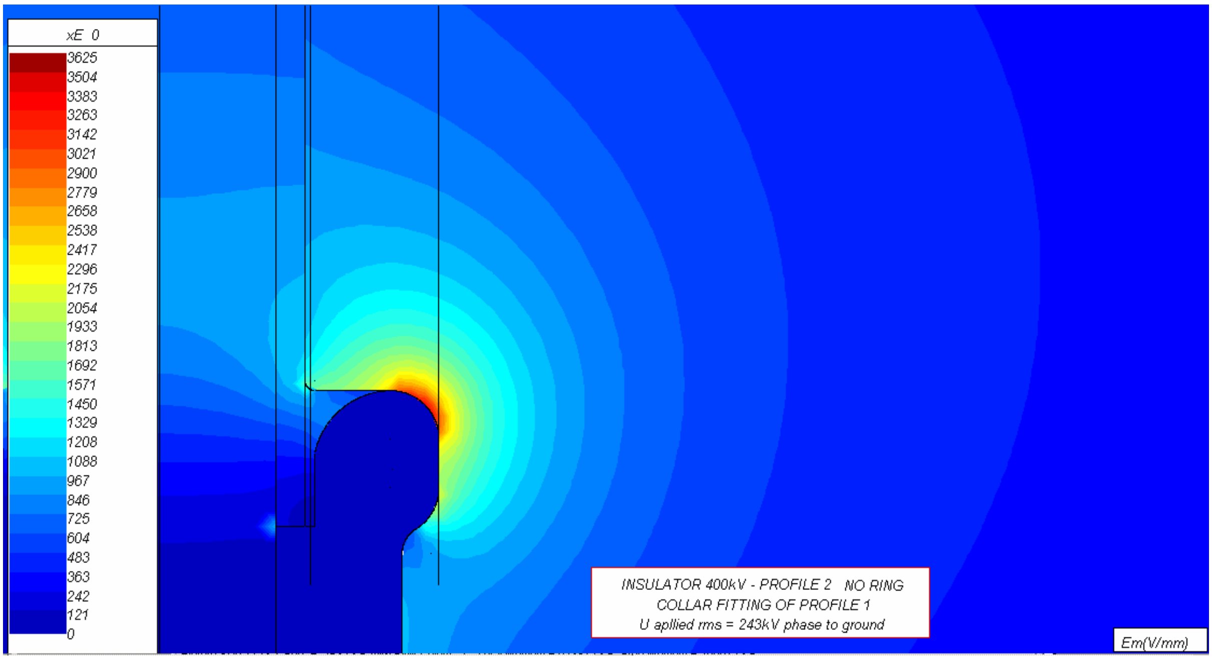

Figure 6 : Insulator profile 2 with collar fitting of the profile1 with no ring. Contours field details.

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CASE 3

INSULATOR PROFILE 1 WITH RING – HEIGHT 25mm

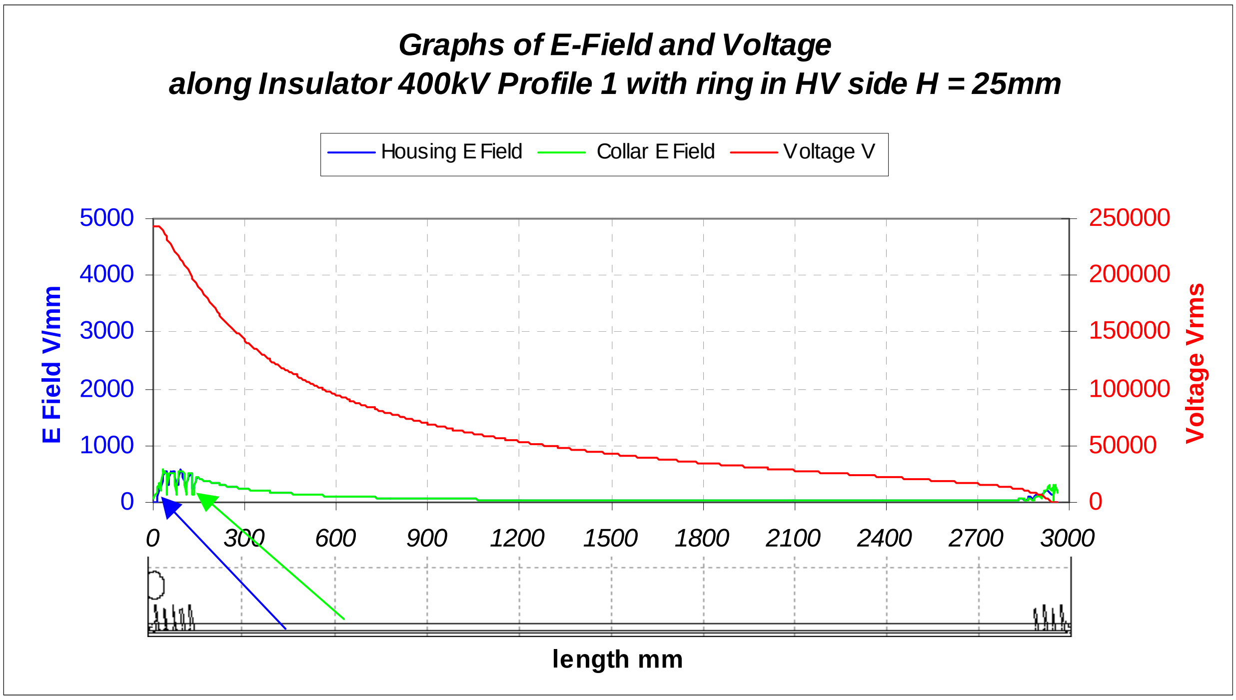

Figure 7

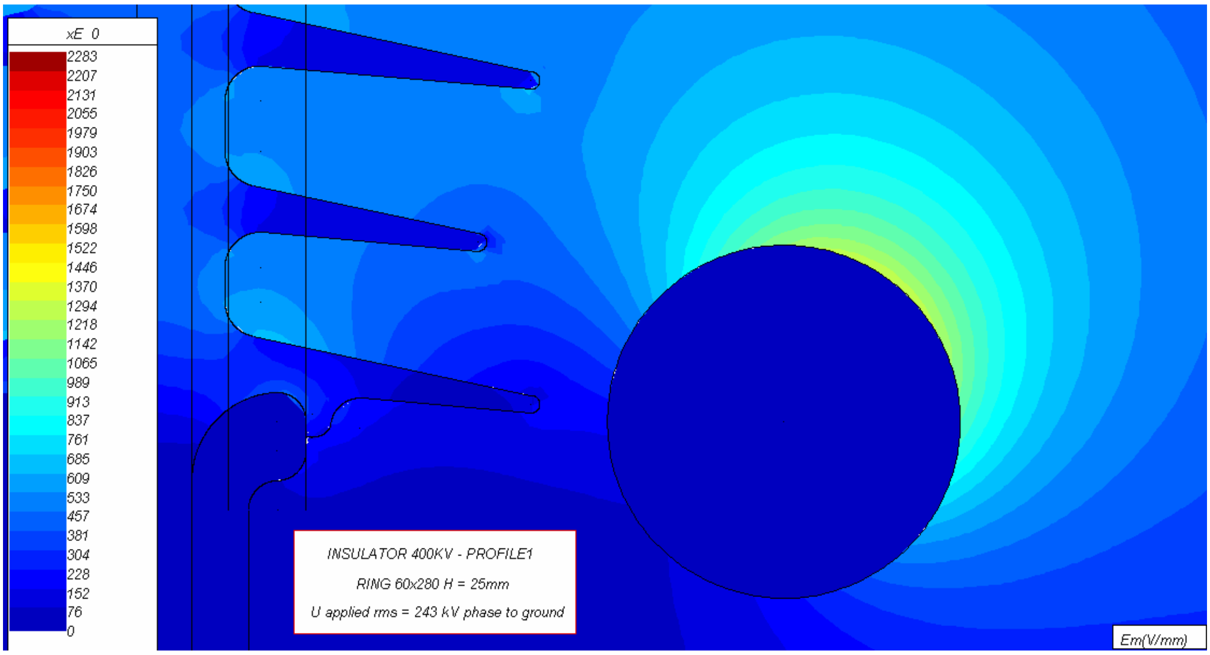

Figure 8 : Insulator profile 1 with ring at 25mm above the top of collar fitting.

APPENDIX 3 - PAGE 2/2

CASE 3

INSULATOR PROFILE 2 WITH RING – HEIGHT 25mm

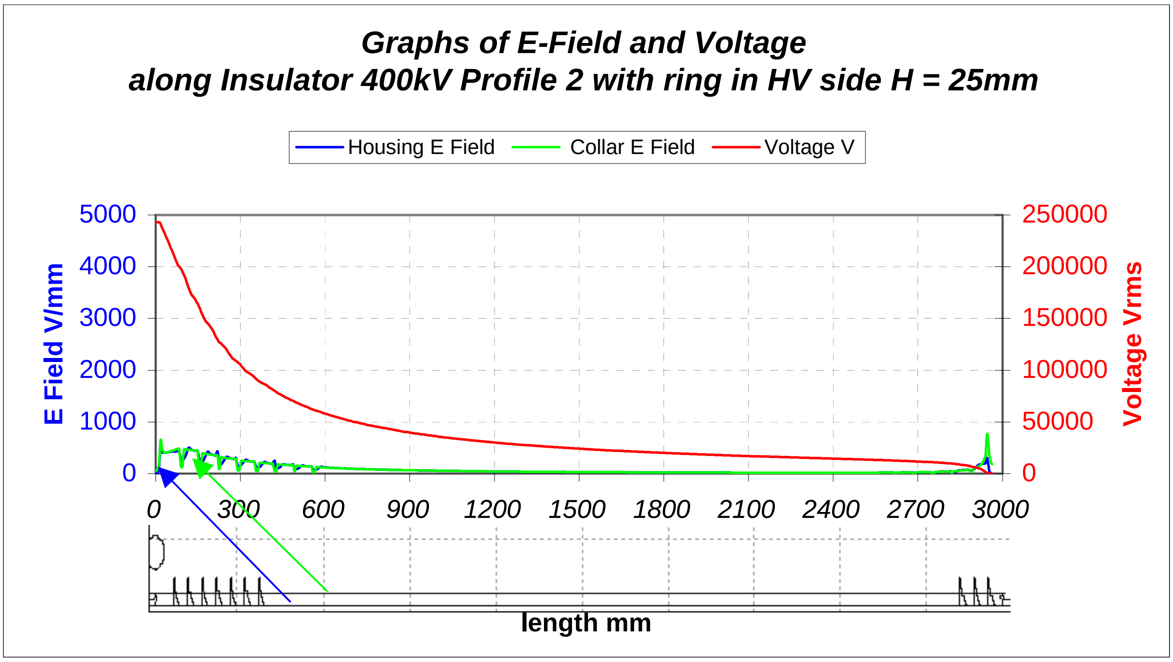

Figure 9

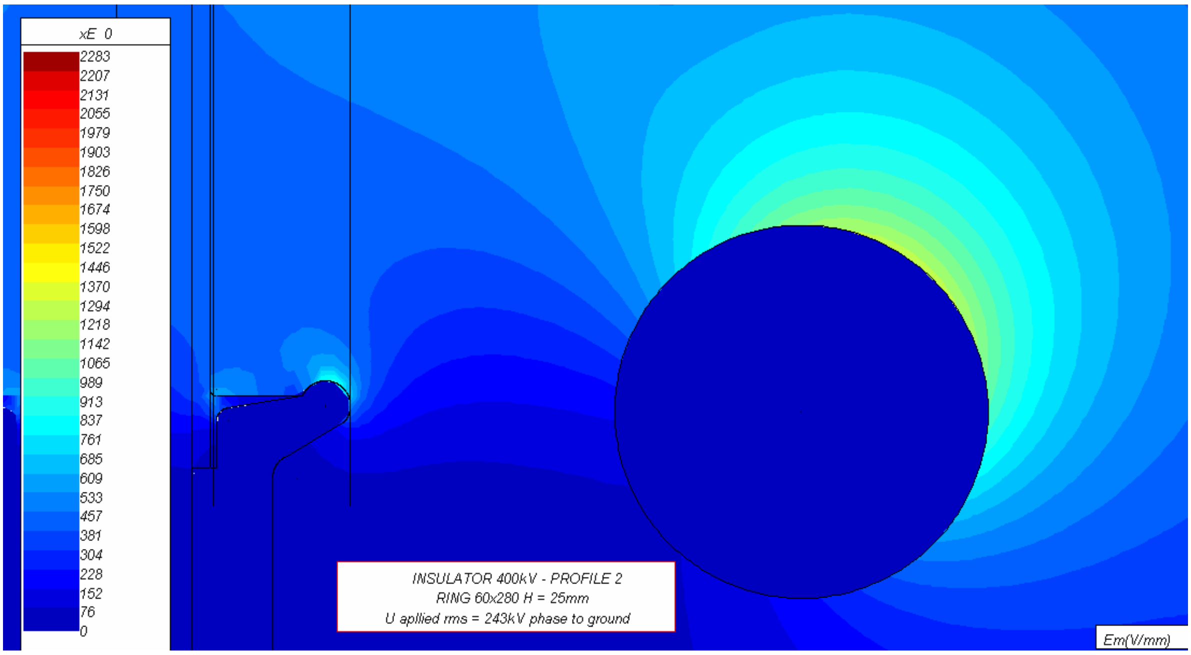

Figure 10 : Insulator profile 2 with ring at 25mm above the top of collar fitting.

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CASE 4

INSULATOR PROFILE 1 WITH RING – HEIGHT 50mm

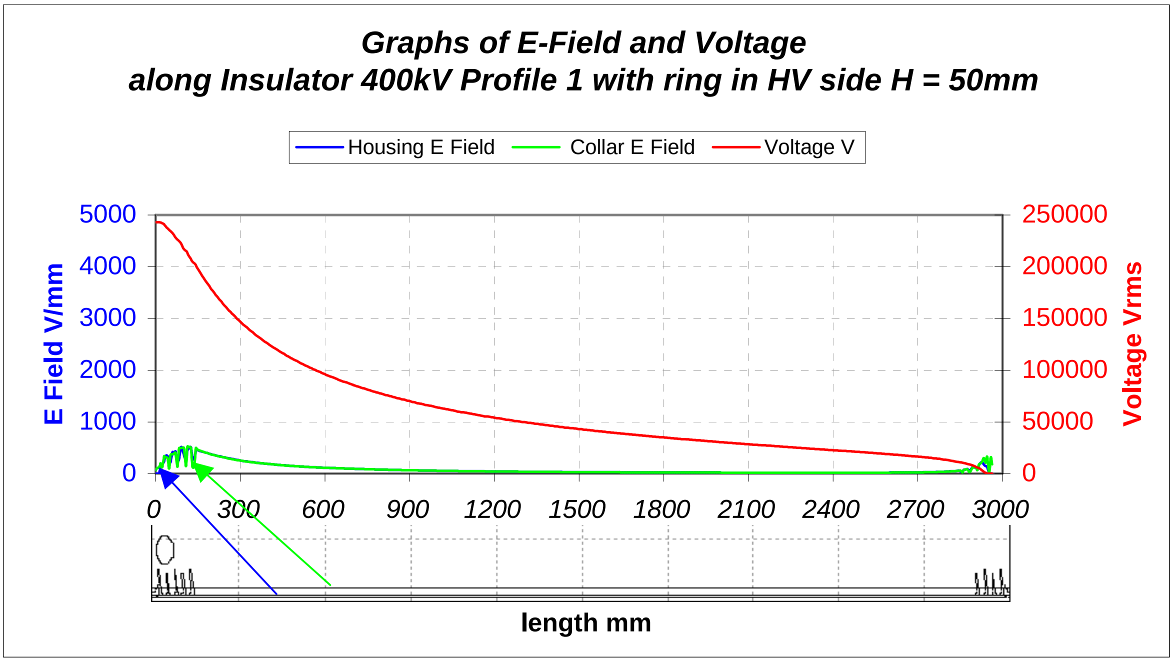

Figure 11

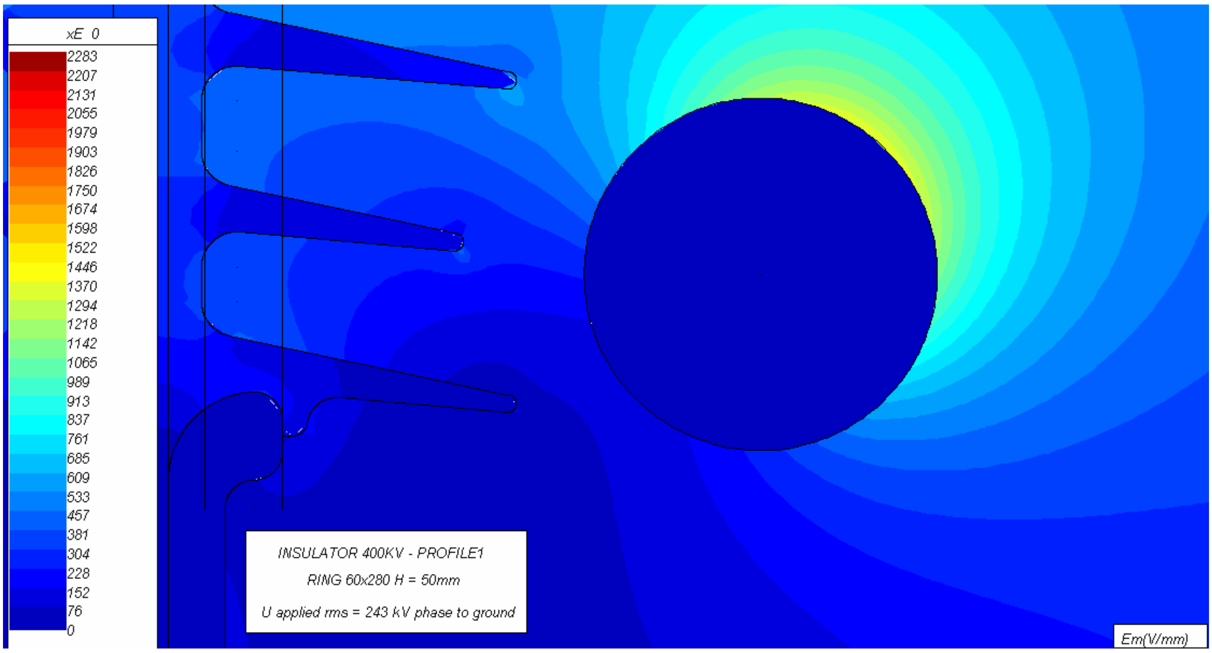

Figure 12 : Insulator profile 1 with ring at 50mm above the top of collar fitting.

APPENDIX 4 - PAGE 2/2

CASE 4

INSULATOR PROFILE 2 WITH RING – HEIGHT 50mm

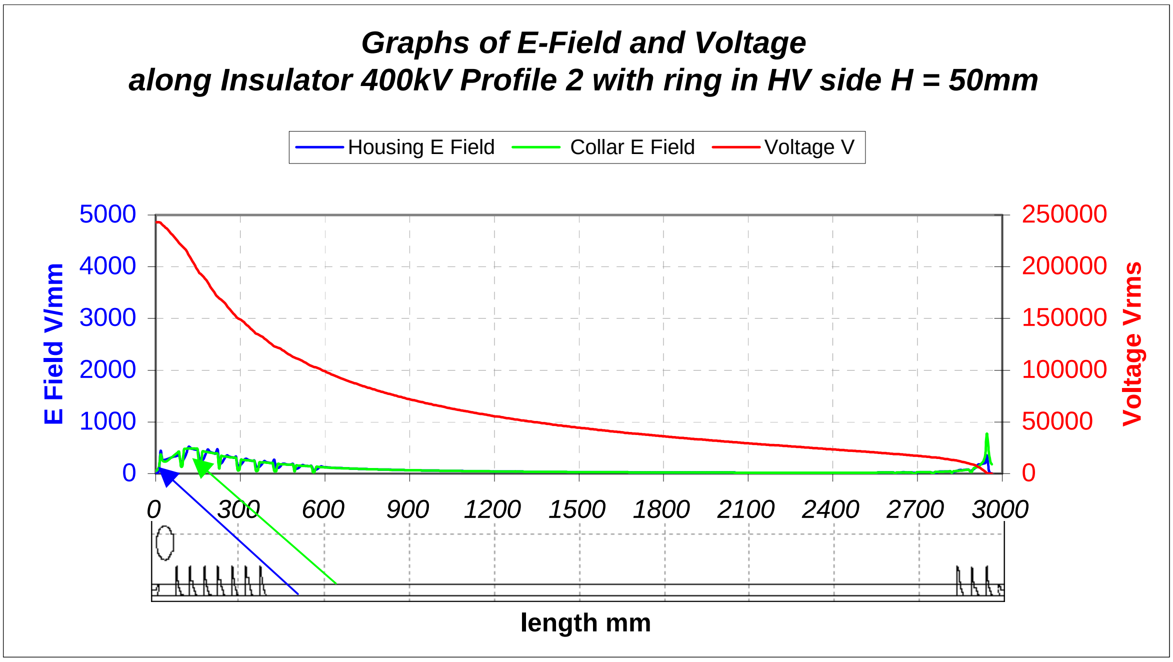

Figure 13

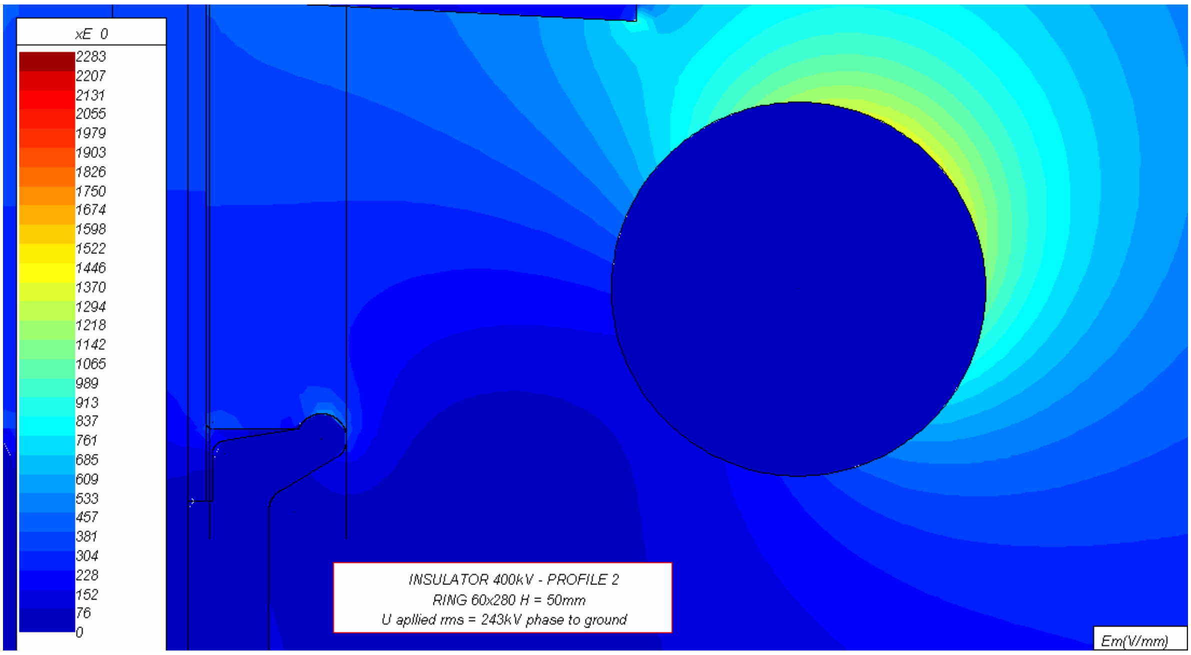

Figure 14 : Insulator profile 2 with ring at 50mm above the top of collar fitting.

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CASE 5

INSULATOR PROFILE 1 WITH RING – HEIGHT 75mm

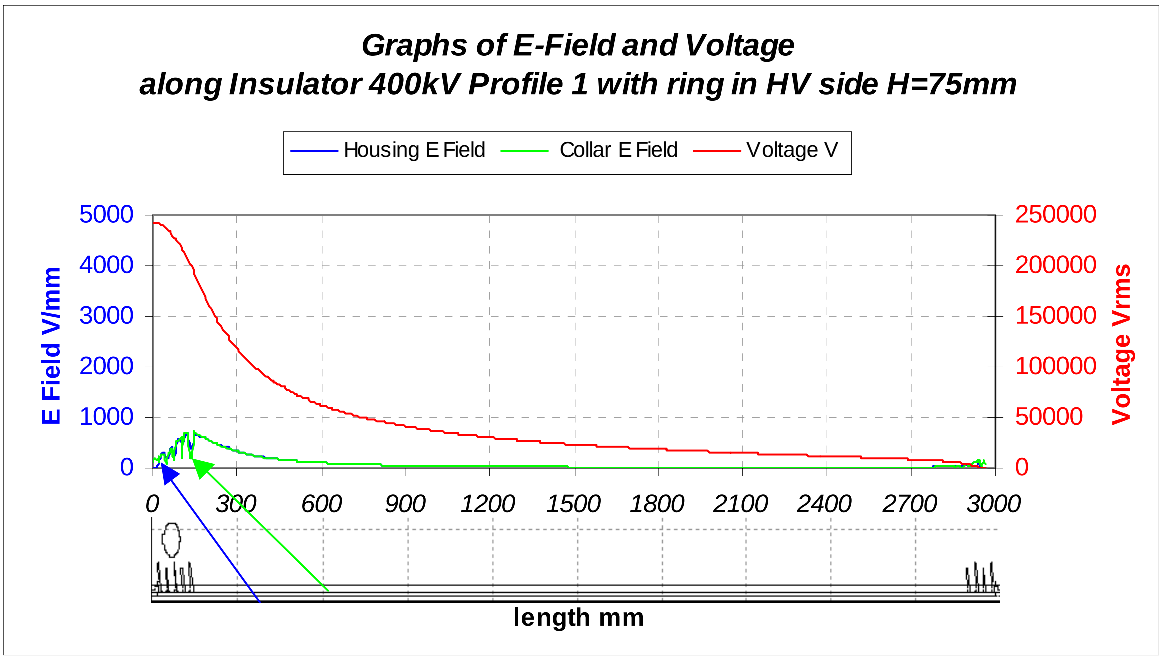

Figure 15

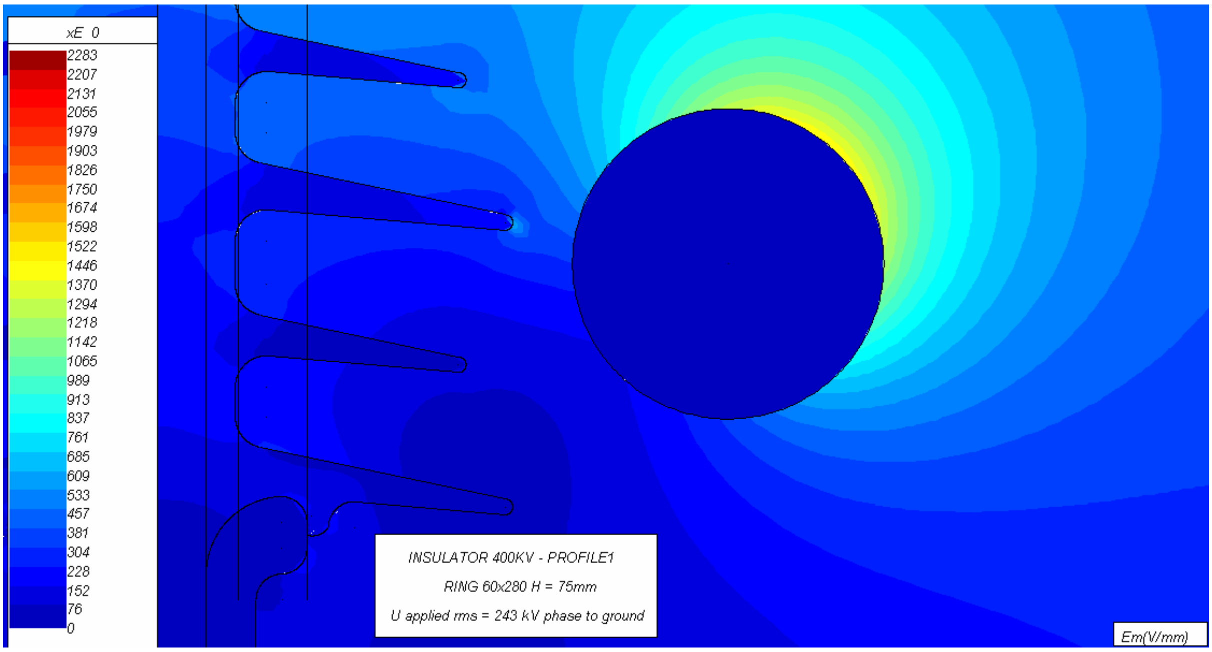

Figure 16 : Insulator profile 1 with ring at 75mm above the top of collar fitting.

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CASE 5

INSULATOR PROFILE 2 WITH RING – HEIGHT 75mm

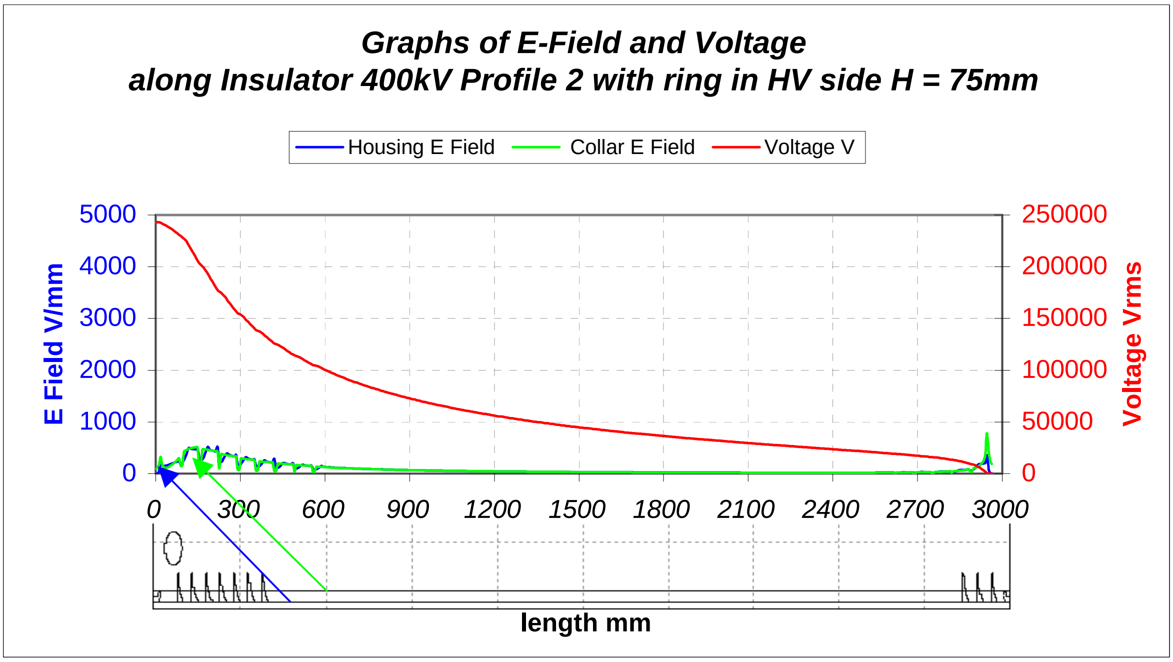

Figure 17

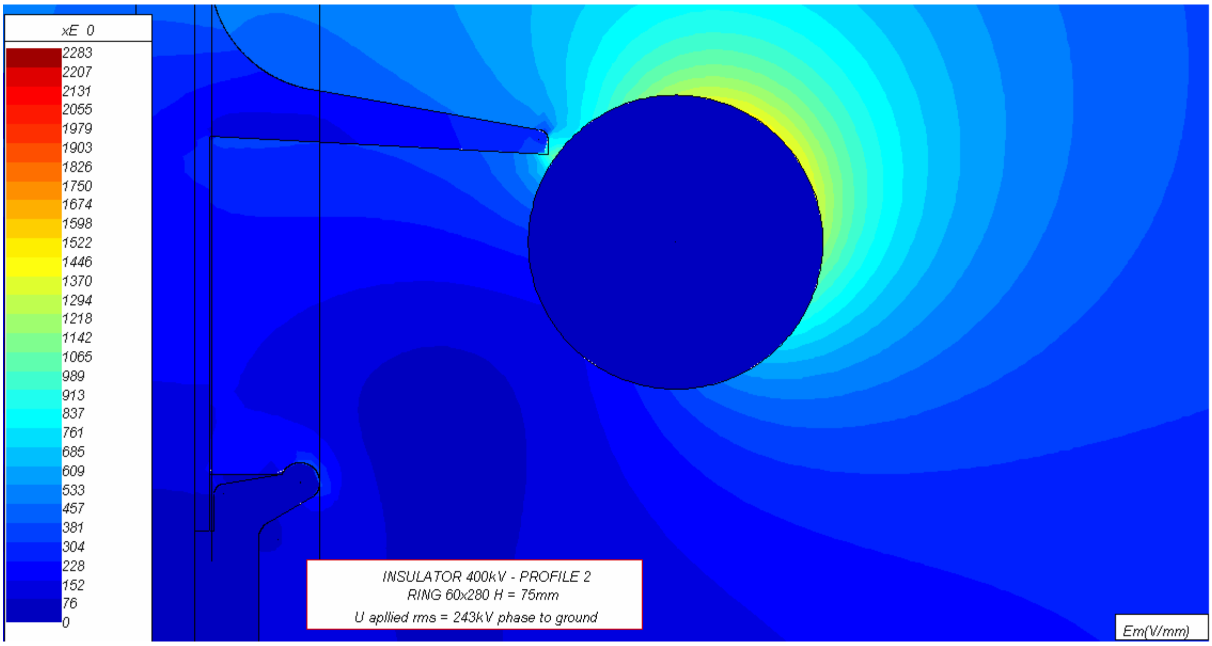

Figure 18 : Insulator profile 2 with ring at 75mm above the top of collar fitting.

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CASE 6

INSULATOR PROFILE 1 WITH RING 20/280 mm
Position 2 : HEIGHT 50mm

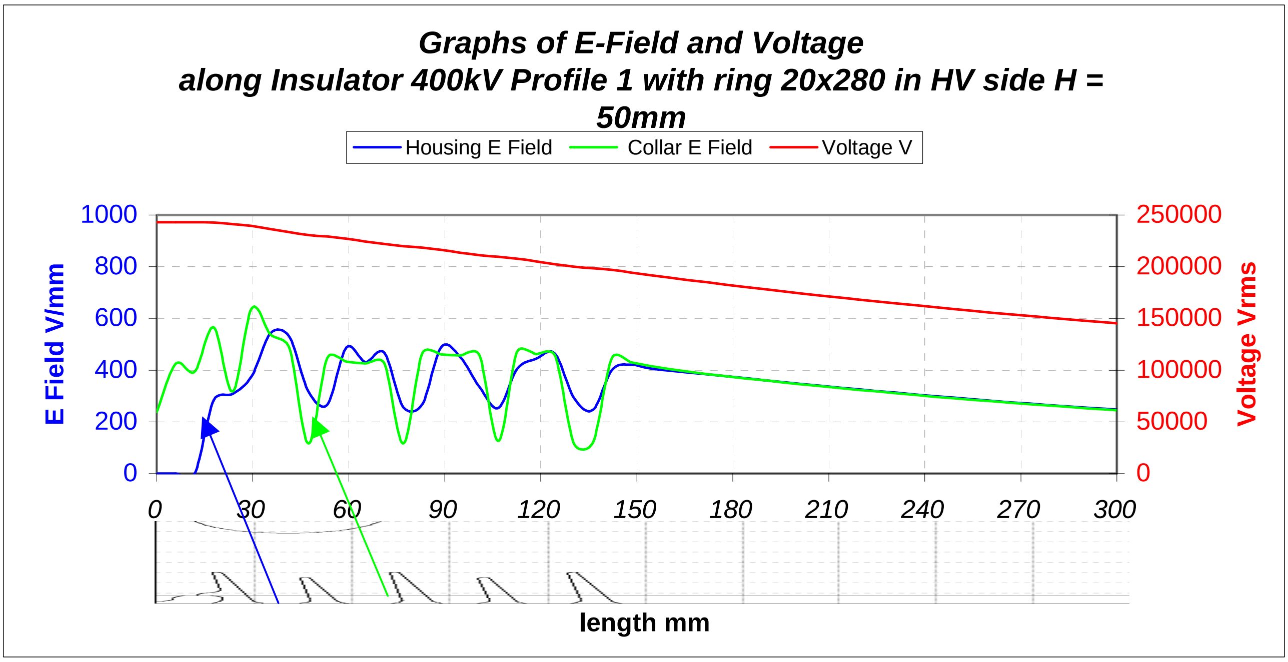

Figure 19

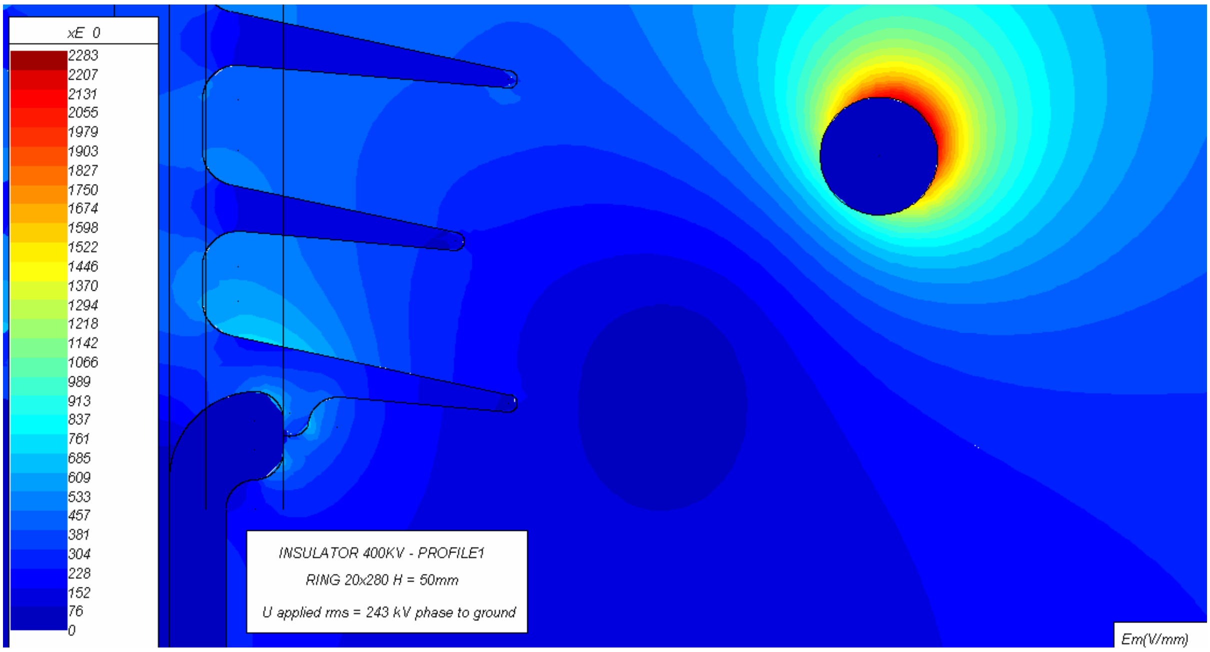

Figure 20 : Insulator with ring 20x280 at 50mm above the top of collar fitting.

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CASE 6

INSULATOR PROFILE 1 WITH RING 40/280 mm

Position 2 : HEIGHT 50mm

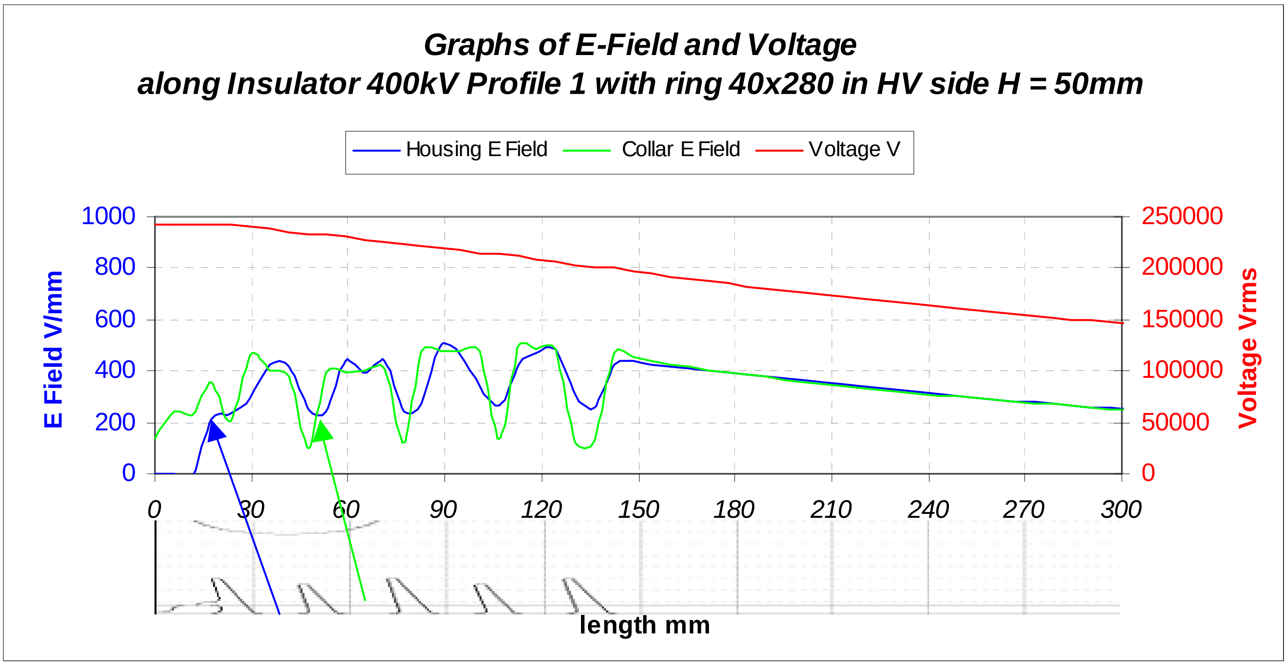

Figure 21

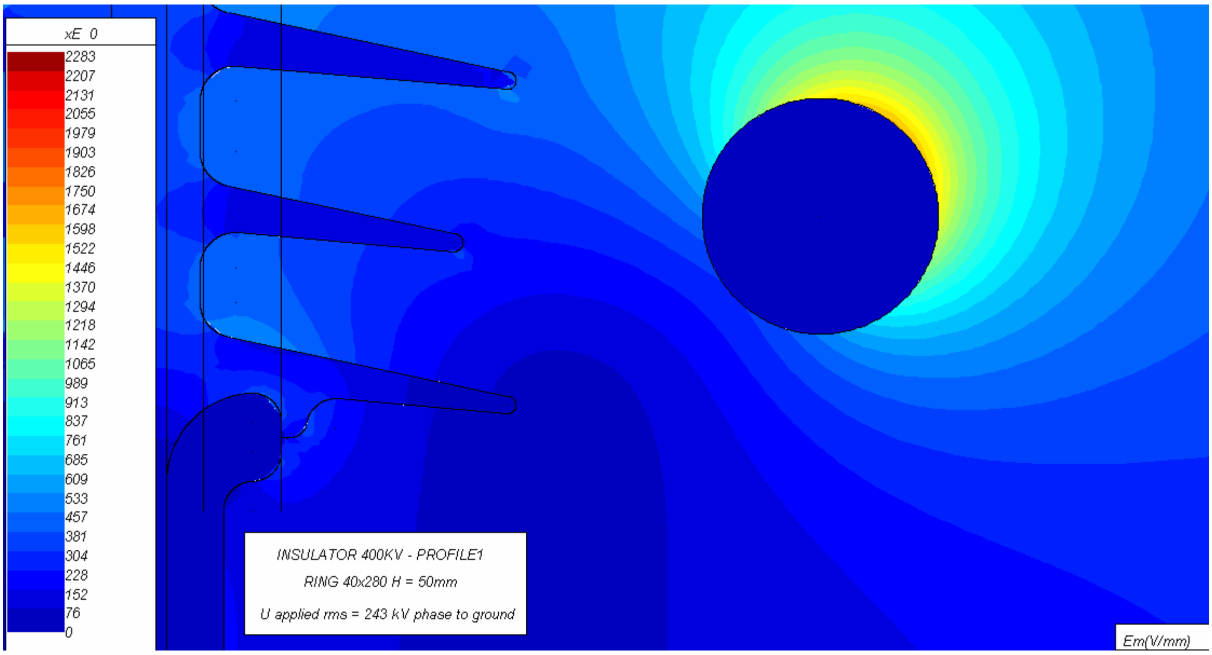

Figure 22 : Insulator with ring 40x280 at 50mm above the top of collar fitting

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CASE 6

INSULATOR PROFILE 1 WITH RING 70/280 mm

Position 2 : HEIGHT 50mm

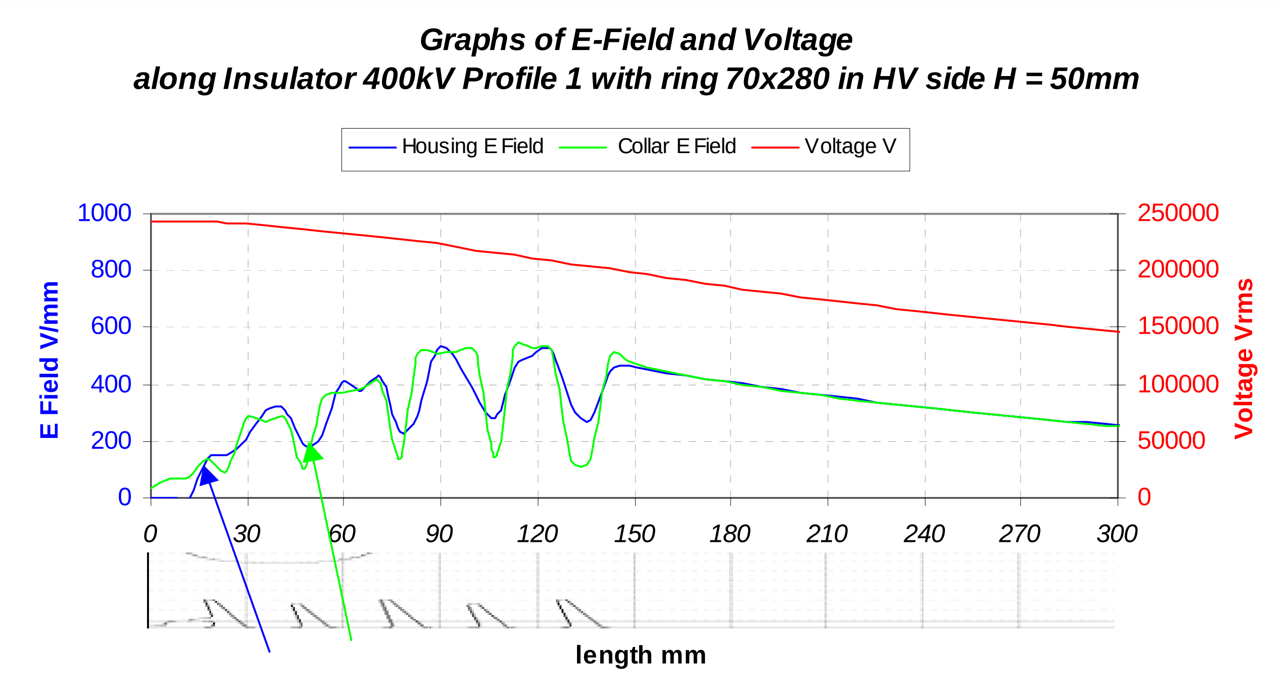

Figure 23

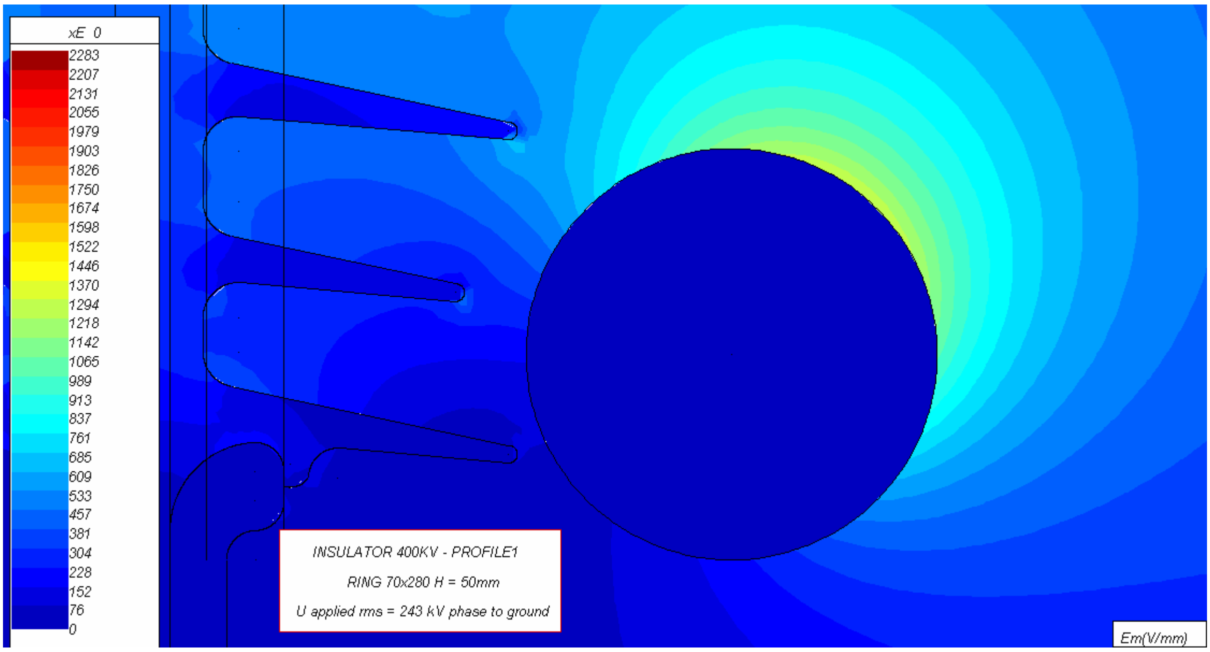

Figure 24 : Insulator with ring 70x280 at 50mm above the top of collar fitting.

APPENDIX 7

CASE 7

INSULATOR PROFILE 1 WITH RING 60/390 mm

Position 2 : HEIGHT 50mm

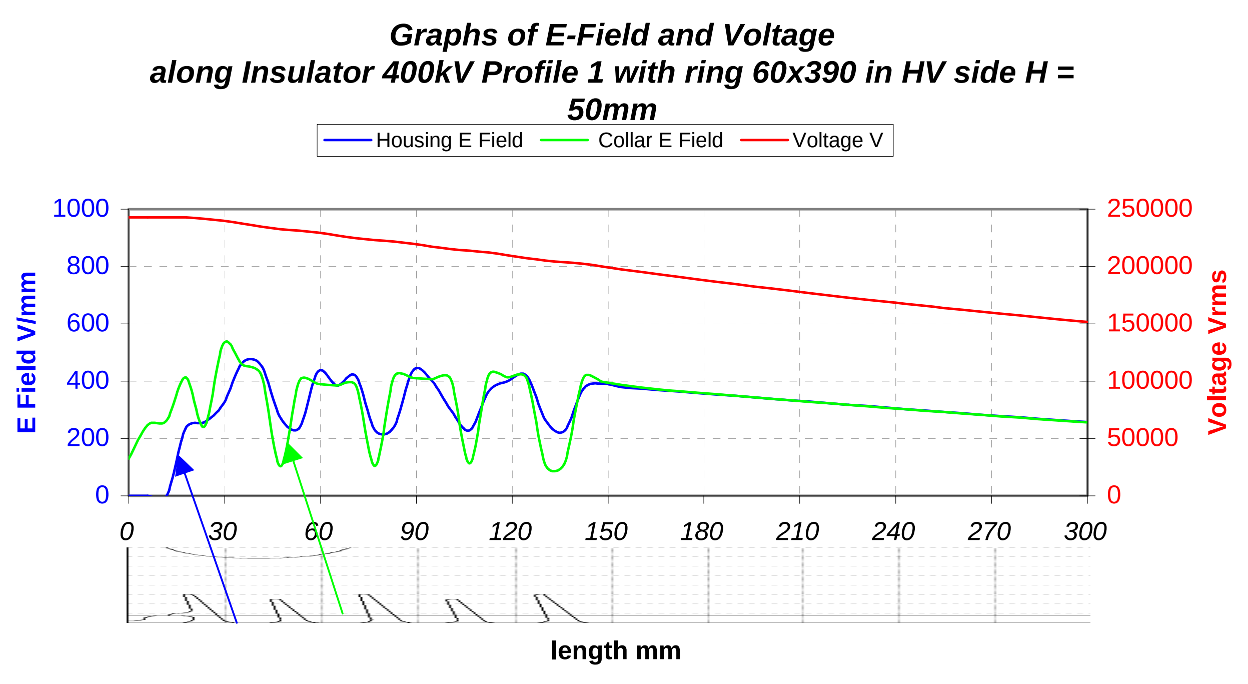

Figure 25

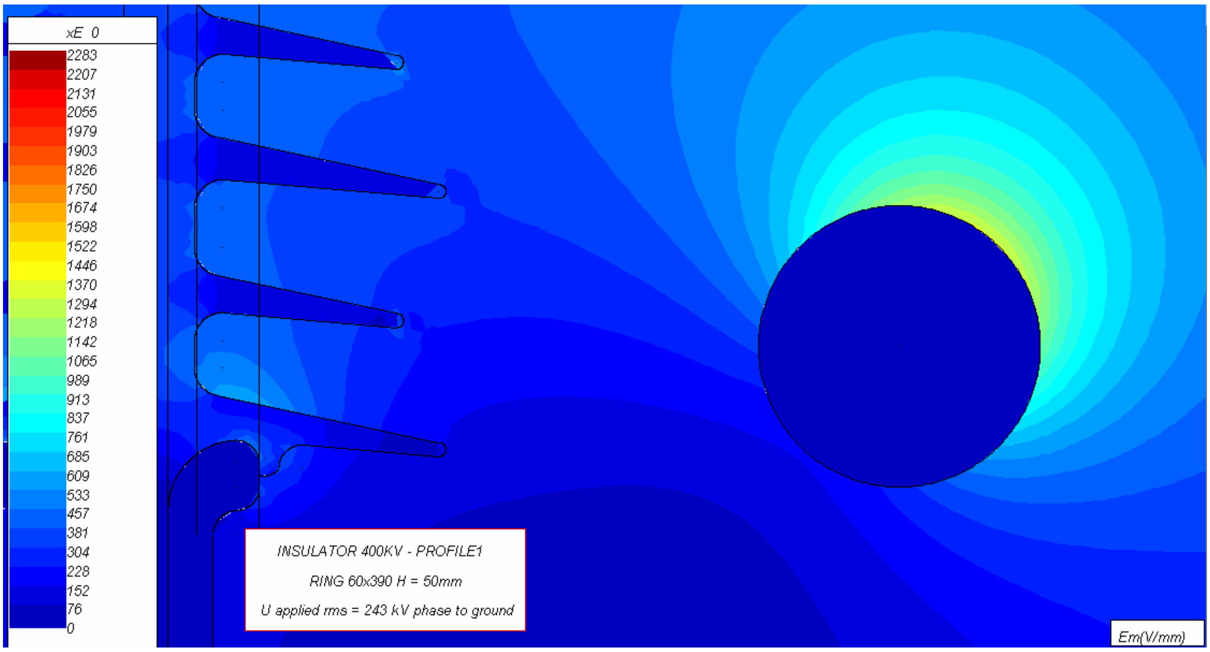

Figure 26 : Insulator with ring 60x390 at 50mm above the top of collar fitting.