Modeling Electric Fields in High Voltage Submersible Changeover Switch

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Abstract: Controlling electric field distribution in high voltage components is critical to avoid excessive electric stress on the insulation and thus reducing the risk of insulation breakdown and damage to equipment. For subsea applications this is even more important due to the costs involved in accessing and replacing the damaged parts. This paper describes how Comsol Multiphysics 4.0 have been used for modeling electric fields in high voltage components inside a submersible changeover switch using electrostatic 2D simulations in the AC/DC module.

Keywords: High Voltage, Electrostatic, Field simulation.

1. Introduction

In oil wells where the pressure has been reduced, pumps are used to increase the pressure in the well, leading to an increased lifetime and improved oil recovery. Subsea pumps are subject to harsh environments and wear down quickly. The pumps are a critical part in the production system, and to reduce the risk of breakdown and production stop, oil companies can use a dual pump system, where the second pump is utilized when the first is out of service. Subsea umbilicals is a major cost in such a system, rapidly increasing with sea depth, and with two pumps one need two umbilicals unless a system is used for switching between the two pumps. A subsea changeover switch removes the need for two umbilicals giving potentially large reductions in production costs.

In such dual pump setup, the switch becomes a critical component where failure will have large consequences. Its design must therefore be such that it will withstand the stress subjected to it throughout the lifetime of the pumps it is supposed to serve. Pumps are typically 3-6 MW, with high voltage and current which makes electric field control and cooling of high importance.

The switch consists of a switching element encapsulated in an oil filled, pressure compensated container. The pressure compensation removes the need for the thick walls needed to withstand the pressure on large sea depths, up to 4000 m. The oil serves both as a pressure compensating- and insulating medium. The oil also works as a part of the cooling system, transporting heat to the outer walls and the sea water.

High electric stress can cause partial discharges (PD) [1], which can eventually lead to dielectric breakdown, and must be avoided. PD is a local breakdown of the dielectric which starts when a certain threshold value is reached. This value will depend on the conductor and insulation configuration and can be raised by choosing a proper design.

This paper focuses on two areas for improvement, aiming at lowering the electric field strength. The first is where the conductor is attached to the switching element and the second is the conductor feedthrough between two oil filled chambers.

2. The Model

This section describes the modeling of the two parts; the conductor attachment and the feedthrough. The equations to be solved are the Maxwell equations, which in the electrostatic case with no field charge can be reduced to [2]

$$\nabla^2 V = 0.$$

The relationship between the electric field and the electric potential, V, is

$$E = -\nabla V.$$

The electric field, E, in an insulating medium is modified through the relationship

$$D = \varepsilon_r \varepsilon_0 E.$$

Where D is the electric displacement field, ε_r is the relative permittivity, and ε_0 is the permittivity of free space.

2.1 Conductor Attachment

The old configuration consists of a copper rod attached by a screw with cup springs. This is modeled in Figure 1. The new configuration has got a rounded copper shape called Field Shape Sphere added to it, shielding the sharp edges leading to field enhancement.

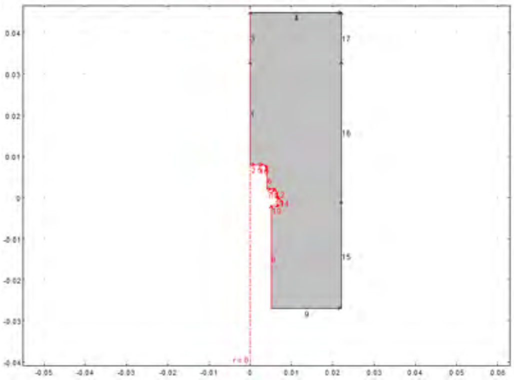

Figure 1: The model of the conductor attachment. The dotted line to the left is the symmetry axis, the red line is the conductor surface with an electric potential of 5 kV, the grey area is mineral oil and the right most boundary is the grounded enclosure wall.

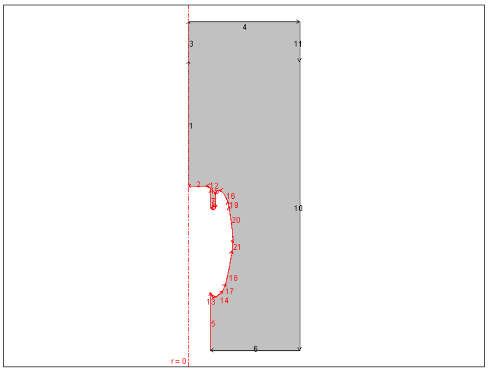

Figure 2: The conductor attachment with the Field Shape Sphere. The dotted line to the left is the symmetry axis, the red line is the conductor surface with an electric potential of 5 kV, the grey area is mineral oil and the right most boundary is the grounded enclosure wall.

This is modeled in Figure 2. In both figures, the left most edge is the symmetry axis. The conducting parts are the white sections in the grey rectangle. Its boundaries, marked with red, have been given an electric potential of 5 kV. The grey area represents the oil filled volume with a relative permittivity of 3. The right most edge is the grounded outer wall, and the top and bottom edges are given a zero charge boundary condition. The models have been meshed with a free triangular mesh, size “Fine”, using the Comsol mesh generator [3]. Mesh quality for the old and new shape is shown in Figure 3 and Figure 4 respectively. The quality of the mesh is represented by a number, q, between 0 and 1. For $q > 0.3$, the solution should not be affected by the mesh quality [4]. From the mesh quality plots one can see that the mesh is good, and that $q \geq 0.7$ for both models. The solution for the electric field was obtained using the MUMPS solver [5].

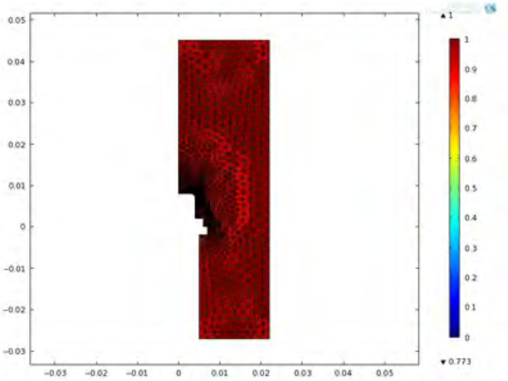

Figure 3: Mesh quality, screw connection with cup springs.

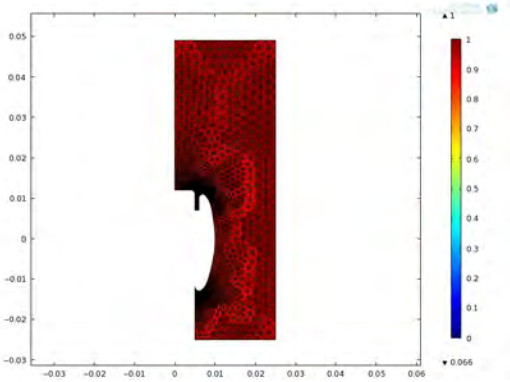

Figure 4: Mesh quality, screw connection with Field Shape Sphere.

2.2 Conductor feedthrough

The feedthrough is where the conductor is taken from the lower chamber or junction box, to the upper chamber where it is attached to the switching mechanism. The old feedthrough,

Figure 10, consists of a PEEK insulator holding the conductor, with silicone rubber boot seal at the bottom. The

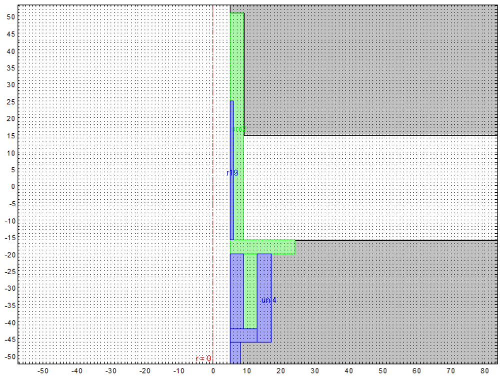

Figure 5: Model of the old feedthrough. The green area is the PEEK insulator, the blue area is silicone rubber, the grey area is mineral oil, the horizontal white rectangle is the wall separating two chambers and the vertical white rectangle is the conductor. The narrow blue area is an air gap.

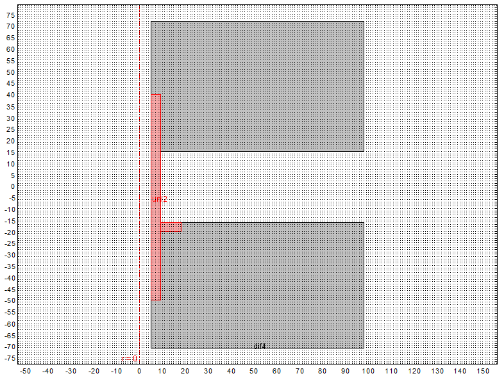

Figure 6: Model of the new feedthrough. The grey area is mineral oil, the red area is the moulded silicon rubber feedthrough, the horizontal white area is the wall separating the two chambers and the vertical white rectangle is the conductor.

wall separating the two chambers is a grounded metal plate. The PEEK feedthrough is modeled with an air gap between the conductor and the insulator, a weakness which could easily occur due to the design. The new design should eliminate this weakness, and the motivation for the model is to show the improvement in the design. The red dotted line is the symmetry axis, and the left most edge of the grey area represents the conductor surface which has an electric potential of 5 kV. The green area is the insulation, which consists of a PEEK insulator with relative permittivity of 4, the large blue area is silicone rubber with relative permittivity of 2.7 and the grey area is mineral oil with relative permittivity of 3. Charge conservation applies between the different insulating materials. The white areas represent the metal parts; the plate separating the two chambers and the conductor. The metal plate and the right most edges of the grey area is grounded, and the top and bottom edges has a zero charge boundary condition.

The new feedthrough replaces the PEEK insulator with a moulded silicone rubber insert. This is shown in Figure 7. The boundary conditions are otherwise the same as for the old feedthrough.

Both feedthroughs have been meshed using a free triangular mesh, size “Fine”. The mesh quality is plotted and shown in Figure 8 and Figure 9. From the mesh quality plots one can see that the mesh is good [4], and that q ≥ 0.7 for both models. The electric field is solved using the MUMPS solver and the solution is shown in Figure 12 and Figure 13.

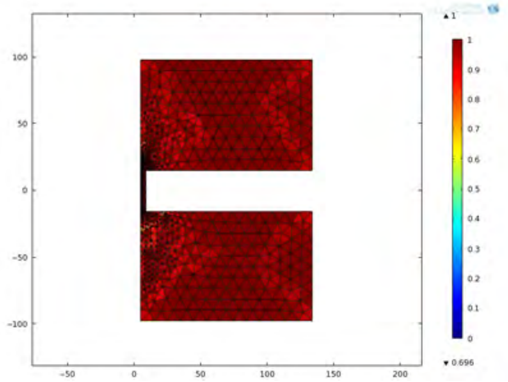

Figure 8: Mesh quality, old feedthrough model. The mesh is built using a free triangular mesh.

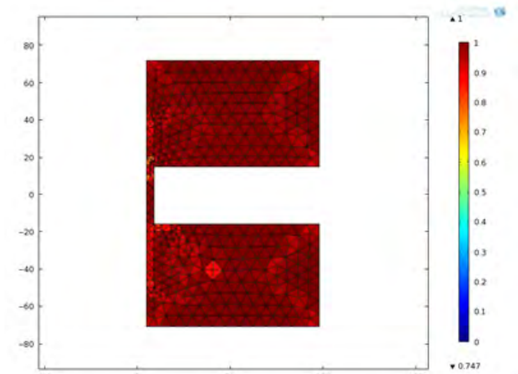

Figure 9: Mesh quality, new feedthrough. The mesh is built using a free triangular mesh.

3. Results

The results for the electric fields are shown in Figures 9, 10, 11 and 12. The calculated maximum electric fields for the conductor connection are 2.46x10^6 V/m for the old one and 1.61x10^6 V/m for the new with the Field Shape Sphere. That yields a reduction in the electric field by 35%.

For the feedthroughs, the calculated maximum electric fields are 3.51x10^6 V/m for the PEEK feedthrough and 1.66x10^6 V/m for the silicone rubber feedthrough – a reduction of 53%.

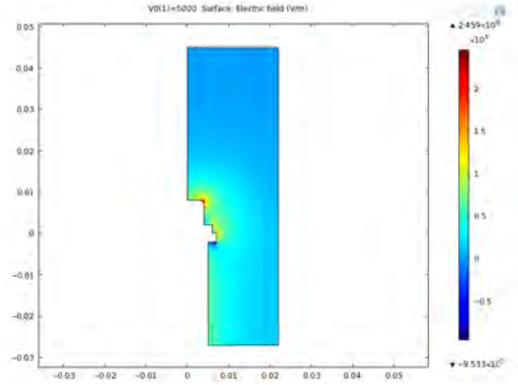

Figure 10: A surface plot showing the solution for the electric field around the conductor attachment. The maximum field strength is 2.46x10^6 V/m.

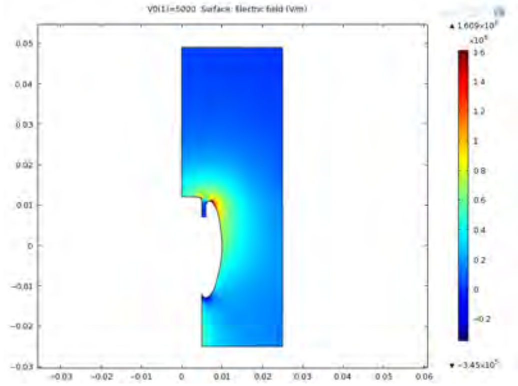

Figure 11: A surface plot showing the solution for the electric field around the conductor attachment with Field Shape Sphere. The maximum electric field is 1.61x10^6 V/m.

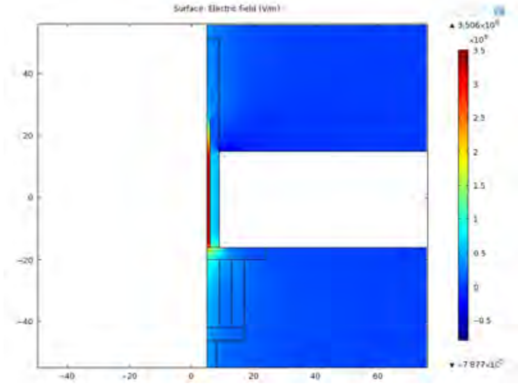

Figure 12: A surface plot showing the solution for the electric field for the old feedthrough model. The maximum field is found in the air gap close to the conductor and is 3.51x10^6 V/m.

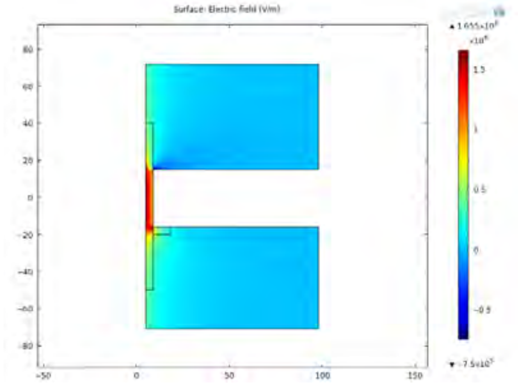

Figure 13: A surface plot showing the solution for the electric field for the new feedthrough model. The maximum electric field is 1.66x10^6 V/m.

	Before	After
Phase	IV [kV]	IV [kV]
A1	4	13
A2	4,6	12
A3	4,6	13
B1	5	13
B2	5	12
B3	5	12

Table 1: Inception voltage for the different phases before and after the modification of the conductor attachment and the feedthrough.

Verification of the calculations by means of measuring the electric field inside the changeover switch has not been possible, but partial discharge (PD) tests have been performed before and after the modifications, and the inception voltage have been recorded for the different phases. The results from the PD tests are shown in Table 1, and one can see that there is a significant increase in the inception voltage after the modifications. The increase in inception voltage can be explained as a result of an increase in the critical field strength due to the change in design. At the same voltage, the field strength is reduced, so it takes a higher voltage to reach the same field strength as before the changes. Calculating the electric field for higher voltages show that with the new design, 11 kV is needed to reach the same field strength as for the old design at 5 kV, Figure 14. This corresponds roughly with the measured inception voltages in Table 1. The differences between the measurements and the calculations can be explained by the simplifications that has been done in the modeling of the two problems.

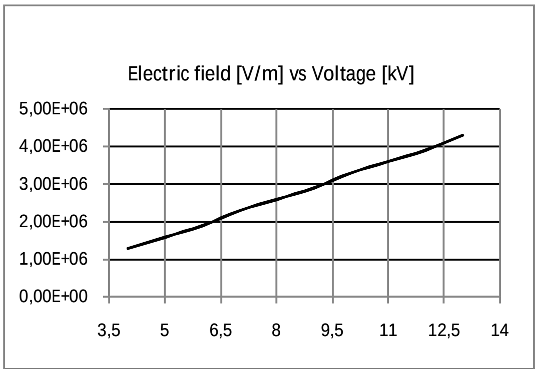

Figure 14: A plot of the electric field strength (y-axis) against voltage (x-axis) for the new feedthrough.

7. Conclusions

In this paper it have been shown how Comsol Multiphysics 4.0 have been used to calculate the electric fields for two different problems. Improvements have been verified by building and testing prototypes based on knowledge gained from the Comsol models. A significant increase in the PD inception voltage has been achieved.

8. References

[1] C. L. Wadhwa, High Voltage Engineering, 2nd edition, *New Age Publishers*, 2007

[2] David J. Griffiths, Introduction to Electromagnetics (third edition), *Prentice Hall, 1999*

[3] Comsol Multiphysics, User’s Manual, *Chapter 5 – Meshing*, page 299-375

[4] Comsol Multiphysics, User’s Manual, *Chapter 5 – Meshing*, page 372

[5] Comsol Multiphysics, User’s Manual, *Chapter 5 – Solving the model*, page 377-453