An App for Calculating the Electric Field outside Electrical Installations

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Abstract: This article describes an app for calculating low frequency electric field outside electrical installations. Recommendations regarding field exposure have been published by international research consortiums and is being implemented in EU law. Many tenures now come with requirements on the electric field in the vicinity and it is important to integrate this into the overall design process. A COMSOL Multiphysics app is constructed to make the electric field calculation directly available to the design engineer. The calculation is based on a parameterized 2D geometry which approximates a wide class of designs. The results from the app is validated against a 3D simulation and the results are shown to be good enough to use in production, while a full 3D model is necessary if better accuracy is desired.

Keywords: Electrostatics, Low frequency electric fields, COMSOL App Builder

1. Introduction

When designing electrical installations there are often requirements on the maximum electric field level allowed in the vicinity. These requirements are in place to make sure that the operation of electrical equipment does not affect the health and safety of the operators or the general public. The requirements apply to all electrical installation and typical examples include substations, capacitor banks and FACTS stations (an example is shown in figure 1).

In this article we consider electric field level verification for low frequency typically 50 or 60 Hz AC and while it will not be discussed specifically the work is also applicable to DC. There are also similar requirement for high frequency electric fields and for magnetic field, which are beyond the scope of this article.

The main method of verification of low frequency electric field levels is simulation. The simulation needed is straight forward to perform for a simulation expert. However, simulation experts are not always available when needed in the projects and postponing the simulation until the end of the design work runs the risk of significant late redesigns.

Figure 1. An ABB shunt capacitor bank.

There would be a large benefit if an automated solution could be found. This would enable a design engineer to do a verification during the design process without involving simulation experts. The case is therefore well suited for implementation in a COMSOL Multiphysics app. This articles explains how this was done for a parametric geometry that covers a large part of the main use cases.

This article is structured as follows. Section 2 gives a more in depth description of the problem at hand. In section 3 the theoretical background is discussed briefly. Section 4 describes the general simulation method and the specific approximations made when constructing an app. Section 5 presents the results and validates the 2D results against a 3D simulation. Discussion is presented in section 6 and conclusions in section 7.

2. Problem Description

There are several international research collaborations that provide guidelines for the recommended maximum levels of electric field in areas where people are allowed access [1, 2]. Recent EU regulation makes it mandatory to verify the electric field level [3]. In addition the customer can often have extra requirements of their own. The specification of the maximum electric field is usually done with two levels (one for authorized personal and one for the general public). The allowed field level is also usually frequency dependent.

In this article the ICNIRP guidelines [1] are used as an example. These represent the work of an international board of scientists tasked with setting guidelines for electrical field exposure. Reference values are stated in [1] and for 50 Hz the requirement is that the general public is exposed to at most 5 kV/m. A somewhat higher level of exposure is allowed for operators at 10 kV/m.

There are many different designs that need to be verified against the electric field requirements. The most common type is an electrical installation such as a substation, capacitor bank or FACTS station, surrounded by one or two grounded fences.

An example of this type of configuration is shown in figure 1, which depicts an ABB shunt capacitor installation surrounded by one fence. Often installations can have two separate fences, where one is for authorized personal and one for the general public.

The main practical problem to be solved is how to describe the geometry of an installation, with enough detail to get the desired accuracy but simple enough to enable efficient simulation.

3. Theory

The purpose of the simulation is to accurately calculate the low frequency electric field outside electric installations. The frequency is typically 50 or 60 Hz and at these frequencies the wavelength is much larger than any electric installation under consideration. The electric fields can therefore be calculated with Laplace equation using the electrostatics interface in COMSOL Multiphysics.

$$-\nabla \cdot (\varepsilon \nabla \phi) = 0 \quad (1)$$

$$E = -\nabla \phi \quad (2)$$

The equations above together with a geometrical representation of the case in question is sufficient for calculating the electric field from a theoretical point of view. The main challenge of this type of simulation lies in the geometry handling.

4. Method

When simulating a configuration such as the one in figure 1, the design is usually available as a CAD drawing. While it is possible to import CAD drawings directly into COMSOL, the drawings usually contain far too much detail and require a large amount of simplification if they are to be used in the simulation. This process takes a long time to perform and is difficult to automate.

The electric field of interest is a significant distance away from the active parts. It is therefore not important to consider details in the electrical components since this would have a small impact on the electric field outside the fence. The most common way of approaching the problem is therefore to construct a 3D geometry, based on the CAD drawings, representing the electrical components with simplified geometric shapes. This typically gives good accuracy of the calculated fields of interest.

A typical geometry involves several components connected to different phases and surrounded by one or two fences. While this represents a sound way of doing the simulations, it still involves significant manual work in setting up the geometry and is not suitable for automation.

4.1 Simplified Geometry Representation

To be able to automate the process, further simplifications are needed. Here the choice is made to go to a 2D axisymmetric geometry (shown in figure 2) and only consider one platform connected to one phase. This may sound too restrictive, but we will show that it is sufficient to get a reasonable approximation of the final value and the process can easily be

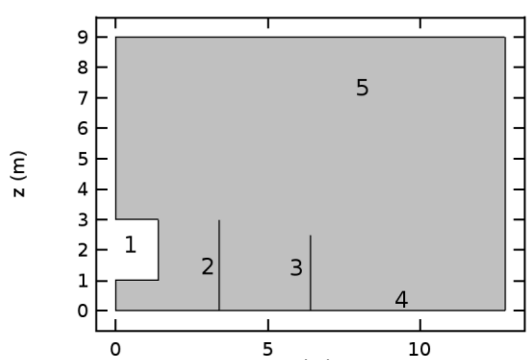

Figure 2. Simplified 2D geometry of an electrical installation. The different parts are (1) the electrical components, (2) first fence, (3) second fence, (4) ground and (5) air box.

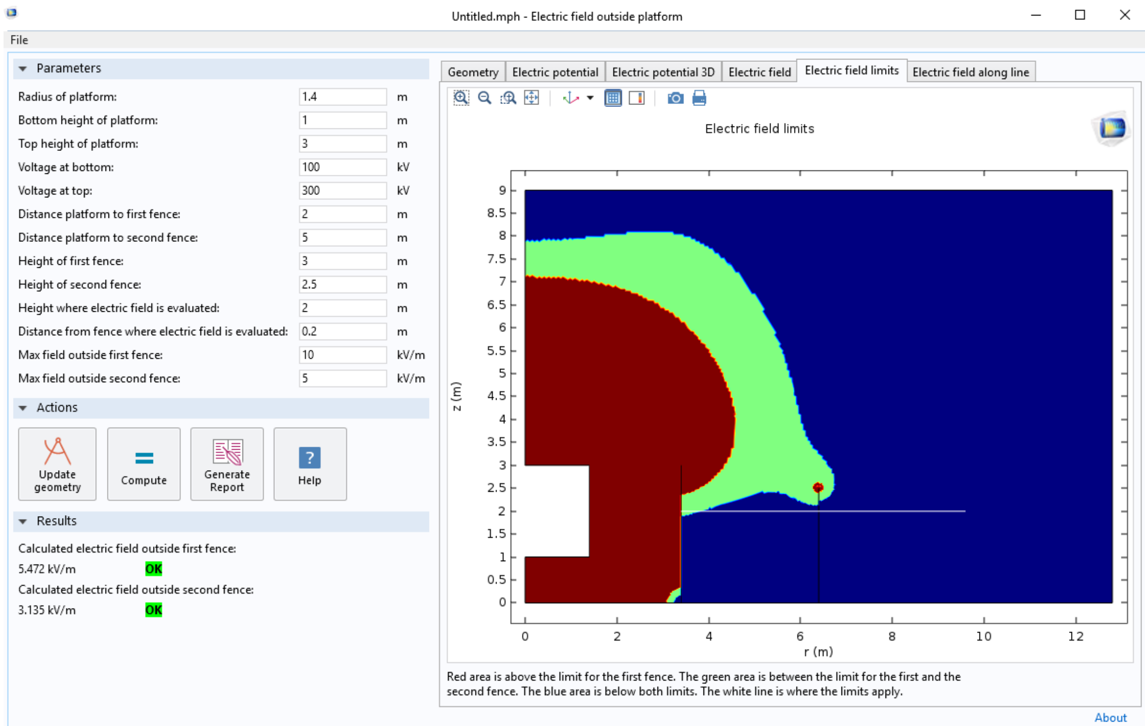

Figure 3. A screenshot of the app. The plot shows the limits for the electric field, with the red area being above the first fence limit (10 kV/m) and the green being above the limit for the second fence (5 kV/m). The white line 2 m above ground indicates where the electric field is evaluated.

complemented with a 3D simulation when better accuracy is desired.

Most real cases involve three phases. However, approximating a three phase design with only one phase is not a significant limitation, since one phase is usually dominant. The other phases causes screening of the electrical field, so approximating the problem with one phase is in any case conservative.

Approximating a 3D platform in 2D leads to some loss of accuracy. The platform or tower usually has a rectangular shape which is approximated as a cylinder. To mitigate this it is recommended that the user chooses the largest dimension of the platform (usually the diagonal distance) as diameter of the cylinder. This makes sure that the calculated field value does not risk becoming too low.

The same argument can be applied to the fences. The real fence is usually built along straight lines, while in the simulation the fence is circular. By picking the shortest distance between fence and platform in the real geometry as the distance between fence and platform in the 2D geometry, the approximation can only lead to a slightly higher field being simulated.

The voltage distribution also needs to be parameterized. There are two main cases considered here. A large fraction of electrical installations contain components at constant potential. This includes a FACTS station where the potential of each platform is simply the same as the corresponding phase. For a capacitor bank the voltage usually increases approximately linearly with the height of the tower, which included as the second option.

4.2 App Design

The app is designed around the simplified geometry described in the previous section. The user is prompted to enter all geometry parameters and allowed electric field levels. An air box is automatically generated with sufficient size not to limit the accuracy. A screenshot of the app is shown in figure 3.

When hitting compute, the computation is started which typically takes less than one minute, where the user is given feedback if the

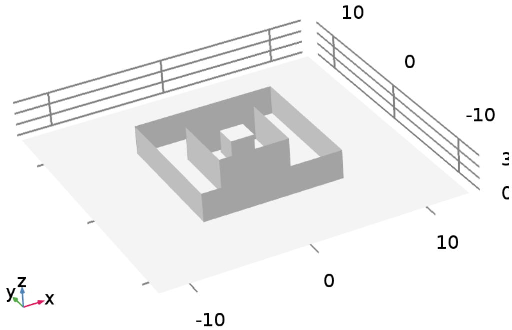

Figure 4. 3D geometry with two fences.

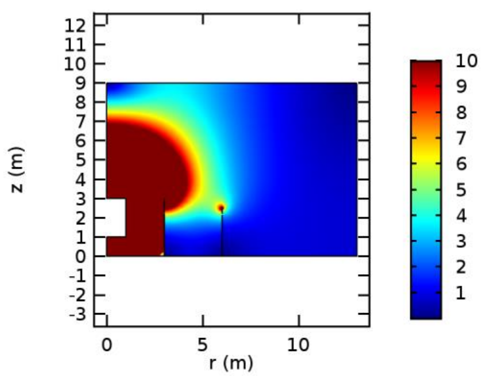

Figure 5. Electric field outside the tower along a cut plane in the 3D geometry. The Electric field is plotted in kV/m and limited to a maximum value of 10 kV/m in the plot.

design is viable. The electric field is measured by doing a cut line at a specified distance above the ground starting a few mesh elements outside the fence.

Several plots are available to the user displaying the geometry and the details of the calculated electric field. A specific plot is available showing where the specified limits lie between allowed and not allowed levels (see figure 3). The intention is to help the user visually understand how the electric field is distributed.

Help documentation is available describing best practice regarding how to operate the app. The app also features an automatic report where the user by the click of a button gets a word report with all the input parameters, plots and results from the calculation. This report can then be efficiently used to document the simulation during the course of the design work.

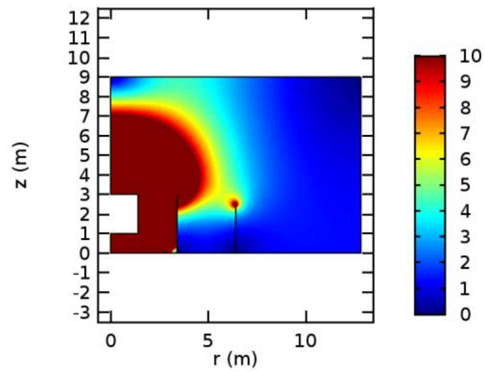

Figure 6. Electric field outside the tower for the 2D geometry used in the app. The electric field is plotted in kV/m and limited to a maximum value of 10 kV/m in the plot.

5. Results

The results focus on one typical example geometry. Here we have chosen a 2 by 2 m square tower 3 m tall with a voltage increasing linearly from 100 to 300 kV. The tower is surrounded by two fences 3 and 2.5 m tall which are 2 and 5 m from the tower. First the analysis is made in a 3D COMSOL model, which is then compared to the results from the app. The electric field is evaluated 2 m above the ground.

The full 3D geometry is shown in figure 4 and making a cut at the center of the platform gives the picture in figure 5. This cut contains the maximum field outside the fence due to symmetry. The maximum field is evaluated to 4.6 kV/m outside the first fence and 2.5 kV/m outside the second fence.

The analysis is now repeated using the app. The tower is approximated as a cylinder and the radius is set to half the diagonal distance of the tower. The distances to the fences are set to the respective minimum distances. The axisymmetric geometry generated with the app is shown in figure 2. The electric field along the 2D plane is shown in figure 6. Here the maximum electric field outside the first fence becomes 5.5 kV/m and 3.1 kV/m outside the second fence.

The values are slightly larger for the 2D approximation, which is intentional by using the largest dimensions of the platform and the smallest distances to the fence. Doing the simulation this way makes sure that any design that is within the electric field limits for the 2D geometry would also pass if a 3D simulation was done.

6. Discussion

The focus of the app design is to construct something easy to use that it can be integrated in the design process without prior experience with electric simulations. This is achieved by approximating the problem using a simplified 2D axisymmetric geometry. The 2D geometry is constructed in a way that the calculated approximate electric field value becomes somewhat larger than if a full 3D geometry was considered, which makes sure that the full geometry complies with the requirements.

As such the tool can be used directly to verify designs. If more accurate optimization is needed the results can be complemented with a full 3D simulation. Having performed the preliminary 2D simulation guarantees that the design will not be that far from optimal. It is therefore expected that the app will be quite useful to the design engineer.

The app is limited to a class of geometries. If the employment of this app in the design process becomes a success, it is easy to construct more similar apps to cover other geometrical configurations.

7. Conclusions

The goal of this study was to construct an app that could make the task of calculating the electric field outside electrical installations accessible to users without prior simulation knowledge. An approximate parameterized 2D geometry is constructed for this purpose and forms the basis of the app. The app is tested against a sample 3D geometry and shown to give good results. The direct results from the app are good enough for most designs and can be complemented with a full 3D simulation if needed. The app therefore fulfills the target and is expected to be very handy during the design process.

8. References

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2. IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0–3 kHz, IEEE Std C95.6 (2002)
3. EU Directive 2013/35/EU - electromagnetic fields