3D-model of an AC/DC Hybrid EHV Transmission Line to Analyze the Electrical Potential along Insulators

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Introduction

To increase the power transfer capacity of existing lines in Germany it is planned to build new HVDC lines or to replace an existing 380-kV three-phase AC system by a HVDC system on the same tower that is called a “hybrid line”. Beside common HVAC technology HVDC technology is considered to be an attractive alternative, due to lower losses, better controllability and the lack of reactive power consumption. The erection of new transmission lines is often associated with demanding approval procedures and conflicts of interests. An interesting technological solution in this context is the hybrid transmission line. Consequently, a DC system and several AC systems will be operated on the same tower. On those hybrid transmission lines the electromagnetic coupling causes interaction between those systems. The mutual influence can be of steady-state or transient type. A possible tower configuration is shown in Fig. 1.

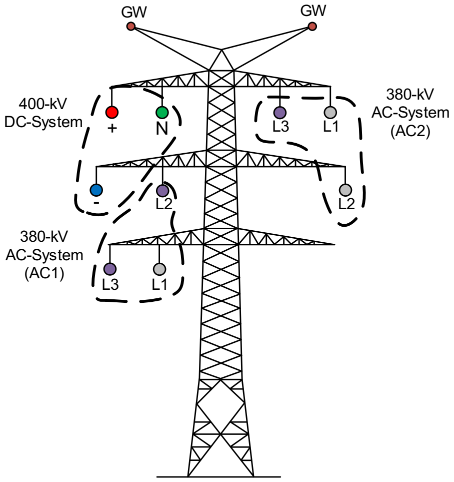

Figure 1. AC/DC hybrid line

The Paper [1] was primarily used for the investigations on the electrical field under the transmission lines for pure AC-transmission lines and hybrid AC/DC lines. The stress on the composite insulators of the AC/DC transmission line were also investigated in [1]. In this study the DC-System is modeled as bipolar HVDC System [1]. This paper considers the electrical field at the tower and the surrounding area for an AC/DC hybrid line, where the DC system may operate in bipolar and monopolar states.

Simulation model of an AC/DC-Hybrid Line in 3D-Space

Finite element numerical model was used in COMSOL Multiphysics to calculate electrical field. The following Maxwell’s equations were used for simulations [2].

$$E = -\nabla V \tag{1}$$

$$\nabla \cdot J = -Q \tag{2}$$

$$J = \sigma E + \frac{dD}{dt} + J_e \tag{3}$$

E is the electrical field intensity, J is the current density σ is the conductivity, D is the electrical flux density and J_e is the externally generated current density [2]. Figure 2 illustrates the 2D arrangement of the simulation models with the associated boundary conditions. For the outer cut surface a homogeneous Neumann boundary condition is applied. The bottom surface (ground) is set to Dirichlet boundary condition of 0 V. Table 1 documents the specific parameters of the simulation model.

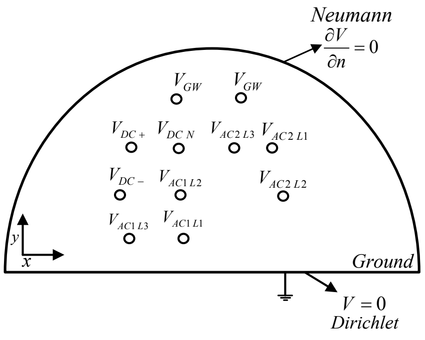

Figure 2. 2D View Model of AC/DC hybrid line including the boundary condition

TABLE I
PARAMETERS OF THE SIMULATION MODEL

HVDC-System	V_{DC+}=400 kV $V_{DC\ N}$=0 V V_{DC-}=-400 kV
380-kV-AC-System (AC1)	V_{L1}=380 kV·sin(ωt) V_{L2}=380 kV·sin(ωt +2π/3) V_{L3}=380 kV·sin(ωt -4π/3)
380-kV-AC-System (AC2)	V_{L1}=380 kV·sin(ωt) V_{L2}=380 kV·sin(ωt +2π/3) V_{L3}=380 kV·sin(ωt -4π/3)
Ground Wire	V_{GW}=0 V

The boundary condition that were shown in 2D view are used for the 3D model. The 3D model represents a 500 m section of a hybrid line and is shown in Fig 3. Besides the conductors the tower, ground wires and insulators are considered. The sag is neglected. (see detailed view in Fig. 4).

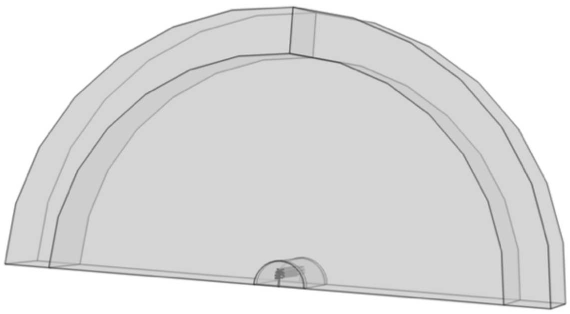

Figure 3. 3D model of the hybrid transmission line in COMSOL Multiphysics

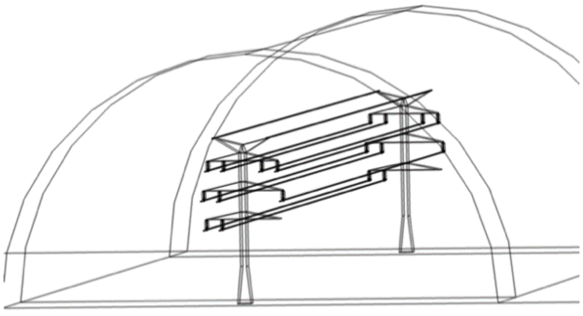

Figure 4. 3D model of the hybrid transmission line (detailed view)

The core of the composite insulator consists of Fiber Reinforced Plastic (FRP). For the electrical insulation of the core and to protect the core from weather sheds a Silicon Rubber (SIR) is used. Fig. 5 shows the 3D model and the cross section view of the composite insulator. The electrical parameters of the insulator are given in Table 2 [3].

3D-structure of
the composite insulator

2D-Cross section view of
composite insulator

Figure 5. Structure of a composite insulator

TABLE II
INSULATOR PARAMETER

SIR relative permittivity	4.3
FRP relative permittivity	7.2

The entire 3D model was discretized with a tetrahedral mesh. The insulator, the tower, the conductors and the surrounding area was modeled by different mesh resolution. Figure 6 and Figure 7 show the discretized model.

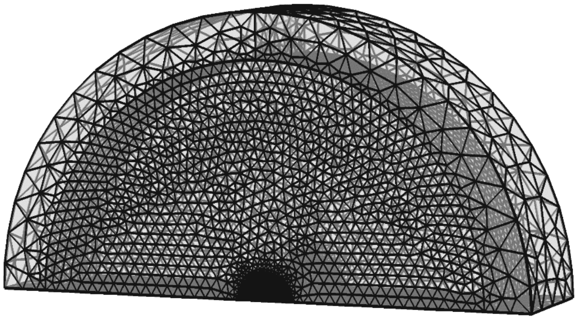

Figure 6. Overview of the discretized 3D model

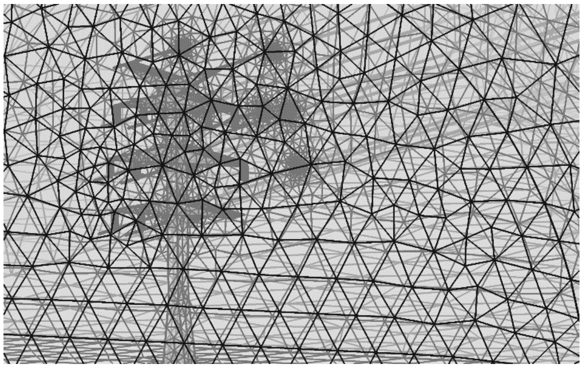

Figure 7. Zoom-in view of the discretized 3D model

Simulation Scenario and Results

The HVDC system is driven by a Full-Bridge Modular Multilevel Converter (FB-MMC) [4], [5]. The bipolar HVDC system consists of a positive and negative pole. As a result, a bipolar HVDC system can be operated in several operation states. In the initial state the HVDC system is in the bipolar state. The pole-to-ground voltage of the positive pole is 400kV and the pole-to-ground voltage of the negative pole is −400kV. Figure 7 illustrates the situation. If for example a positive pole-earth fault occurs, and the DC protection logic detects the fault and the positive pole of the HVDC system enters into blocked state [6]. The faulty pole is out of service. The healthy HVDC pole (in this example it would be the negative HVDC pole) continues to operate normally [6]. As a result the HVDC system automatically changes from bipolar to monopolar state.

During the transition from bipolar to monopolar state, fast time-varying electric and magnetic fields are to be expected. The electromagnetic wave equations of the transmission lines also influence this transient process. These physical phenomena cannot be simulated completely with the Electrical Currents Module of COMSOL Multiphysics. For these reasons, only stationary field calculations are performed.

To achieve the monopolar state, the positive-pole ground voltage is set at time point t_2=0.02 s to 0V. The negative pole continues working in normal operation (see Figure 8).

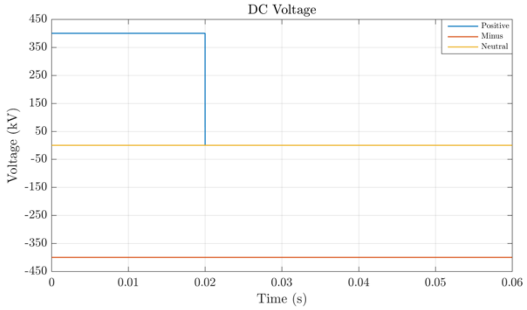

Figure 8. Pole-to-ground voltage of the HVDC-System during bipolar and monopolar operating condition

From time point t_1=0 s to time point t_2=0.02 s the HVDC system is in the bipolar state. The electric field 2 m above the ground is calculated in the center of the 500 m long line. Figure 9 (marked by the red line) shows the exact position.

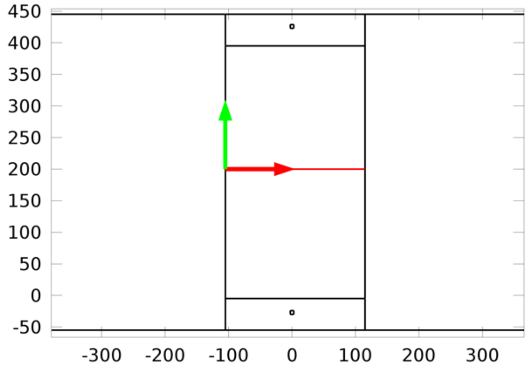

Figure 9. xz-Axis in the xz-Plane of the hybrid transmission line

The electrical field of the AC/DC hybrid transmission line is shown in Fig. 10. The meshed surface is a result of the superposition of discrete time points.

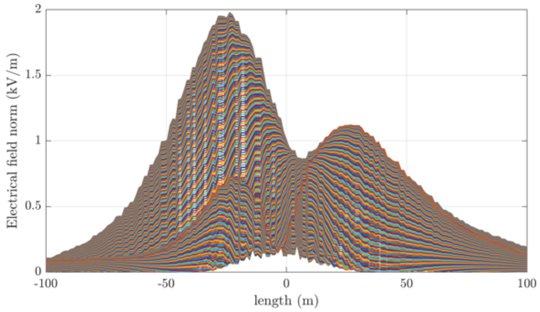

Figure 10. Electrical field 2 m above the ground level, one bipolar HVDC system and two 380-kV HVAC systems

From time point t_2=0.02 s to time point t_5=0.06 s the HVDC system is in the monopolar state. To ensure that no transient effects affect the calculations, the electric field is calculated from time point t_4=0.04s to time point t_5=0.06 s. The simulation results are shown in Fig. 11.

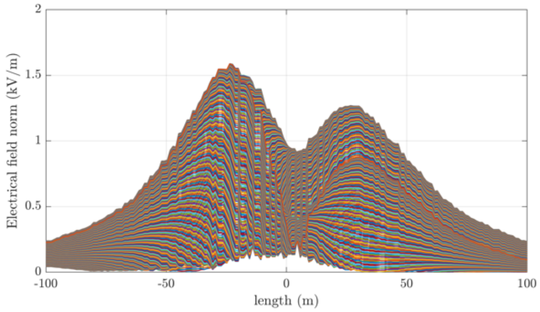

Figure 11. Electrical field 2 m above the ground level, one monopolar HVDC system and two 380-kV HVAC systems

As it can be seen from above figures, the electrical field is influenced by different HVDC operation states.

In the next step, the electrical potential along the insulator of the HVDC system is considered. The paper [1] documents that the HVDC insulators of the HVDC system is stressed by the constant DC-component and by the fundamental frequency component. Now the influence of different HVDC operation states on the HVDC insulators is investigated. On the electrical potential along the insulator at the negative pole of the HVDC system is focused.

In the first scenario the HVDC system is operated from time point t_1=0 s to time point t_2=0.02 s in a bipolar state. In the second scenario the HVDC system from time point t_4=0.04 s to time point t_5=0.06 s operates in a monopolar state. The simulation results as a 2D representation of the array of curves of the electrical potential at different time points is shown in Fig. 12 and Fig. 13.

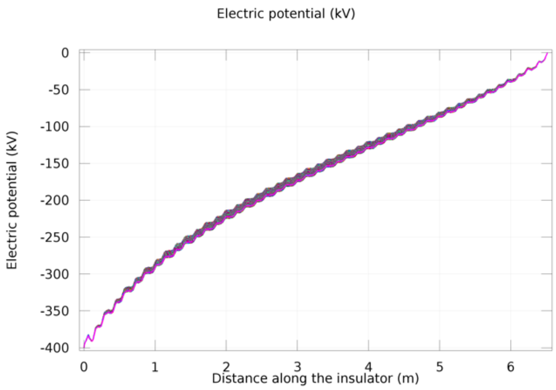

Figure 12. Electrical potential along HVDC insulator (negative pol), HVDC system during bipolar operating condition for a different time step

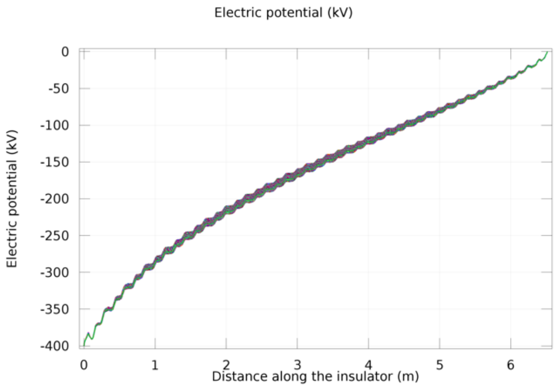

Figure 13. Electrical potential along HVDC insulator (negative pol), HVDC system during monopolar operating condition for a different time step

The electrical potential has the highest amplitude near the conductor and reaches zero at the grounded tower. As it can be seen from the Fig. 12 and the Fig. 13, the electrical potential along the insulators of the healthy pole is influenced by the different HVDC operation states slightly. Furthermore the electrical potential for the time step t_7=0.01 s (bipolar condition) and t_8=0.05 s (monopolar condition) will be shown. In the Fig. 14 an insignificant deviation can be seen.

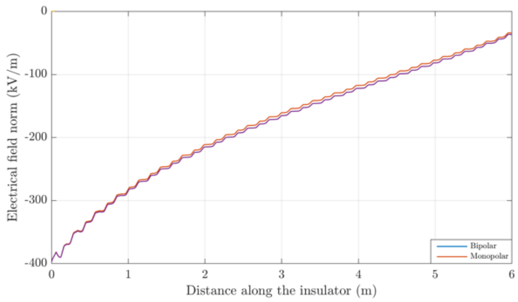

Figure 14. Electrical potential along HVDC insulator (negative pol), HVDC system during bipolar and monopolar operating states at two certain time point

Conclusions

Hybrid AC/DC transmission is a technically challenging subject. At the moment there is a great demand of research in this area. Due to the proximity of the AC and DC systems magnetic and capacitive coupling are of great importance. COMSOL Multiphysics was primarily used for the investigations in [1], focusing on the electrical field for pure AC-transmission lines and hybrid AC/DC lines. This paper continues the work and analyzes the electrical fields for two different HVDC operation states. In the first scenario, the HVDC system operates in the bipolar state. In the second scenario the HVDC system operates in the monopolar state. As it can be seen in this paper, the electrical field under the transmission line is influenced by the different HVDC operation states. The electrical potential along the insulators are influenced by the different HVDC operation states insignificantly. In order to investigate the transient electromagnetic interactions, the RF Module of COMSOL Multiphysics could be used.

References

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