



Unified Approach to the Optimization of Transmission Lines for Maximum Power Transfer Capacity Based on their Electric Field Distribution

Final Project Report

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Power Systems Engineering Research Center
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Executive Summary

Power system load growth and transmission corridor constraints are driving industry activity to develop transmission line designs to increase power transfer capacity. One area of activity is high surge impedance loading (HSIL). Examples include compact structure design, upgrading existing transmission lines and developing entirely new transmission line designs. Recent research relating electric field spatial uniformity to transmission line power transfer capacity and critical flashover voltage showed that most transmission line electrical design parameters can be related to the spatial distribution of electric field between phase conductors. One specific result was that the higher the surge impedance loading of a transmission line, the more spatially uniform the electric field between phases. Yet, a necessary consequence of this more spatially uniform electric field is that the critical flashover voltage becomes smaller. In fact, in the limit of a completely spatially uniform electric field, it approaches the operating voltage of the transmission line. Hence, more attention needs to be paid to the level of overvoltage that can be tolerated. This observation underscores the need for better overvoltage predictions to quantify insulation margins for HSIL designs.

Calculation of overvoltage profiles during (for example) energization of a high voltage transmission line is part of the normal design process for these lines. However, commonly used tools for performing these studies do not account for corona loss which is known to attenuate voltage waves on transmission lines. These corona losses have a notable impact on transient overvoltages which are formed by the superposition of forward and reflected voltage traveling waves. This is particularly true for line-to-ground exposures. The idea of including corona losses has been known for many years, but it has historically been difficult to quantify the impact given the difficulty in modeling this nonlinear phenomenon in a way that is practical for high-volume simulation. Yet, since more precision is needed in the prediction of overvoltages, it is important that these losses be incorporated into the studies. To this end, this work extends existing work on calculating corona loss for simple transmission lines using a small number of discrete loss elements to allow fully distributed loss calculations on transmission lines with bundled conductors. In this approach, the finite difference time domain (FDTD) method with distributed corona losses (modeled as dynamic capacitance) was used for the calculation. This method allows more precise location and better estimates of the maximum overvoltages that will occur under the conditions studied (i.e., energization and reclosing). Finally, the model was adapted for practical use in high-volume statistical transient simulation and applied to an example 500 kV line. Transients included line energization and trapped charge reclosing.

The efficiency and practicality of the model was demonstrated through high-volume statistical simulation of switching surges on an example 500 kV transmission line of varying length. Overvoltage profiles and statistical distributions were generated from 9500 simulations obtained by random breaker close timing and variation in line length and altitude. Distributed corona losses reduced 98th percentile line-to-ground switching overvoltages by 4%–14% of nominal. The estimated line-to-ground switching surge flashover probability was 54%–80% lower with corona loss. Corona had less impact on line-to-line overvoltages, but the effects were still notable. Results highlight the importance of considering detailed overvoltage profiles and accounting for corona loss attenuation when seeking to carefully quantify insulation design margins.

Detailed switching overvoltage profiles obtained through distributed techniques, such as the FDTD method, provide information that could be important for refining the design of high-voltage insulation. The cases in this work focused on energization and trapped charge reclosing, but the method could also be used to gain additional insight for switching surges limited by pre-insertion resistors or controlled closing schemes. Results illustrate how simplified overvoltage profiles could underreport flashover probability.

The research demonstrated that such an approach is practical with modern computing capability, reasonable simplifications, and the application of techniques such as digital filtering to improve simulation stability. Detailed overvoltage profiles that account for voltage attenuation by distributed corona losses provide valuable information for projects seeking to carefully quantify insulation design margins for optimization of transmission capacity in HSIL applications.

Project Publications:

- [1] J. T. Leman and R. G. Olsen, “Bulk FDTD Simulation of Distributed Corona Effects and Overvoltage Profiles for HSIL Transmission Line Design,” *Energies* 2020, 13, 2474; doi:10.3390/en13102474.

Student Theses:

- [1] Jon. T. Leman. *Unified Approach to the Optimization of Transmission Lines for Maximum Power Transfer Capacity Based on their Electric Field Distribution*. PhD, Washington State University, December 2020.