NORTHERN ARIZONA UNIVERSITY

College of Engineering, Forestry & Natural Sciences

Ansoft Maxwell Laboratory Activities used to Investigate Electromagnetics Concepts within Power Engineering Applications

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Abstract

Several laboratory activities were created with the intent of: 1) Developing student proficiency in advanced electromagnetics simulation software (e.g., Ansoft Maxwell), 2) Deepening students' understanding of fundamental electromagnetics concepts, and 3) Exposing students to the field of power engineering in a required course. Students investigated "real-life" issues such as the skin effect, the force between two busbars, the electric and magnetic fields surrounding power lines, and substation grounding grids. The activities were tested with novice users and refined through feedback from two electromagnetics laboratory sections during the Fall 2011 semester. Student engagement in and enjoyment of the activities was particularly encouraging.

Requirements and Objectives

Each laboratory activity was designed according to the following requirements:

- Introduce students to at least one new capability or feature of the Ansoft Maxwell software utility.
- Address at least one new (compared to other labs) fundamental electromagnetics concept.
- Apply to power engineering.
- Be completed within 1.5 – 2.0 hours with minimal assistance.

The following design elements were also taken into account, to improve student engagement and learning. At least a few of these elements were included in each activity:

- Address a fundamental electromagnetics concept that students traditionally struggle with.
- Address a concept that students will likely encounter in their careers.
- Relate to students' everyday lives.
- Involve individual research.
- Provide opportunities for students to independently choose and investigate aspects of a design.

In addition, each group verbally reviewed their findings with the instructor and/or teaching assistant before leaving the lab. If students had obtained questionable data or still struggled with misconceptions, they were guided through understanding the problem and were assigned additional brief tasks to help clarify remaining issues. Students therefore received immediate feedback which improved both their learning and the grades for their lab reports.

Example Activities

1. Fundamental Concept: Voltage, Potential Difference

Believe it or not, even advanced undergraduate electrical engineering students struggle with the fundamental concept of voltage. Therefore, we wanted to provide another avenue for students to explore this concept. A power engineer on our industry advisory council suggested a substation ground grid as the "real life" context for this activity, and effective grounding is an issue that could be encountered by students in a wide variety of careers and in their own homes.

Students investigated the conductivity and resistivity of various soil types and chose values that they believed well represented the soil around campus, giving them additional exposure to electromagnetic material properties.

The students also investigated why copper was often used in grounding rods, and they had to include a scientific discussion and references about this topic in their lab reports.

The students first simulated voltage gradients across their soil's surface due to a line-to-ground 345 kV fault (Figure 1). They then analyzed the effects of adding the horizontal mesh component of the ground grid, using recommendations from the "IEEE Guide for Safety in AC Substation Grounding" while constructing the grid (Figure 2). Finally, they added grounding rods to the mesh – with the depth, location, and number of rods being chosen independently by each student group – and analyzed whether the resulting Step and Touch Potentials would be safe, according to general IEEE guidelines. *(Note, discussion of deadly currents and voltages is almost guaranteed to raise students' interest!)*

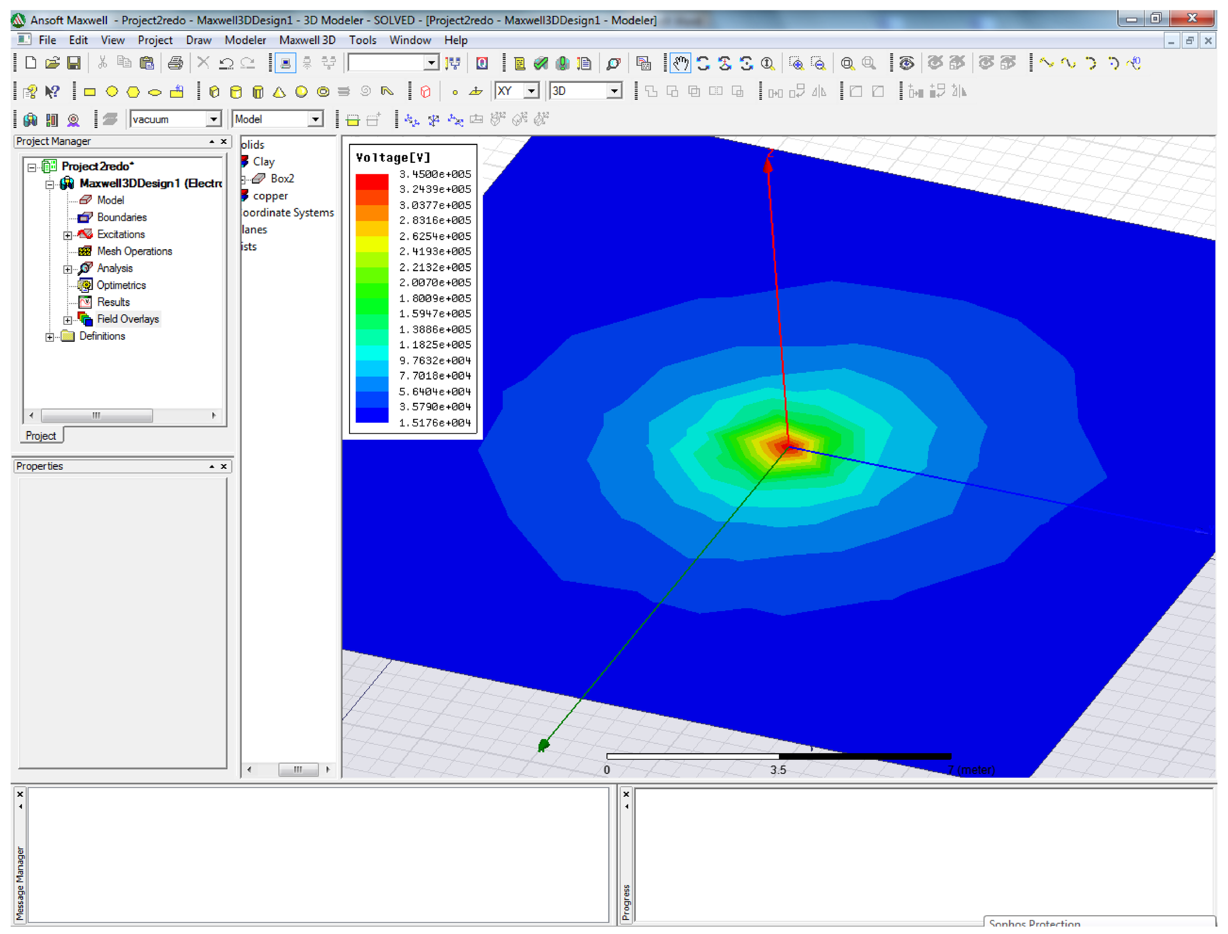

Figure 1: Example student Ansoft Maxwell simulation of the voltage gradient produced by a 345kV line-to-ground fault. The jagged lines result from the trade-off between faster simulation times and finer resolution.

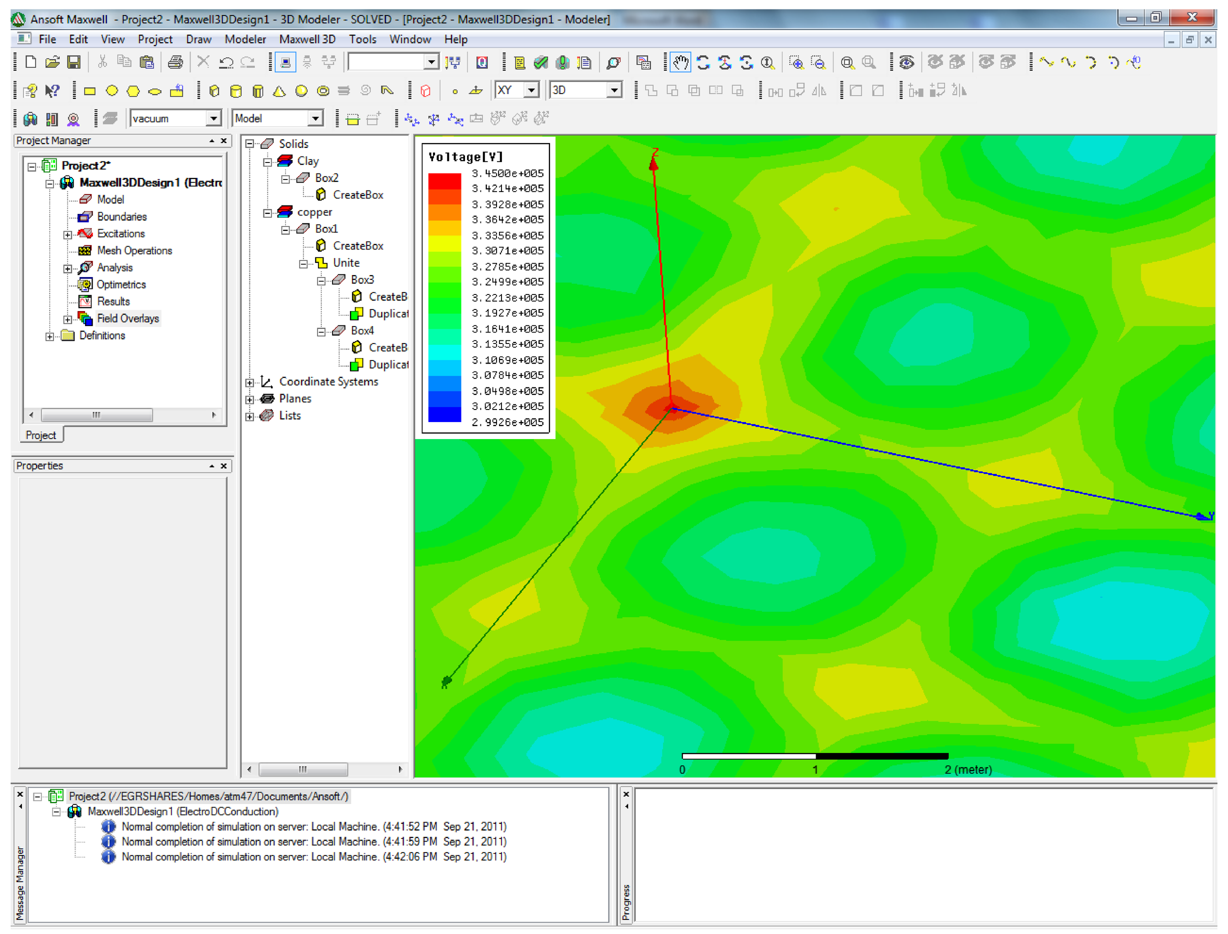

Figure 2: Example student Ansoft Maxwell simulation of the voltage gradient produced by a 345kV line-to-ground fault when a horizontal grid is added 0.5 meters below the soil surface.

The students also developed basic CAD and 3D visualization skills while creating the models for these investigations, and they gained experience with common numerical analysis issues (e.g., mesh size) and Ansoft Maxwell's DC-Conduction mode as well. The activity thus addressed all of the requirements and objectives, resulting in high student engagement and (as indicated by informal assessments) improved learning. The following quotations from student lab reports also provide an indication of the students' thought processes:

> "We selected a conductivity of 50 mS/m. This is because it was about the mid-point of the clay soil which we choose to work with. The reason why we wanted to work with clay soil is because it had high conductivity and low resistivity which would cause the voltage to spread far into the soil."

> "The reason why steel grounding rods are coated with copper is because copper is a relatively cheap noble metal. Noble metals are metals that are found in nature. These types of metals are very resistive to corrosion when exposed to water and oxygen. Processed metals such as steel and iron are susceptible to corrosion in the presence of electrolytes such as water. When a noble metal such as copper is joined to a processed metal the copper becomes the cathode and the processed metal becomes the anode. A copper coating on a steel wire presents a cheap solution to having a durable mostly steel grounding wire. This information was researched from http://www.comm-omni.com/polyweb/coppergrrods.htm."

> "This is a picture of the simulation with a copper grid added to help reduce the step voltage. Again the white bar represents a distance of one meter. A person with a step of one meter could easily step from the yellow to green area. This would result in a step voltage of approximately 8 kV. While this is an improvement over our first simulation, this is still outside the IEEE standards. In our final simulation we will add additional grounding rods to the grid to lower the step voltage further."

2. Fundamental Concepts: Electric Fields, Image Theory

When listing the fundamental electromagnetics concepts that both relate to power engineering and affect students' lives, it's hard to ignore the importance of and public interest in the electric and magnetic fields surrounding power lines. Due to the amount of highly publicized yet unscientific statements made about these fields, students were first assigned a prelab where they 1) reviewed the environmental impact statement for a proposed transmission line, which included data about the typical field strengths emitted by home electronics, 2) selected a topic from that statement (related to electric and magnetic fields) that interested them, 3) found refereed scientific publications about that topic, and 4) summarized their findings in a 1-page report.

For the simulation part of the lab, students selected a line voltage, height, and right-of-way width from a set of typical transmission line specifications. Since this was the first simulation of the semester, detailed instructions and a significant amount of time and assistance were required for the students to successfully create even this simple model, but their proficiency increased dramatically with each subsequent simulation.

The students obtained magnitude and vector plots of the electric field in a plane perpendicular to the transmission line, with and without a ground plane of sandy soil (see Figure 3 for one example). Students verbally interpreted these plots to the TA and instructor. They were expected, for example, to know that the electric field vectors would be directed away from positive voltage (i.e., positive charge), would decay by ~1/r away from the line, and would be perpendicular to the surface of good conductors. At a more advanced level, students were expected to understand that image theory and the principle of superposition would cause the field strength near the conductive ground to be approximately twice the strength in free space alone.

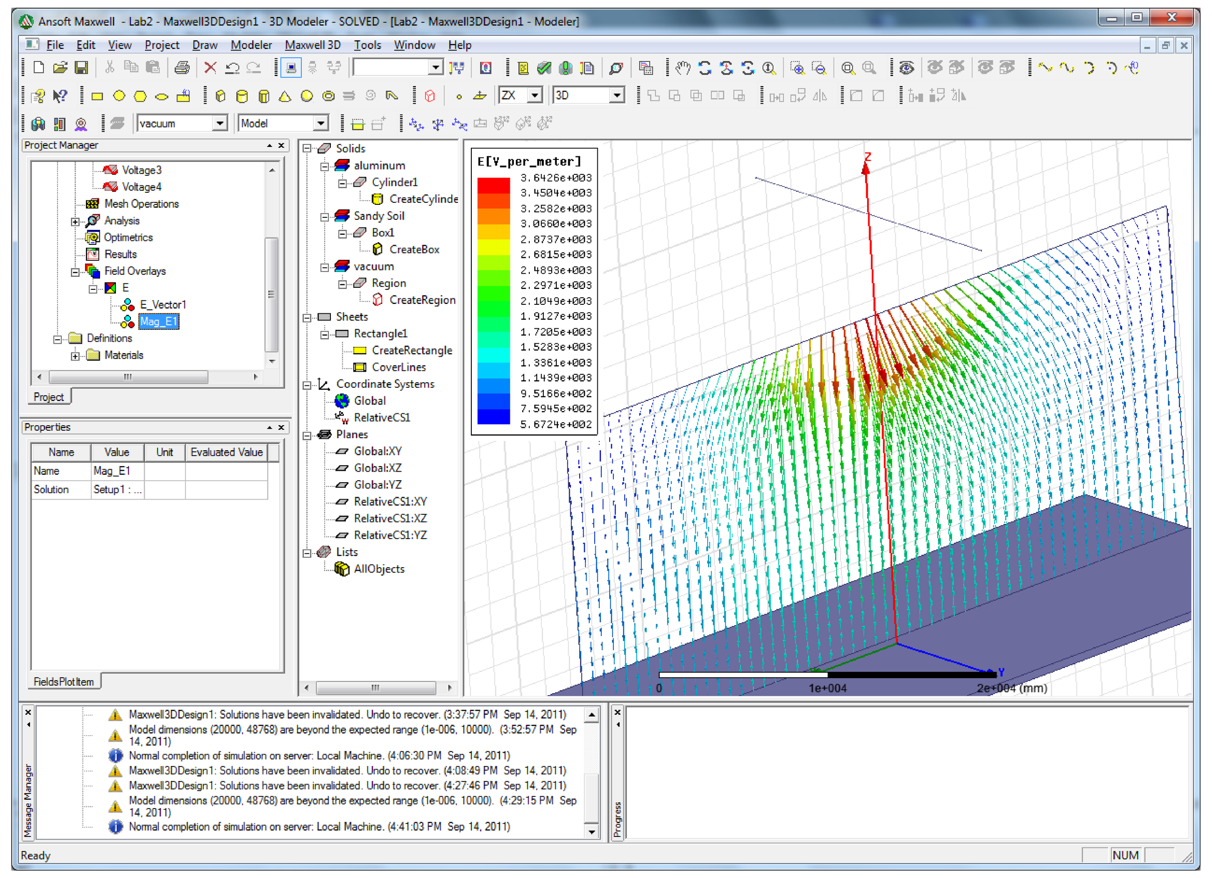

Figure 3: Student Ansoft Maxwell simulation of the electric fields produced by a 230 kV transmission line above a sandy ground.

As shown by the below quote, students compared their simulated results to the standards set by the state of Florida:

> "The standards set by the state of Florida state, 'The maximum electric field on the ROW of a transmission line with a nominal voltage greater than 230 kV and up to 500 kV shall not exceed 10 kV/m.' For the transmission line we chose, the electric field magnitudes near the ground were about 1336 V/m, which is within the limits set by Florida."

3. Additional Completed Activities

Along with the laboratory activities discussed above, students also created simulations to help them analyze the skin effect, the magnetic fields created by DC currents, the force between busbars, the response of various materials to external magnetic fields, and the effectiveness of magnetic field shielding.

4. In-Progress and Planned Activities

We are currently in the process of simulating the open-circuit voltage and power generated by the Southwest Windpower Air-X wind turbine (a permanent magnet, ~400 Watt system) at a range of rotational speeds. A testbench has been created to compare students' simulated values with actual measurements.

In addition, we plan to include an activity that would investigate core saturation in a transformer, and *we would appreciate your ideas* about other interesting and important power engineering applications of fundamental electromagnetics!

Acknowledgments

Special thanks to Arizona Public Service for funding this project and providing suggestions for power engineering applications of specific electromagnetics concepts. Please contact Dr. Kipple at allison.kipple@nau.edu for further information and electronic copies of the laboratory activities.