

Simulating Insulation Discharge Processes in the Laboratory Part 2

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Abstract— A significant amount of research has been published in recent years on Polarization – Depolarization Currents (PDC), although little has been published on simulating these processes in the laboratory. Over the past few years an ongoing project related to simple simulation models had been pursued and published. In this paper we will provide summary results on non-linear simulation performed on the discharge process and compare them to results provided in previous papers. We will examine the effects of changing parameters in an enhanced and dynamic system model and compare to results previously published.

Keywords— Polarization, Depolarization, Insulation, Modeling, MATLAB, SimuLink, SciLab, xCos, SciCos, iCircuit, LTSpice

I. INTRODUCTION

This project continues to review simulation methods for evaluating insulation system polarization-depolarization currents (PDC). The original paper by McKinnon [1] outlined the use of the models outlined in a proposed update to IEEE Std 43 [2] including how the model would match real-world applications. The second paper in this series by McKinnon, Penrose and Frost [3] outlined the application of the model in a linear software system such as LTSpice® including required modifications to match real world applications. The conclusion was that the linear simulation software programs are unable to effectively simulate polarization and depolarization models as these processes are not linear.

The objective of this study was to review several non-linear modeling programs and determine if they could more accurately simulate the processes. This was performed by attempting to build the same model as used in McKinnon, Penrose and Frost and performing analysis using each of the selected tools. We reviewed the applications using capability, complexity, pricing and accuracy in relation to the model and outputs determined in McKinnon and McKinnon, Penrose and

Frost. In this paper we will discuss our experiences with the simulation software and identify the results from the selected system.

II. SIMULATION SOFTWARE REVIEW

There are a number of non-linear simulation programs available for performing the analysis. These include both commercial systems and open source. The industry cornerstones appear to be based upon MATLAB® for commercial systems and SciLab® for open source systems. In both cases, there is a nearly identical look and feel with their purpose being able to manage complex non-linear calculations for virtually any type of application. Each are extremely powerful tools, in their own right, and have supporting simulation capabilities. With MATLAB there is a suite of add-ins for license-purchase including a visual simulation program called SimuLink®. With SciLab there is an included suite of add-ins plus additional add-ins developed for both no cost and fee, including models. There is an included simulation program called xCos® which provides a visual representation of what is being modeled and an included library.

Both are not particularly intuitive, from a programming standpoint, with the primary benefit of the commercial system being a much greater level of documentation, training and support. Some of this is at no cost and some are for fee as well as structured classes and a ready supply of published books on broad and specific topics. The open-source systems were found to be similar to the commercial systems so that someone experienced in one was capable of working with the other. However, the open-source documentation tends to be challenging, support and training difficult, and a limited number of books available usually on earlier editions of the topic.

One of the investigators of this project had MATLAB available. However, the library for electrical/electronic simulation in in SimuLink carried a significant annual licensing fee that was beyond the budget for the program. An attempt at performing the study using the existing resources was found to be overly complex for the simple circuit being evaluated and it was determined that a review of the simulation portion of this commercial product would be attempted in the future.

A review of the open-source SciLab and xCos system allowed the investigators to evaluate a model using the components of the electrical/electronic library. Fig. 1 is the skeleton model attempted in xCos which identified an immediate limitation in the upper resistance limit that could be used well under the GigOhm range required for the study.

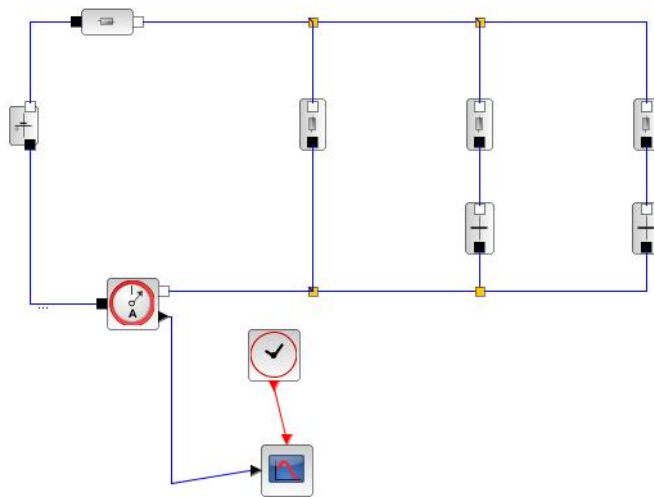


Fig.1: xCos Circuit Evaluation

It was determined that lower values would be used and compensated for in programming. This became quite complex and the number of errors involved caused the investigators to determine that this would not be a good choice for simple circuit evaluation. During review of documentation, it was found that a group that had been developing under SciLab and xCos had differences and had released an open source system called SciCos®. It was evaluated and also found to have similar limitations as the open source SciLab system.

Overall, investigators continue to use each of these tools in more complex engineering evaluations as well as complex calculations and graphics. The conclusions of this paper deal with the application of a simple insulation model and not the

scope of the systems evaluated nor their suitability within the scope of their design.

The continued search for a simple circuit simulation tool resulted in an evaluation of a Windows 8® and Apple® application called iCircuit®. The initial review was on a Windows 8.1 system and a few limitations were found including the ability to make changes and add channels to the built-in scope tool. However, the model was functioning exactly as the investigators had hoped and a further review identified that all of the capabilities were available in the Apple version. Therefore, the studies and data were performed on an Apple system.

The modeling process was intuitive and short YouTube® video and limited text documentation were required to explore the model. The simulation system was specifically developed to perform analysis on non-linear systems and had added visual real-time simulation capabilities that showed current flow through the circuit allowing the investigators to see the portion of the circuit emphasized at each point (Fig. 2). There were also no limitations on the values for resistors and capacitors. The investigators were also able to make changes to the scope and add values from each of the components on-the-fly. All data could be exported into an .CSV for import to spreadsheet software.

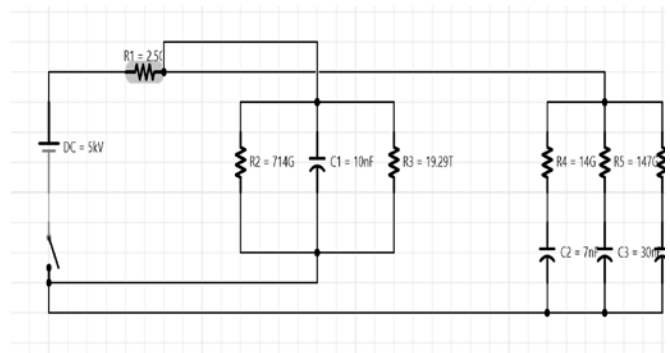


Fig. 2: iCircuit Model for Evaluation

The limitation found with this system was the inability to return the circuit to an initial state. The simulation was performed real-time and it either required a real-time discharge or the addition of circuit components to discharge the circuit. This feature also meant that the circuit would begin to discharge once the circuit was opened.

III. CIRCUIT ANALYSIS

The circuit identified in Fig. 2 was first discharged and then charged with data collected within the simulation software.

Based upon McKinnon, Penrose and Frost, the following currents were analyzed:

- R1: Series resistance of test instrument in amps – 2.5 GigOhms;
- R2: Surface leakage across the insulation system surface in amps – 714 GigOhms;
- C1: Geometric capacitance of the insulation system in amps – 10 picoFarads;
- R3: insulation system conduction current in amps – 19.29 TerraOhms;
- R4-6 and C2-4: absorption current in amps:
 - R4 = 14 GigOhms
 - R5 = 147 GigOhms
 - R6 = 307 GigOhms
 - C2 = 7 picoFarads
 - C3 = 30 picoFarads
 - C4 = 72 picoFarads

This data was based upon a 1200 kW generator tested with a Megger® model BM25 insulation resistance test instrument. The model functioned effectively within the constraints of LTSpice. With the selected software system the current associated with charging appeared as shown in Fig. 3.

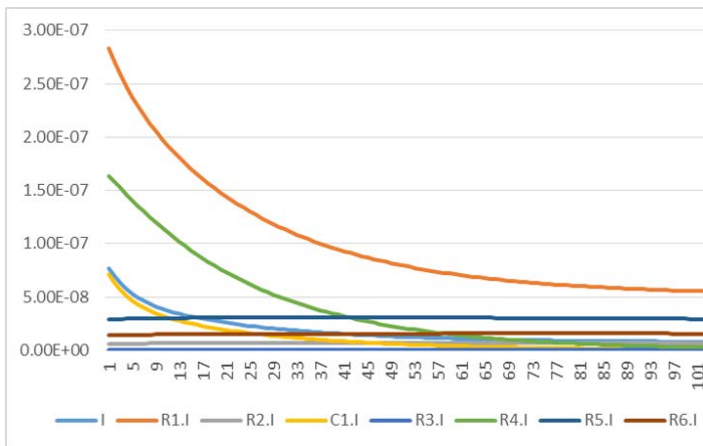


Fig. 3: Total Currents (in amps) for Charging

The applied voltage in the circuit was 5000 Volts DC and the applied circuit current across R1 at 1 minute and 10 minutes was 6.38×10^{-7} Amps and 5.56×10^{-8} Amps respectively resulting in 7.8 GigOhms at 1 minute and 89.9 MegOhms at 10 minutes, duplicating the LTSpice results.

The discharge results appeared as shown in Fig. 4 once the circuit was opened. Fig. 5 is the polarization and depolarization currents compared.

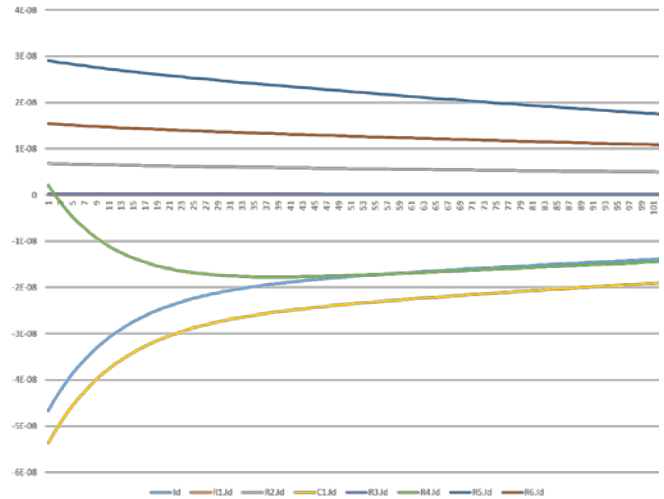


Fig. 4: Total Currents (in amps) for Discharging

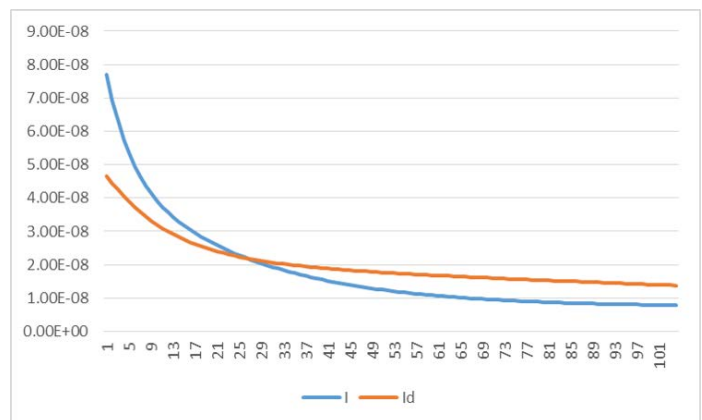


Fig. 5: Polarization and Depolarization Current (Amps)

Fig. 5 is presented with the negative values of the depolarization from the output of the model changed to absolute values. While it is not a perfect representation of the expected values in a real-world test, it is reasonably close.

Fig. 6 represents the model from McKinnon, Penrose and Frost for moisture on the insulation. The values from Fig. 2 remain the same with the addition of a parallel to R2, the surface leakage, consisting of a

resistor (1 Ohm) and a capacitance (1 uF) determined by experiment.

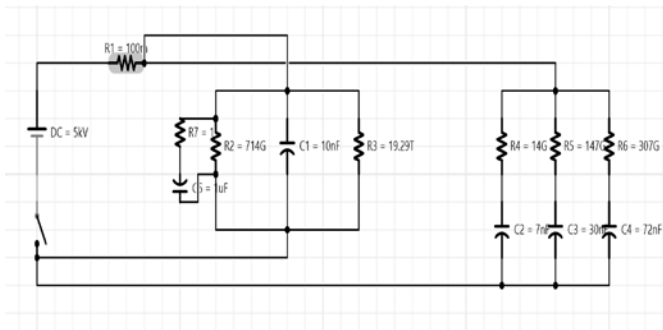


Fig. 6: Addition of Moisture Circuit

During the operation of the Fig. 6 model, it was noted that the insulation resistance performed in a different manner than the previous attempts with LTSpice. The basic results of the model at 5000 Vdc across R1 during charging were 0.021 Amps at 1 minute and 0.0199 Amps at 10 minutes. This would be 238 MegOhms and 251 MegOhms respectively.

The charging current for Fig. 6 is shown as Fig. 7 and it shows a very rapid change in current that levels off relatively quickly. This follows suit in cases of severe moisture or similar contamination.

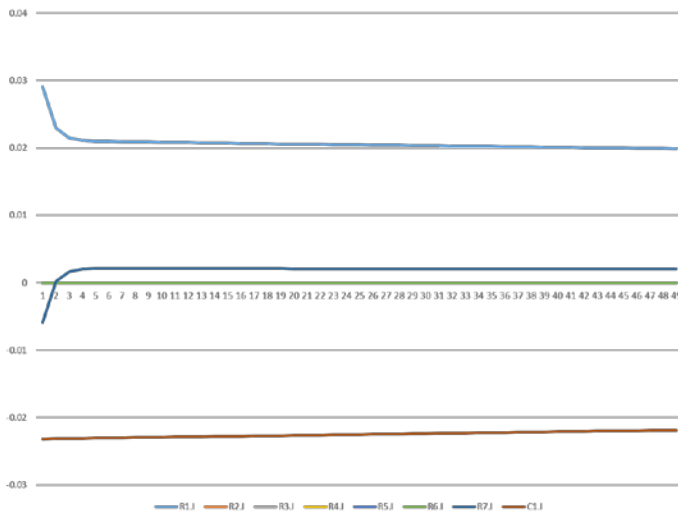


Fig. 7: Charging Currents in Amps

The combined polarization and depolarization graph appears as shown in Fig. 8.

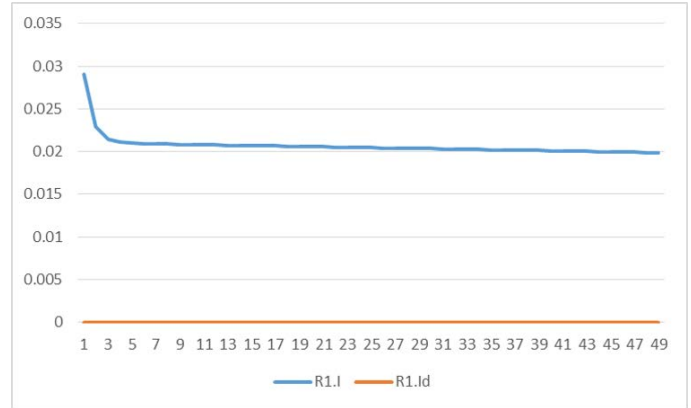


Fig. 8: Contamination Charging and Discharging

Again, the results of the model do not precisely match reality, but are relatively close. The investigators feel that additional work with this tool will result in improved models for evaluating the charging and discharging of insulation systems.

IV. CONCLUSION

Following the original study, the objective was to review software simulation tools that would provide a more accurate platform for the representative model found in IEEE Std. 43-2013. The challenges related to the selection of an accurate dynamic tool that would represent a relatively simple circuit included funding, complexity and limitations of the platform. The result was the selection of a dynamic version of LTSpice, which was the linear platform used in the first study, called iCircuit, an Apple and Windows 8 application that provides for dynamic analysis.

It was determined that the simulation platform would provide relatively useful information that could be compared to real-world analysis. However, it was also determined that there were several differences that may be able to be improved upon with enhancements to the model.

One of the lessons learned in this project has been that the more complex systems may not always be the best solutions for simple simulation. There are a selection of available systems that can be used to evaluate real world findings. In the case of the examples in this paper, the adjustments and additions to the models in McKinnon, Penrose and Frost were not required on this platform.

REFERENCES

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