# Simulating Insulation Discharge Processes in the Laboratory

David L. McKinnon
PdMA Corporation
Tampa, FL USA
McKinnon@PdMA.com

Howard W Penrose, Ph.D., CMRP
Vice President, Engineering and Reliability Services
Dreisilker Electric Motors, Inc.
Glen Ellyn, IL USA
hpenrose@dreisilker.com

Nancy Frost, PhD.
Vice President, Technical
Krempel Insulation Technologies
Albany, New York USA
drnancyfrost@gmail.com

***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. In this paper we will provide summary results of simulations performed on the discharge process of insulation systems and comparing them to results provided by PDC monitoring. We will examine the effects of changing various parameters such as leakage resistance-to-ground, capacitance-to-ground, and absorption current branches as shown in the standard insulation system models. We will also provide a summary of results encountered when various elemental effects such as moisture and contamination are incorporated into the system models.**

***Keywords-Polarization, Depolarization, Insulation, Modeling***

## I. INTRODUCTION

The concept of modeling insulation systems for simulation of insulation systems in a variety of laboratory conditions provides insight into the types of test results that would be obtained when those conditions exist. This can be significantly complex in a machine insulation system when using the 'standard model' outlined in IEEE Std 43[1] as these systems tend to be more chaotic than what is produced in a computer simulation. In the case of this paper the freely available LTSpice®[2] was utilized which provides a simple system to implement such a model. As shown in the previous paper by McKinnon[3], the analyst would have to duplicate the as-found data using a variety of methods that defeat the concept of evaluating what would happen in various conditions. The true purpose of the model is to provide enough information to assist the analyst in identifying the cause of the signature, or to identify the various signatures that could be detected in machine defects. In order to accomplish this with a linear simulation program the analyst would have to use the output as an approximation of how various defects would appear. The end result would be the points where, for instance, capacitive discharges would appear, but not the actual appearance.

For the purpose of this paper two 1200kW, 2-pole, 4160 Volt, generators were utilized for testing. Testing was performed with a Megger® model BM25 instrument which can produce Polarization Index (PI) and Dielectric Discharge (DD) test results (Figure 1).

Figure 1. 1200kW Generator Under Test

The machine is connected as a two circuit wye-delta machine, form wound with epoxy-mica and 48 slots. The slot area in contact with the coil measures 6.45 cm high by 1.45 cm wide and 51.28 cm in length less air vents. Total leakage measured with a DC high potential tester at 5 kV was 0.7 micro-Amperes. The insulation system on the coils was 0.31 cm thick and the individual conductors were made of a heavy build insulation and Double Dacron Glass (DDG). The estimated dielectric constant used for the study was 4.4.

Polarization Index readings were taken on each of two machines in several states which included: wound with green coils; uncured epoxy varnish insulation; and, cured epoxy varnish insulation. All testing was performed at 22$^{o}$C +/- 2$^{o}$C at 40% +/- 5% humidity. The results were not corrected for temperature.

## II. MODEL DEVELOPMENT

Following the method from McKinnon[3], a model was developed (Figure 2) to emulate the results from the PI tests (Figure 3) and physical information from the machine following aging of the coils. It is important to note that the absorption values had to be estimated and tweaked to provide a system that approximated the original system. Prior to experimentation it was assumed that the more accurate the resulting curve, the more accurate the changes which would provide working data.

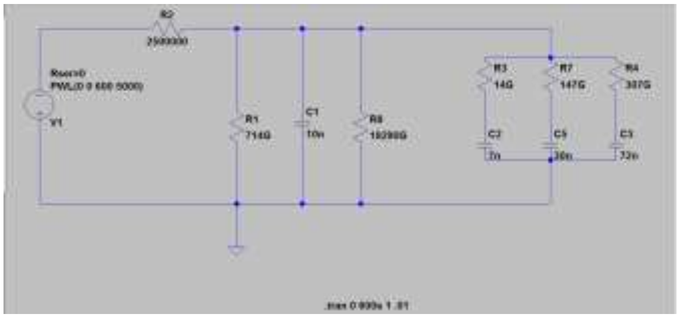

Figure 2. Base Model

Figure 3. Polarization Index Aged Coils

Each of the values utilized in Figure 2 were developed using the systems outlined in IEEE Std 95[4] and McKinnon[3].

## III. Polarization Depolarization Current

A significant amount of information has been published on the use of Polarization Depolarization Current (PDC) testing for the evaluation of insulation systems [5-8]. There are several schools of thought that look at either just PDC or a combination of PDC and Dielectric Dissipation Factor (DDF) and Capacitance (C). For the purposes of this paper, we will concentrate only on the simulation of PDC as both DDF and C require the injection of variable frequencies for evaluation.

In the case of PDC, it is useful in the detection of moisture absorption and contamination, uncured insulation systems, and brittle insulation systems in larger form-wound machines[7],[8]. The traditional evaluation is performed using a log-log system, which is not available as part of the LTSpice simulator being used in this study. One of the challenges with PDC evaluations using the log-log methodology is that the technician requires significant experience with another being the difficulty in fault analysis. In these cases, the use of the model presented in this paper should provide some assistance.

## IV. Application of the Model

The simulation software limitations were found to be relatively significant, at first, as well as not being able to present the full PDC in one graph. The result was having to compare two separate simulations in addition to adding in the defects for depolarization only. There were also two different methods determined for developing the curves on the depolarization simulation:

- Altering the applied voltage timing on the power supply in the model;
- Adding a switch and resistors and capacitors to simulate the change in the system and changes in discharge (Figure 4).

The challenge using both of the methods is that at the applied time there is an abrupt change versus the gradual change seen in actual testing. It may be possible to add additional circuits and components to create a more realistic looking curve; however, the implication is that such additions would not simulate reality. This is due to the traditional model being composed of just resistance and capacitance.

Another variation from actual test results is that in order for the model to work the voltage varies from zero to full voltage for PI and from full voltage to zero for depolarization. The instruments applied in real testing have full voltage applied within seconds and the decrease in currents related to insulation resistance increase with polarization.

Figure 5 represents the depolarization current curve based upon the model with discharge from 5000 Volts to 0 Volts with

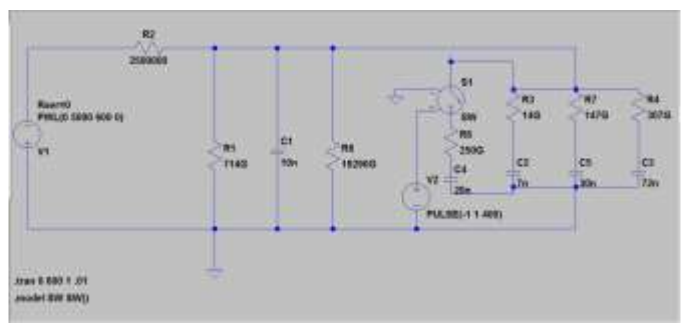

Figure 4. Depolarization with Additional Absorption Circuit Timed to Close at 400 Seconds

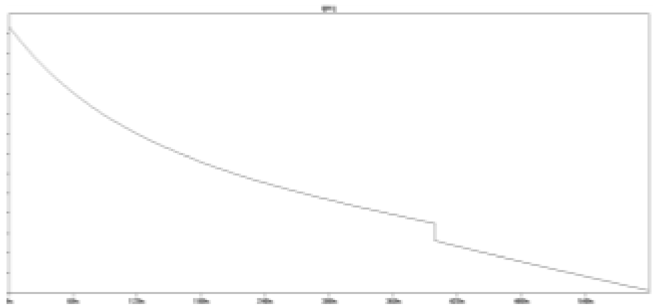

Figure 5. Depolarization Current

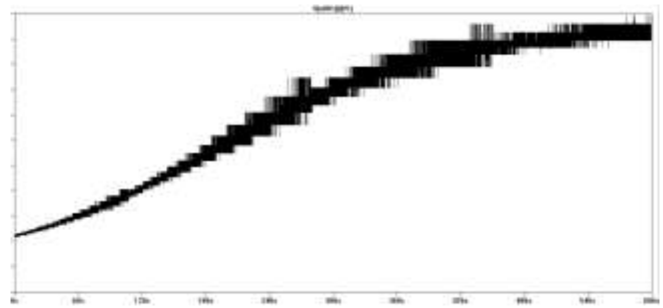

Figure 8. Polarization Index Profile Aged Insulation

the additional absorption current circuit added at 400 seconds. The value of the additional circuit determines the issues associated with uncured or damp insulation. Figure 6 would represent the polarizing currents.

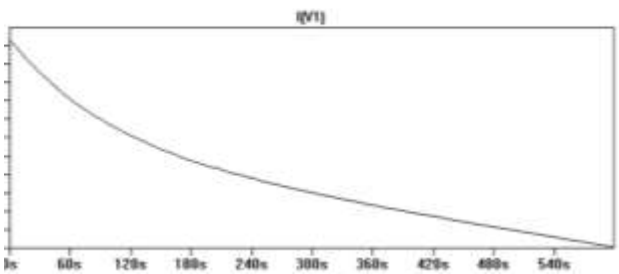


Figure 6. Polarization Current

As noted, the value of the currents are based upon the circuit design and the use of variable voltage across the circuit. The PDC curve shapes are what need to be represented.

Figure 7 represents the circuit for PI testing associated with 'aged' insulation in the slots and end turns of a machine resulting in a change to the geometric capacitance and conductance. Note as in Figure 8 that the discharges are continuous due to limitations of the simulation software. Also noted is the requirement to reduce the test instrument (R2) circuit resistance which would otherwise mask the discharges. This waveform can be compared to Figure 3.

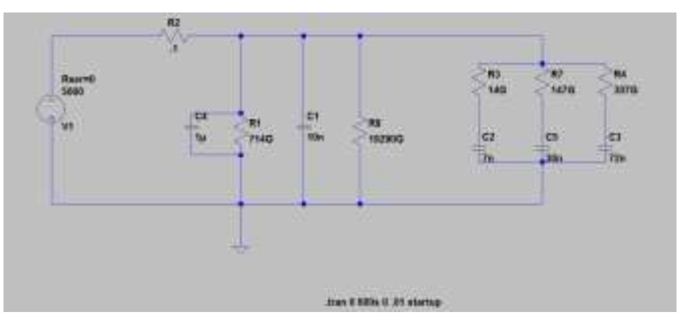

Figure 7. Circuit for Aged Insulation

## V. CONCLUSION

Programs such as LTSpice have limitations as they are designed to simulate linear electronic models while insulation systems are not truly linear. At the same time, the information developed can be used for approximation of polarization and depolarization currents, polarization index and other insulation system testing. Understanding the limitations of the simulation software and how to use it for approximation of insulation system defects can further understanding of failures, assist in reliability and diagnostic programs, and assist in machine design.

## REFERENCES

[1] *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery*, IEEE Standard 43, 2000.

[2] *LTSpice,* http://www.linear.com, 2013.

[3] D. L. McKinnon, *Simulating Insulation Systems Under Various Environmental Conditions in the Laboratory*, Conference Record of the 2012 International Symposium on Electrical Insulation, Puerto Rico, 2012.

[4] *IEEE Recommended Practice for Insulation Testing of AC Electric Machinery(2300 V and Above) with High Direct Voltage, IEEE Std 95, 2002*

[5] S. A. Bhumiwat, *On-Site Non-Destructive Dielectric Response Diagnosis of Rotating Machines*, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 17, No. 5, October, 2010.

[6] C. Sumereder, R. Woschitz, M. Muhr, *Polarization-Depolarization Measurements at Insulation Systems for Rotating Machines*, Proceedings of the 2005 International Symposium on Electrical Insulating Materials, June 5-9, 2005, Kitayushu, Japan.

[7] E. David, R. Soltani, L. Lamarre, *PDC Measurements to Assess Machine Insulation*, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 17, No. 5, October 2010.

[8] E. David, R. Soltani, L. Lamarre *Impact of Humidity on Dielectric Response of Rotating Machines Insulation System*, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 17, No. 5, October 2010.