Kerr Electro-Optic Measurements and Nonuniform Electric Field Reconstructions

by

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Submitted to the Department of Electrical Engineering and Computer Science
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Electrical Engineering

at the
Massachusetts Institute of Technology
May 1999

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To my parents and brother

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Abstract

This thesis uses Kerr electro-optical tomography as a new method to measure electric field and space charge distributions in insulating liquids when the applied electric field magnitude and direction are not constant along the light path. This technology can be used to experimentally verify the electrical design of high voltage devices, to monitor and diagnose the electrical health of high voltage devices and systems, to provide information on the remaining life, and to prevent failure caused by dielectric breakdown.

The Kerr electro-optic method passes low power laser light through a high voltage region filled with an insulating liquid, such as transformer oil. Because the insulating liquid becomes slightly birefringent under high electric field stress, incident linearly or circularly polarized light propagating through the high field stressed medium becomes elliptically polarized. By using a polariscope to analyze the elliptically polarized light due to electric field induced birefringence (Kerr effect), we can measure the electric field distribution in the insulating liquid so that the space charge distribution can be calculated from Gauss' law, $\rho = \nabla \cdot \epsilon \bar{E}$. Making use of the measured data, together with insulating liquid properties, such as dielectric constant, breakdown field strength, resistivity, dissipation factor, thermal conductivity, thermal stability limit, etc., optical measurements can help evaluate the electrical design and health of high voltage systems.

Because the Kerr effect in most liquids is very weak, the detected optical signal is very sensitive to electrical noise and small disturbances. In this thesis we studied methods to increase the optical signal level and to suppress electrical noise so that the measurement results can accurately recover the electric field using the "onion peeling"

method of radial discretization in axisymmetric geometries. Measurements were performed using low Kerr constant transformer oil ($B \approx 2.3 \times 10^{-15}\mathrm{m/V^2}$) and high Kerr constant propylene carbonate ($B \approx 1 \times 10^{-12}\mathrm{m/V^2}$) with parallel-plate, point-plane, and point-ring-plane electrode geometries. We also examine some measurements with non-axisymmetric electrode geometry. We compare experimentally determined electric field distributions with theoretical or computer simulated results under space charge free conditions to provide a comparison for nonzero space charge distributions. Theoretical analyses of significant space charge effects are presented for parallel-plate and coaxial cylindrical electrodes.

Thesis Supervisor: Markus Zahn

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Acknowledgments

I wish to thank Prof. Markus Zahn, supervisor of my thesis, for helping and guiding me throughout my thesis research. It was my pleasure to work under his guidance during my four years at MIT. His enthusiasm for research helped me continue to make progress no matter what kind of problems I encountered.

I would like to express my gratitude to our technician Wayne Ryan who helped me design my experimental setup and shared his experience with me, and to Rocky Albano for his expertise in machining the high voltage electrode assemblies.

I am very fortunate to have the opportunity to work with the other Ph.D. students in the High Voltage Research Laboratory. They are Darrell Schlicker, Afsin Ustundag, Yanqing Du, and Alexander Mamishev. I especially thank Afsin for being my research partner in developing the Kerr electro-optic tomography technology.

I also want to thank Ansoft Corp. for providing their computer software Maxwell which was used for many of the computer simulations performed in this thesis, and to thank the MIT Department of Electrical Engineering and Computer Science for awarding me the Winton Hayes, Edwin S. Webster and Grass Instrument Co. Fellowship.

In addition, I also want to acknowlege the support by the National Science Foundation under Grant No. ECS922038 which funded the early part of this research program.

Finally, special warm appreciation is expressed to Wendy Wan-Chun Wang. Her support and encouragement helped me to finish this thesis.

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