Preface

Many of the standard books on transformers are now over ten years old and some much older. Much has changed in the transformer industry since these books were written. Newer and better materials are now available for core and winding construction. Powerful computers now make it possible to produce more detailed models of the electrical, mechanical and thermal behavior of transformers than previously possible. The ever-increasing competition in the global market has put tremendous responsibilities on the transformer industry to increase transformer reliability while reducing cost, since high quality, low cost products have become the key to survival. However, it is difficult, if at all possible, to meet today's transformer design demands via conventional design techniques.

Today, artificial intelligence is widely used in modeling nonlinear and large-scale systems, especially when explicit mathematical models are difficult to obtain or are completely lacking. Moreover, artificial intelligence is computationally efficient in solving hard optimization problems.

The limitations of the analytical techniques as well as the progress of computers facilitated the development of numerical techniques for the solution of electromagnetic field problems. Among the numerical techniques, the most popular method for the solution of electromagnetic field problems is the finite element method. A very real advantage of the finite element method is its ability to deal with complex geometries. Another advantage is that it yields stable and accurate solutions.

The subject of the book is *Modern Transformer Design*. This book introduces a novel approach to transformer design using artificial intelligence and numerical techniques.

The author worked in the transformer industry for 10 years before joining academia. He has vast experience in the design, development and manufacturing of transformers. The author has developed the bulk of the results presented in the book during the last 10 years, while some of the results appear for the first time.

There is no other book including shell type transformer design by means of magnetic field analysis and artificial intelligence techniques. Most of the material in the book is an expanded and detailed version of the author's original work in the field of transformer design. The basic philosophy of the book is that we learn by applying. That is why the book has many numerical examples that illustrate the use of the techniques for a variety of real-world transformer designs.

The book will be particularly useful to graduate and postgraduate students in electric power engineering devices, researchers in the design and implementation of power transformers, transformer designers and power engineering professionals. More specifically:

1. Graduate and postgraduate students as well as researchers will learn new methodologies for transformer design optimization (TDO). Moreover, they will be able to apply and extend the methodologies of the book to the optimization of different types of transformers or to the optimization of other electrical machines and devices. They will also find real and accurate data since all transformer design examples are from actual constructed and tested transformers.

2. Transformer designers will be helped to apply artificial intelligence to optimizing their transformer designs. In order to assist them, the book presents the basic principles of artificial intelligence methods in separate chapters and in stand-alone form, i.e., the transformer designers will find the majority of the information they need within the book. Moreover, transformer designers can extend the methodologies of the book to optimize the designs of specific transformer types and technologies they use at their transformer manufacturing plant.

3. Power engineering professionals working in electric utilities, industries, public authorities and design offices will find information to improve transformer specifications. They will find methodologies in the book that will help them in their transformer purchasing decisions. In particular, they will save money by purchasing the most cost-effective and energy-efficient transformers.

The material of the book is organized in three parts and eight chapters. Part I, which includes Chaps. 1 and 2, is devoted to the presentation of conventional transformer design. Part II, which includes Chapts. 3 to 5, presents the evaluation and optimization techniques that will be used in the third part of the book for the solution of a number of transformer design problems. Part III, which includes Chaps. 6 to 8, is dedicated to modern transformer design and it illustrates clearly how artificial intelligence and numerical techniques successfully solve a number of hard transformer design evaluation and optimization problems.

Chapter 1 is an introduction to transformer fundamentals. It describes the basic principles for the analysis of magnetic circuits, the correspondence between electric and magnetic circuits, and the modeling of magnetic materials used in the construction of the transformer magnetic circuit. It presents a transformer equivalent circuit, a method to determine the parameters of the equivalent circuit, and formulas to compute voltage regulation and efficiency. It defines the electrical characteristics of a transformer, e.g., rated power, rated voltages, frequency, no-load losses, load losses, and impedance voltage. It describes two interesting transformer operating modes, i.e., overloading and parallel operation. It gives a list of standards that are typically used for transformer manufacturing. It presents the type, routine, and special tests that are performed on transformers. It classifies transformers according to their use, cooling medium, insulating medium, and core construction.

Finally, Chap. 1 describes the type and characteristics of transformers studied in this book.

Chapter 2 deals with the conventional design of wound core type transformers. It formulates the TDO problem and solves it using a multiple design method that is commonly referred to as the conventional TDO method. A design example of an actual commercial transformer is worked out throughout this chapter showing all the calculations that are needed to design a transformer. The example-driven presentation of the conventional TDO method makes this chapter unique in the transformer design literature.

Transformers involve magnetostatic problems. These problems can be solved by analytical and numerical techniques. The limitations of the analytical techniques as well as the progress of computers has facilitated the development of numerical techniques. Among the numerical techniques, the most popular method in the solution of magnetostatic problems is the finite element method. A very strong advantage of the finite element method is its ability to deal with complex geometries. Another advantage is that it yields stable and accurate solutions. Chapter 3 presents the finite element method for the solution of linear and nonlinear magnetostatic problems, the latter being very common in transformer design. Carefully selected arithmetic examples make clear the application of the finite element method in the solution of linear and nonlinear magnetostatic problems.

Classification aims at predicting the future class, and forecasting aims at predicting the future value of a system that is intrinsically uncertain. Chapter 4 briefly presents two artificial intelligence methods, namely decision trees and artificial neural networks. The decision tree methodology is a nonparametric inductive learning technique, able to produce classifiers for a given problem that can assess new, unseen situations and/or uncover the mechanisms driving this problem. The artificial neural network is a computer information processing system that is capable of adequately representing nonlinear functions. The decision tree technique is appropriate for the solution of classification problems. The artificial neural network method is suitable for the solution of both classification and forecasting problems.

Chapter 5 is devoted to optimization and is organized into five sections. Section 5.1 is an introduction to optimization. Section 5.2 presents an active set method that effectively solves quadratic programming problems. Section 5.3 describes the sequential quadratic programming method, which is one of the best methods for solving nonlinearly constrained optimization problems. The sequential quadratic programming method iteratively solves a sequence of quadratic programming subproblems. Section 5.4 presents the branch-and-bound method, which, in conjunction with sequential quadratic programming, effectively solves mixed-integer nonlinear programming problems (such as the TDO problem of Chap. 7). Section 5.5 is devoted to the genetic algorithm method, which successfully solves complex optimization problems (such as the transformer no-load loss minimization problem of Chap. 7). The four optimization methods that are presented in this chapter are accompanied by carefully selected and analytically solved arithmetic examples that make clear the application of the methods to the solution of a variety of optimization problems.

Chapter 6 is devoted to the evaluation of transformer technical characteristics. Decision trees and artificial neural networks solve the no-load loss classification problem. Artificial neural networks solve the no-load loss prediction problem. Impedance voltage evaluation is implemented using a particular finite element model with detailed representation of winding geometry.

Chapter 7 deals with modern design optimization of wound core type transformers. Four methods are presented that solve important transformer design problems. First, genetic algorithms are combined with artificial neural networks to optimally group $4 \cdot N$ available individual cores into N transformers so as to minimize the total no-load loss of N transformers. This method significantly reduces the no-load loss design margin as well as the cost of transformer main materials. Second, decision trees and artificial neural networks successfully solve the winding material selection problem, thus avoiding the need to optimize the transformer twice, once with copper and once with aluminum windings. Third, a mixed integer programming–finite element method is developed for solution of the TDO problem. Finally, a recursive genetic algorithm–finite element method is developed to solve the TDO problem and is compared with the mixed integer programming–finite element method. The recursive genetic algorithm approach can also be very useful for the solution of other optimization problems in electric machines and power systems.

Chapter 8 deals with transformer selection by electric utilities and industrial transformer users. It reviews the classical total owning cost formula and it also introduces the external environmental cost due to transformer losses. Using the methodologies of this chapter, transformer users will save money by purchasing the most cost-effective and energy-efficient transformers.

Much of the material presented in this book was obtained through teamwork with colleagues at the National Technical University of Athens, the Technical University of Crete and Schneider Electric AE.

I would like to express my most sincere thanks to Professor Nikos Hatziargyriou, supervisor of my PhD dissertation, for his continuous guidance, encouragement and support throughout my PhD and for introducing me to artificial intelligence based transformer design. Special thanks go to Professor Antonios Kladas for excellent and fruitful research collaboration in the area of numerical techniques for analysis of the transformer magnetic field.

I sincerely acknowledge the rich and ample experience gained while working in Schneider Electric AE and I am grateful to all my erstwhile senior colleagues. I would particularly like to express my sincere gratitude to Mr Athanasios Souflaris, Mr Yiannis Bakopoulos, Mr Spiros Elefsiniotis, Mr Dimitrios Paparigas, and Mr Dionissios Spiliopoulos for their support and guidance.

It was a great pleasure for me to collaborate with three PhD students in the area of transformer design. I would like to express my sincere thanks to Dr Marina Tsili, Dr Eleftherios Amoiralis and Dr Themistoklis Kefalas for our fruitful collaboration.

I would like to thank Professor Nikola Rajakovic, Professor Vlastimir Glamocanin, Professor Suad Halilcevic, Professor Antonios Kladas and three more anonymous reviewers for the time invested to review this book and for their constructive comments that helped me to improve the quality, presentation and organization of the book.

Thanks are also due to Mr Anthony Doyle from Springer for his invitation to write this book and for believing in the project from the beginning as well as to Mr Simon Rees and Ms Claire Protherough from Springer who gave very good editorial input.

This book would not have been possible without the understanding and patience of my wife Liza.

Chania, Greece
January 2009

Pavlos S. Georgilakis

http://www.springer.com/978-1-84882-666-3

Spotlight on Modern Transformer Design
Georgilakis, P.S.
2009, XX, 427 p., Hardcover
ISBN: 978-1-84882-666-3