Article

A Nonlinear Circuit Analysis Technique for Time-Variant Inductor Systems

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Abstract: Time-variant inductors exist in many industrial applications, including sensors and actuators. In some applications, this characteristic can be deleterious, for example, resulting in inductive loss through eddy currents in motors designed for high efficiency operation. Therefore, it is important to investigate the electrical dynamics of systems with time-variant inductors. However, circuit analysis with time-variant inductors is nonlinear, resulting in difficulties in obtaining a closed form solution. Typical numerical algorithms used to solve the nonlinear differential equations are time consuming and require powerful processors. This investigation proposes a nonlinear method to analyze a system model consisting of the time-variant inductor with a constraint that the circuit is powered by DC sources and the derivative of the inductor is known. In this method, the Norton equivalent circuit with the time-variant inductor is realized first. Then, an iterative solution using a small signal theorem is employed to obtain an approximate closed form solution. As a case study, a variable inductor, with a time-variant part stimulated by a sinusoidal mechanical excitation, is analyzed using this approach. Compared to conventional nonlinear differential equation solvers, this proposed solution shows both improved computation efficiency and numerical robustness. The results demonstrate that the proposed analysis method can achieve high accuracy.

Keywords: variable inductor; nonlinear circuits analysis; sensor nonlinear dynamics; mechatronics

1. Introduction

Time-variant inductors exist in many industrial applications such as electric motors [1], power electronics [2], magnetic bearings [3], Linear Variable Differential Transformers (LVDT) [4], piezoelectric actuators [5] and fluidic valves [6]. The changing inductance will make the flux inside a motor nonuniform, which causes eddy currents to occur. The eddy current loss (induction loss) is a major loss in addition to Ohmic losses in the copper, hysteresis loss and mechanical loss [7–9], especially if a motor is running at high speed [10,11]. Recent studies also indicate that the induction loss also introduces distortions in MRI imaging systems [12]. The industry has been expected to reduce induction loss in order to not only improve the power efficiency but to also cancel the steady state ripples resulting from the eddy currents. Previously, the researchers have focused on the this topic by topology or structural optimization approaches such as using an special spinning echo [13] and novel interface circuits [14].

On the other hand, many techniques utilize the eddy currents for sensing, such as metal detection sensors [15], motor fault diagnosis sensors [16] and non-destructive sensors [17]. Some automatic

Nonlinear Circuit Analysis An Introduction

John Lawrence Dickens

Nonlinear Circuit Analysis An Introduction:

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tables formulas and definitions Extensive bibliographic references   Circuit Simulation Methods and Algorithms Jan Ogrodzki,1994-09-26 Circuit Simulation Methods and Algorithms provides a step by step theoretical consideration of methods techniques and algorithms in an easy to understand format Many illustrations explain more difficult problems and present instructive circuits The book works on three levels The simulator user level for practitioners and students who want to better understand circuit simulators The basic theoretical level with examples dedicated to students and beginning researchers The thorough level for deep insight into circuit simulation based on computer experiments using PSPICE and OPTIMA Only basic mathematical knowledge such as matrix algebra derivatives and integrals is presumed   *A Nonlinear Circuit Analysis Program* John Lawrence Dickens,1971   *Linear Circuit Analysis* Bernard James Ley,Samuel G. Lutz,Charles F. Rehberg,2013-04   *Proceedings of the Symposium on Nonlinear Circuit Analysis* Symposium on Nonlinear Circuit Analysis,1957   **VLSI Circuit Simulation and Optimization** V. Litovski,Mark Zwolinski,1996-12-31 Circuit simulation has become an essential tool in circuit design and without it s aid analogue and mixed signal IC design would be impossible However the applicability and limitations of circuit simulators have not been generally well understood and this book now provides a clear and easy to follow explanation of their function The material covered includes the algorithms used in circuit simulation and the numerical techniques needed for linear and non linear DC analysis transient analysis and AC analysis The book goes on to explain the numeric methods to include sensitivity and tolerance analysis and optimisation of component values for circuit design The final part deals with logic simulation and mixed signal simulation algorithms There are comprehensive and detailed descriptions of the numerical methods and the material is presented in a way that provides for the needs of both experienced engineers who wish to extend their knowledge of current tools and techniques and of advanced students and researchers who wish to develop new simulators   **Introduction to Circuit Analysis and Design** Tildon H. Glisson,2011-02-18 Introduction to Circuit Analysis and Design takes the view that circuits have inputs and outputs and that relations between inputs and outputs and the terminal characteristics of circuits at input and output ports are all important in analysis and design Two port models input resistance output impedance gain loading effects and frequency response are treated in more depth than is traditional Due attention to these topics is essential preparation for design provides useful preparation for subsequent courses in electronic devices and circuits and eases the transition from circuits to systems   Linear and Nonlinear Circuits: Basic and Advanced Concepts Mauro Parodi,Marco Storace,2020-01-03 This book provides readers with the necessary background information and advanced concepts in the field of circuits at the crossroads between physics mathematics and system theory It covers various engineering subfields such as electrical devices and circuits and their electronic counterparts Based on the idea that a modern university course should provide students with conceptual tools to understand the behavior of both linear and nonlinear circuits to approach current problems posed by new cutting edge devices and to address future developments and challenges the book places equal emphasis on linear and

nonlinear two terminal and multi terminal as well as active and passive circuit components This second volume focuses on dynamical circuits which are characterized by time evolution and by the concept of state The content is divided into a set of introductory and a set of advanced level topics mirroring the approach used in the previously published volume Whenever possible circuits are compared to physical systems of different natures e g mechanical or biological that exhibit the same dynamical behavior The book also features a wealth of examples and numerous solved problems Further topics such as a more general framing of linear and nonlinear components will be discussed in volume 3 **Intermodulation Distortion in Microwave and Wireless Circuits** José Carlos Pedro,Nuno Borges Carvalho,2003 In today s fast changing competitive environment having an up to date information system IS is critical for all companies and institutions Rather than creating a new system from scratch reengineering is an economical way to develop an IS to match changing business needs Using detailed examples this practical book gives you methods and techniques for reengineering systems for flexibility and reliability It helps you reengineer a system to continue to provide for business critical missions as well as achieve a smooth transformation to an up to date software technology environment What s more it shows you how to redevelop a flexible system that can evolve to meet future business objectives reduce start time and save money in the reengineering process
Linear and Nonlinear Circuits: Basic & Advanced Concepts Mauro Parodi,Marco Storace,2017-07-03 This book provides readers with the necessary background information and advanced concepts in the field of circuits at the crossroads between physics mathematics and system theory It covers various engineering subfields such as electrical devices and circuits and their electronic counterparts Based on the idea that a modern university course should provide students with conceptual tools to understand the behavior of both linear and nonlinear circuits to approach current problems posed by new cutting edge devices and to address future developments and challenges the book places equal emphasis on linear and nonlinear two terminal and multi terminal as well as active and passive circuit components The theory is developed systematically starting with the simplest circuits linear time invariant and resistive and providing food for thought on nonlinear circuits potential functions linear algebra and geometrical interpretations of selected results Contents are organized into a set of first level and a set of advanced level topics The book is rich in examples and includes numerous solved problems Further topics such as signal processing and modeling of non electric physical phenomena e g hysteresis or biological oscillators will be discussed in volume 2 *Nonlinear Circuit Analysis* Richard A. Johnson,2012 **Nonlinear Circuit Analysis: I (proc.Of The Symp.On) New York, Apr.23-24, 1953** Polytechnic Brooklyn, University of Michigan Official Publication University of Michigan,1989 Each number is the catalogue of a specific school or college of the University Nonlinear Circuit Analysis Polytechnic Institute of Brooklyn. Microwave Research Institute,Symposium on Nonlinear Circuit Analysis,1957 Handbook of RF and Microwave Power Amplifiers John L. B. Walker,2012 This is a one stop guide for circuit designers and system device engineers covering everything from CAD to reliability **Nonlinear Circuit**

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