

Complex Behavior in Switching Power Converters

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Invited Paper

Power electronics circuits are rich in nonlinear dynamics. Their operation is characterized by cyclic switching of circuit topologies, which gives rise to a variety of nonlinear behavior. This paper provides an overview of the chaotic dynamics and bifurcation scenarios observed in power converter circuits, emphasizing the salient features of the circuit operation and the modeling strategies. In particular, this paper surveys the key publications in this field, reviews the main modeling approaches, and discusses the salient bifurcation behaviors of power converters with particular emphasis on the disruption of standard bifurcation patterns by border collisions.

Keywords—Bifurcation, chaos, dc–dc converters, nonlinear dynamics, power electronics, switching power converters.

I. INTRODUCTION

Power electronics is a discipline spawned by real-life applications in industrial, commercial, residential, and aerospace environments. Much of its development evolves around some immediate needs for solving specific power conversion problems. In the past three decades, this branch of electrical and electronic engineering has undergone an intense development in many aspects of technology [1], including power devices, control methods, circuit design, computer-aided analysis, passive components, packaging techniques, etc. The principal focus in power electronics, as reflected from topics discussed in some key conferences [2], [3], is to fulfill the functional requirements of the application for which its circuits are used. Like many areas of engineering, power electronics is mainly motivated by practical applications and it often turns out that a particular circuit topology or system implementation has found widespread applications long before it has been thoroughly

analyzed. For instance, the widespread application of a simple switching converter may date back to more than three decades ago. However, good analytical models allowing better understanding and systematic circuit design were only developed in the late 1970s [4] and in-depth analytical characterization and modeling is still being actively pursued today. Despite their common occurrence in power electronics circuits, nonlinear phenomena have only recently received appropriate formal treatments.

In this paper, we review some of the nonlinear phenomena observed in typical power electronics systems. Our intention is to provide an overview of the recent research effort in the study of nonlinear phenomena in power converters, and to summarize the essential analytical approaches that can be used to perform a systematic study of the nonlinear behavior of such systems. The rest of the paper is outlined as follows. We begin in Section II with a brief overview of power electronics circuits, followed by a discussion of the benefits of studying chaotic dynamics in power electronics in Section II-C. A quick tour of some recent findings is presented in Section III. In Section IV, we present a discussion of the modeling methods for characterizing nonlinear behavior such as bifurcation and chaos in switching converter circuits. In Section V, we focus on the typical bifurcation scenarios observed in switching power converters, expounding their most relevant aspects from a practical viewpoint.

II. BRIEF OVERVIEW OF SWITCHING CONVERTERS OPERATION

The basic operation of any power electronics circuit involves toggling among a set of linear or nonlinear circuit topologies, under the control of a feedback system. As such, they can be regarded as *switched* or *piecewise-smooth* dynamical systems.

For example, in simple direct current–direct current (dc–dc) converters, such as the ones shown in Fig. 1, an inductor is “switched” between the input and the output through an appropriate switching element (labeled as *S*

Manuscript received June 15, 2001; revised November 26, 2001. This work was supported in part by the Research Grants Council, Hong Kong, under Grant PolyU 5131/99E.

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Publisher Item Identifier S 0018-9219/02/05253-2.

Complex Behavior Of Switching Power Converters

Scott Replinger



Complex Behavior Of Switching Power Converters:

Complex Behavior of Switching Power Converters Chi Kong Tse,2003-07-28 Power electronics is a discipline spawned by real life applications in industrial commercial residential and aerospace environments Much of its development evolves around some immediate need for solving specific power conversion problems This comprehensive book focuses on the typical bifurcation scenarios and nonlinear behavior observed in swit *Quantum, Nano, Micro and Information Technologies* Yuan Zhi Wang,2010-11-11 Selected peer reviewed papers from the 2010 International Symposium on Quantum Nano and Micro Technologies ISQNM 2010 October 27 28 2010 Chengdu China **Chaos Analysis and Chaotic EMI Suppression of DC-DC Converters** Bo Zhang,Xuemei Wang,2015-04-30 Introduces chaos theory its analytical methods and the means to apply chaos to the switching power supply design DC DC converters are typical switching systems which have plenty of nonlinear behaviors such as bifurcation and chaos The nonlinear behaviors of DC DC converters have been studied heavily over the past 20 years yet researchers are still unsure of the practical application of bifurcations and chaos in switching converters The electromagnetic interference EMI which resulted from the high rates of changes of voltage and current has become a major design criterion in DC DC converters due to wide applications of various electronic devices in industry and daily life and the question of how to reduce the annoying harmful EMI has attracted much research interest This book focuses on the analysis and application of chaos to reduce harmful EMI of DC DC converters After a review of the fundamentals of chaos behaviors of DC DC converters the authors present some recent findings such as Symbolic Entropy Complexity and Chaos Point Process to analyze the characters of chaotic DC DC converters Using these methods the statistic characters of chaotic DC DC converters are extracted and the foundations for the following researches of chaotic EMI suppression are reinforced The focus then transfers to estimating the power spectral density of chaotic PWM converters behind an introduction of basic principles of spectrum analysis and chaotic PWM technique Invariant Density and Prony and Wavelet analysis methods are suggested for estimating the power spectral density of chaotic PWM converters Finally some design oriented applications provide a good example of applying chaos theory in engineering practice and illustrate the effectiveness on suppressing EMI of the proposed chaotic PWM Introduces chaos theory its analytical methods and the means to apply chaos to the switching power supply design Approaches the subject in a systematic manner from analyzing method chaotic phenomenon and EMI characteristics analytical methods for chaos and applying chaos to reduce EMI electromagnetic interference Highlights advanced research work in the fields of statistic characters of nonlinear behaviors and chaotic PWM technology to suppress EMI of switching converters Bridges the gap between numerical theory and real world applications enabling power electronics designers to both analyze the effects of chaos and leverage these effects to reduce EMI *Automatic Manufacturing Systems II* Run Hua Tan, Ji Bing Sun, Qing Suo Liu,2012-06-14 Selected peer reviewed papers from the 2nd International Conference on Advanced Engineering Materials and Technology AEMT 2012 July

6 8 2012 Zhuhai China *Handbook of Research on Advanced Intelligent Control Engineering and Automation* Azar, Ahmad Taher, 2014-11-30 In industrial engineering and manufacturing control of individual processes and systems is crucial to developing a quality final product Rapid developments in technology are pioneering new techniques of research in control and automation with multi disciplinary applications in electrical electronic chemical mechanical aerospace and instrumentation engineering The Handbook of Research on Advanced Intelligent Control Engineering and Automation presents the latest research into intelligent control technologies with the goal of advancing knowledge and applications in various domains This text will serve as a reference book for scientists engineers and researchers as it features many applications of new computational and mathematical tools for solving complicated problems of mathematical modeling simulation and control Intelligent Computing Based on Chaos Ljupco Kocarev, Zbigniew Galias, Shiguo Lian, 2009-02-03 Chaos is a fascinating phenomenon that has been observed in nature laboratory and has been applied in various real world applications Chaotic systems are deterministic with no random elements involved yet their behavior appears to be random Observations of chaotic behavior in nature include weather and climate the dynamics of satellites in the solar system the time evolution of the magnetic field of celestial bodies population growth in ecology to mention only a few examples Chaos has been observed in the laboratory in a number of systems such as electrical circuits lasers chemical reactions fluid dynamics mechanical systems and magneto mechanical devices Chaotic behavior has also found numerous applications in electrical and communication engineering information and communication technologies biology and medicine To the best of our knowledge this is the first book edited on chaos applications in intelligent computing To access the latest research related to chaos applications in intelligent computing we launched the book project where researchers from all over the world provide the necessary coverage of the mentioned field The primary objective of this project was to assemble as much research coverage as possible related to the field by defining the latest innovative technologies and providing the most comprehensive list of research references *IEEE Transactions on Circuits and Systems*, 2006 Tutorial Guide, 2003 **Chinese Journal of Electronics**, 2008 **The Proceedings of the AES ... International Conference**, 2006 **Alternative Energy Systems** M. Godoy Simões, Felix A. Farret, 2008 Durable and cost effective induction power generators have undergone numerous improvements that make them an increasingly attractive option for renewable energy applications particularly for wind and hydropower generation systems From fundamental concepts to the latest technologies *Alternative Energy Systems Design and Analysis with Induction Generators* Second Edition provides detailed and accurate coverage of all aspects related to the design operation and overall analysis of such systems Placing a greater emphasis on providing clear precise and succinct explanations this second edition features new revised and updated content as well as figures tables equations and examples Each chapter introduces a multi step chapter length problem relating the material to a real application The solution appears at the end of the chapter along with additional practice problems and references New

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