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Suppressing Electromagnetic Interference in Switching Converters by Chaotic Duty Modulation

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DISSERTATION

zur Erlangung des akademischen Grades

DOKTOR-INGENIEURIN

der Fakultät für Mathematik und Informatik

der FernUniversität in Hagen

von

Yuhong Song, M.Sc.

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Keywords: Switching power supply – Switching converter – Chaotic duty modulation – Electromagnetic interference (EMI) – Electromagnetic compatibility (EMC) – Stability – Remaining useful life

Abstract: The switching converter generates serious electromagnetic interference (EMI), which impairs other devices' performance and harms human being's health. As a way of chaos technique, chaotic modulation has been developed to suppress EMI of the switching converter by dispersing the energy into a wide frequency band and smoothing the peaks of the EMI spectrum. Unlike the well-studied chaotic frequency modulation, the chaotic duty modulation is concerned in this dissertation, which is just to change the duty of the transistor driving-pulse while maintains the fixed switching frequency. Chaotic duty modulation is realized by appending an external chaotic signal to the existing PWM module of the switching converter, which is practicable without the loss of the generality. It is thus verified that this proposal of using chaotic duty modulation in switching converters for EMI suppression is feasible and lays a foundation for industrial applications.

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Before 2010, I only knew that "butterfly effect" relates to one sentence, "A butterfly from the Amazon river basin rainforest in South America, occasionally flaps its wings, which could cause a tornado in Texas of the United States two weeks later". With the further study, I understood the real meaning behind "butterfly effect", which is the poetic description of the chaotic phenomenon. Together with relativity and quantum mechanics, chaos is considered as one of the three monumental scientific discoveries in the twentieth century. Our real world is essentially nonlinear, thus chaos is ubiquitous, attracting so much research interest in the past few decades. However, for a long time, chaos has been considered to be harmful and useless, and thus controlled to prevent its appearance in the nonlinear systems. Recently, chaos has been found helpful and useful for some engineering applications, such as secure communication, motor control and electromagnetic interference (EMI) suppression. However, the research achievements are mostly embodied in the theory and laboratory prototype and industrial applications have been in a wait-and-see status.

The idea of trying to offer the feasible schemes for commercial switching converters motivated me to make a research on applying chaos in reducing EMI. Chaos technique has been applied in switching converters in two ways: parameter control and spread spectrum modulation. The parameter control is strictly demanded to maintain chaos under various conditions, i.e., different loads, which results in the complexity of system design. Chaotic modulation has been developed to suppress EMI of switching converters by dispersing the energy into a wide frequency band and smoothing the peaks of the EMI spectrum. My research, focusing on chaotic duty modulation, has proposed the spread spectrum schemes in commercial switching converters. Meanwhile, simulations and experiments have been conducted to verify the effectiveness of the proposed schemes on EMI reduction. Furthermore, on the basis of spectral properties of chaotic signal, which is normally represented by Fourier Transform, the central frequency has been defined to be the frequency corresponding to the greatest spectral peak of chaotic signal. It has been proved that the chaotic duty modulation is the most effective to suppress EMI when the central frequency of chaotic signal is equal to the switching frequency of transistor in switching converters.

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Abstract

A switching power supply, namely switching converter, which is characterized by high efficiency, small volume and light weight, has developed rapidly in recent years and has been gradually deployed instead of linear power supplies in electronic and electrical domains. The switching power supply makes use of the pulse-width modulation (PWM) technology to control the nonlinear components, so that they have a switching action of high frequency, resulting in high change rates of voltage and current. Consequently, the switching converter generates serious electromagnetic interference (EMI), which impairs other devices' performance and harms human being's health. Hence, suppressing EMI has become a common concern in the design and the application of switching converters.

Traditionally, EMI is dealt by filtering or shielding, or both. Filtering aims to reduce the conducted EMI by adding the filters to the system. In practice, multiple filters should be employed in a switching converter because a single filter is restricted by its narrow frequency band. Shielding aims to block the converter from emitting or receiving the radiated EMI with barriers made of conductive material. These traditional filtering and shielding techniques have the disadvantages in weight, size and cost, and their engineering applications depend on the experience of engineers. Additionally, it has been found that soft switching technique can be used to reduce EMI. However, it needs an auxiliary control module to guarantee zero voltage or zero current during the transformational period of transistors, resulting in a complicated design. Hence, using chaos in switching converters has become new preferable technique to tackle the EMI problems due to the pseudo-random and continuous spectrum characteristics of chaos.

As a way of chaos technique, chaotic modulation has been developed to suppress EMI of the switching converter by dispersing the energy into a wide frequency band and smoothing the peaks of the EMI spectrum. It is well known that the effectiveness of EMI suppression is related to chaotic signals used for chaotic modulation. From this study, it is further found that the central frequency of a chaotic signal, corresponding to the largest peak of its frequency spectrum, should be close to a half of the switching frequency of a power supply to reach optimal EMI suppression.

Unlike the well-studied chaotic frequency modulation, the chaotic duty modulation is concerned in this dissertation, which is just to change the duty of the transistor driving-pulse while maintains the fixed switching frequency. Chaotic duty modulation is realized by appending an external chaotic signal to the existing PWM module of the switching converter, which is practicable without the loss of the generality.

It is followed with a qualitative verification of the stability of power supplies under chaotic duty modulation via the classic control theory, and practically, the useful life through the failure model and critical components, which is also ensured under chaotic duty modulation. It is thus verified that this proposal of using chaotic duty modulation in switching converters for EMI suppression is feasible and lays a foundation for industrial applications.

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