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Chaotic Behavior in High-Gain Interleaved Dc-dc Converters

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Abstract

In this paper, chaotic behavior in high gain dc-dc converters with current mode control is explored. The dc-dc converters exhibit some chaotic behavior because they contain switches. Moreover, in power electronics (circuits with more passive elements), the dynamics become rich in nonlinearity and become difficult to capture with linear analytical models. Therefore, studying modeling approaches and analysis methods is required. Most of the high-gain dc-dc boost converters cannot be controlled with only voltage mode control due to the presence of right half plane zero that narrows down the stability region. Therefore, the need of current mode control is necessary to ensure the stability of this type of boost converter. A significant number of the work reported so far has concentrated on explaining the chaos phenomena in the language of the nonlinear dynamics literature. In addition to analyzing and studying chaotic behaviors, this presents some ideas about moving toward gainful utilization of the nonlinear properties of power electronics. Simulation and experimental studies are included to validate the theory, and results will be discussed.

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Keywords: Chaos, bifurcation; nonlinear; Dc-dc; boost; buck; High-gain; interleaved

1. Introduction

Power electronics that are used to convert dc input voltage to dc output voltage can be divided into four categories, as shown in Fig. 1. Linear regulators are usually employed in auxiliary applications, and switched capacitors, which are used as battery charge equalizer and power suppliers to computer servers [1-2]. The switching mode power supply is controlled by pulse width modulation (PWM), and it is the most common type of converter and it used in applications interfacing renewable energy sources to the microgrid [3, 4]. The PWM converters are controlled by devices that take an error signal and convert it to a signal that is suitable for turning on and off the

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active switches. These switches increase the nonlinearity in the dynamic behavior. The PWM signal has a frequency in the range of 10 to 200 kHz, and working with high frequency makes the circuit prone to exhibit some chaotic behavior. Chaos is an unexpected long-term state of disorder. It is happening in nonlinear dynamic systems. To better understand this phenomenon, different tools have been developed [5-7]. Bifurcation figures are an example of an evaluation tool used to study the reaction of the system to change one or more parameters. The bifurcation usually plotted in 2D figures with one variable varying on the x-axis and the other variable on the y-axis. This tool can be helpful if one or more input is highly variable such solar PV voltage, and can improve the design and operation of a system [8-10]. Plotting bifurcation figures in higher dimension requires expensive computations, and hence is not of interest in this paper. In power electronics, one can plot the bifurcation diagram using the discrete models by observing state variables [7]. Other techniques used to test the performance of power electronic converters can be summarized in Fig 2. A phase portrait is a tool that shows if the trajectory is going to converge to a stable point or diverge. The Poincare map is suitable if continuous system discretization is preferred. This method places Poincare section at a selected position on state space and then obtains the discrete time model of the continuous system by finding the intersection of the surface and the trajectory. Time domain waveforms show the transient response and the steady state response. The x-axis is the time, and the y-axis is the dependent variable that changes with time (e.g., inductor current). The Bode plot is a graph to see a behavior of a transfer function against (versus) the frequency. It is widely used to test the stability of a system. The bode plot contains a magnitude plot and an angle plot of the transfer function. The Cobweb plot visualizes sequential iterations of a function. Having to plot the iterations, the long-term stability status can be inferred, and the behavior of the system can be investigated.

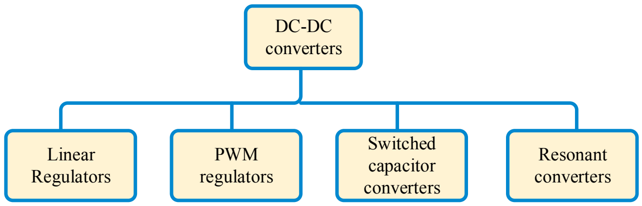

Fig. 1. Types of dc-dc converters

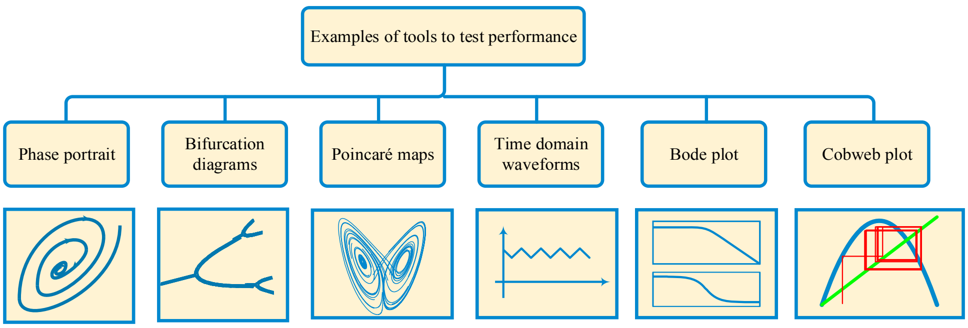

Fig. 2. Examples of tools used to test performance of a system

Figure 3 shows the bifurcation diagram with four different periods and the phase portrait and time-domain waveform associated with each period. In steady state (period 1), the period and the sampling interval are the same. The time domain waveform has one corresponding sample during the interval. The state space trajectory in phase portrait starts from a point and returns to the same point. In other words, the state space trajectory has a single loop. In period 2, the period-doubling bifurcation occurs. During this period, the time-domain waveform has two corresponding samples during the sampling interval. The state-space trajectory is no longer continuous single loop. In period 4, the period-quadrupling bifurcation occurs. The time-domain waveform has four corresponding samples during the sampling interval. The phase portrait has multiple loops. The system is still stable under period 2 and

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