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Impact of Inductor Resistance on the Dynamic Behaviour of a DC–DC Boost Converter Using Bifurcation and Chaos Theory

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Abstract

The DC output voltage of some renewable energy systems such as photovoltaic systems and fuel cells is often of a low value. This requires some power electronic devices to step up the voltage to a suitable value which is required by inverters. Since the DC–DC converter is a nonlinear dynamic system due to its operation mode, a nonlinear method should be used for system analysis and design.

This paper aims at analysis of the dynamic system, estimating the impact of inductor resistance on that behaviour and determining the stable operation regions of the system. The converter is simulated by a set of differential equations with considering the inductor internal resistance. The solutions have been derived and the outcome is a development of a mathematical model which is suitable for the discrete time map. Based on the established model, an algorithm for producing bifurcation diagrams is designed and a computer program in Matlab environment is written. Several computer simulations have been carried out and conclusions drawn, which would be useful for convertor and control design and for optimization of the operation mode of the converter system, avoiding the possible bifurcation and chaos phenomena in the long term.

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Keywords: DC-DC boost converter; Dynamic behaviour; Bifurcation and Chaos theory; Impact of internal inductor resistance

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1. Introduction

The DC output resulting from some renewable energy systems such as Photovoltaics and fuel cells is often of low value. Therefore electronic devices are required to step up the voltage to a suitable value. So, mostly, such systems are provided by DC –DC Boost Converters to work on raising the voltage to be proper for inverter input.

Due to the fact that DC-DC is a dynamic system because of its nonlinear elements and its operational mode with fixed period T and variable duty cycle D, and due to its feedback control circuit, so its operational mode is a nonlinear one which is varying with time. This requires using nonlinear methods for designing and analyzing the system.

This research work aims at analyzing the dynamic behaviour of DC-DC boost converter generally; and to estimate the impact of inductor resistance on such behaviour, as well as defining the stable regions of the system operation by using the Bifurcation & Chaotic Theory. Since this theory is unfamiliar, so far, in the engineering domain, we will firstly give a brief review of it, then we continue explaining it through applications to boost DC-DC converters.

2. Basic principles of Bifurcation & Chaotic Theory [1] [6]

In mathematics, a deterministic system is a system in which no randomness is involved in the development of future states of the system. A deterministic model will thus always produce the same output from a given starting condition or initial state. Physical laws that are described by differential equations represent deterministic systems, even though the state of the system at a given point in time may be difficult to describe explicitly. Small differences in initial conditions (such as those due to rounding errors in numerical computation) yield widely diverging outcomes for chaotic systems, rendering long-term prediction impossible in general. This happens even though these systems are deterministic, meaning that their future behaviour is fully determined by their initial conditions, with no random elements involved. In other words, the deterministic nature of these systems does not make them predictable. This behaviour is known as deterministic chaos, or simply ***chaos***. The systems studied in chaos theory are deterministic. If the initial state were known exactly, then the future state of such a system could be predicted. However, in practice, knowledge about the future state is limited by the precision with which the initial state can be measured.

Before chaos taking place, normally bifurcation happens, where soft and small change in the values of system parameters lead to qualitative and sudden change in its behaviour. So, bifurcation and chaos are considered as twin [1].

Applying the theory of bifurcation and chaotic to nonlinear electronic circuits started in 1982 through applying this theory on simple circuits such as Chua's circuit, and other electronic circuits [2-5].

3. The mathematical model of DC-DC boost converters considering inductor resistance [7]

Figure 1 shows the converter circuit including current control, and taking into consideration the inductor resistance **r**. The circuit includes the following elements: controlled electronic switch, diode, practical inductor (non ideal), capacitor, and Ohmic load. The control circuit is a sequential circuit, controlled by clock pulses and it is a current path with feedback including clock pulse generator, comparator, set-reset Flip-Flop and other elements. We presume that the converter operates as CCM.

Assuming that the switch is closed at t = 0, $\mathbf{i_L}$ increases (storing power in the inductor magnetic field) until reaching the value Iref which leads to making the flip-flop opening the switch until reaching the next pulse, in which the switch is closed again.

Figure 2 shows the operations taking place during the periods switch on and off. **During the switch on period**, the power is stored in the inductor, while the capacitor provides the load with power. At the same time, the capacitor voltage decreases. **During the switch off period**, the stored power in the inductor transfers into the capacitor and the load, while the capacitor voltage increases.