The Simulation-Based Analysis of the Nonlinear Dynamics of a Single-Stage Boost Converter

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Abstract
Nonlinear dynamics, such as bifurcation and chaos, have received a lot of interest in the scientific community. The area of power electronics is dynamic and nonlinear, with chaos playing a key role. Time dynamics and nonlinearity cannot be ignored or it will be the default situation in power electronics. The current work uses a bifurcation diagram to simulate the study of bifurcation and chaotic behaviour in a single stage boost converter. It also conveys parameter change and its influence on the bifurcation diagram and stability.

Keywords: *Nonlinear Dynamics, Bifurcation, Chaos, Boost Converter.*

INTRODUCTION

In the era of science, it is often assumed that deterministic systems have predictable outcomes when beginning conditions are constants or zero. But it all fell apart when chaos entered the picture. Many research groups are studying, investigating, and implementing nonlinear phenomena, notably chaos [1-5]. Chaotic dynamics may be traced back to Poincaré's work on celestial mechanics about 1900 [1, 6]. Lorenz proposed in 1963 that basic nonlinear systems can exhibit complicated, chaotic behaviour [1]. Van der Pol reported the first version of chaotic behaviour in the electronics domain in 1927 [7]. In 1980, Ballieul, Brockett, and Washburn proposed chaotic behaviour in DC-DC converters [5]. Other researchers, such as Linsay and L. Chua, are well-known in the field of electronics for their work on nonlinear circuits based on capacitors and diodes [6, 8-9].

The Chuas diode is now known as the "Memristor" [10-12]. Recently, power converter topologies with single and multistage converter topologies have been extensively studied in terms of chaos and stability [13-17]. Power electronics is concerned with the conversion and handling of huge amounts of power using electronic circuits. Power conversion takes the form of AC-AC, AC-DC, DC-AC, and DC-DC. The DC-DC converter is often referred to as a chopper or a DC amplifier. Conventional methods are used to analyse the linear and steady-state performance of converters and electric controllers [18-21], but nonlinear features and dynamic behaviour of converters are not addressed and examined at scale. The current work is concerned with the nonlinear dynamics of a DC-DC boost converter in terms of bifurcation diagram and stability. The remainder of the paper is arranged as follows, with the circuit operation of the boost converter briefly provided in the second part. Section III provides a brief overview of the chaos and bifurcation phenomena. Section IV described the chaos and bifurcation processes as chosen circuit characteristics such as input supply voltage (VIN) and load resistance were varied (RL). The final segment depicts the finale.

BOOST CONVERTER

A boost converter is often referred to as a step up DC-DC converter. It is commonly employed in applications where the output voltage must be greater than the input supply voltage, such as power supply and motor control. Figure 1 depicts a typical boost converter. The circuit schematic includes the following components: a DC supply (VIN), an inductor (L), a MOSFET as a switch, a diode (D), a capacitor (C), and a load resistance (RL). The duty cycle of the MOSFET is used to regulate the output voltage. The following is how the circuit works: When the MOSFET is turned on, the diode is reverse biassed, and so the output stage is switched off. At this point, the inductor current grows linearly, which means that the inductor absorbs energy from the supply and stores it. At this point, the capacitor enters the picture and discharges through load resistance. When the switch is opened, the diode becomes forward biassed, and the output stage gets energy from both the inductor and the input. As a result, the net energy transferred from input to output is always larger in a particular switching cycle. [22-23]

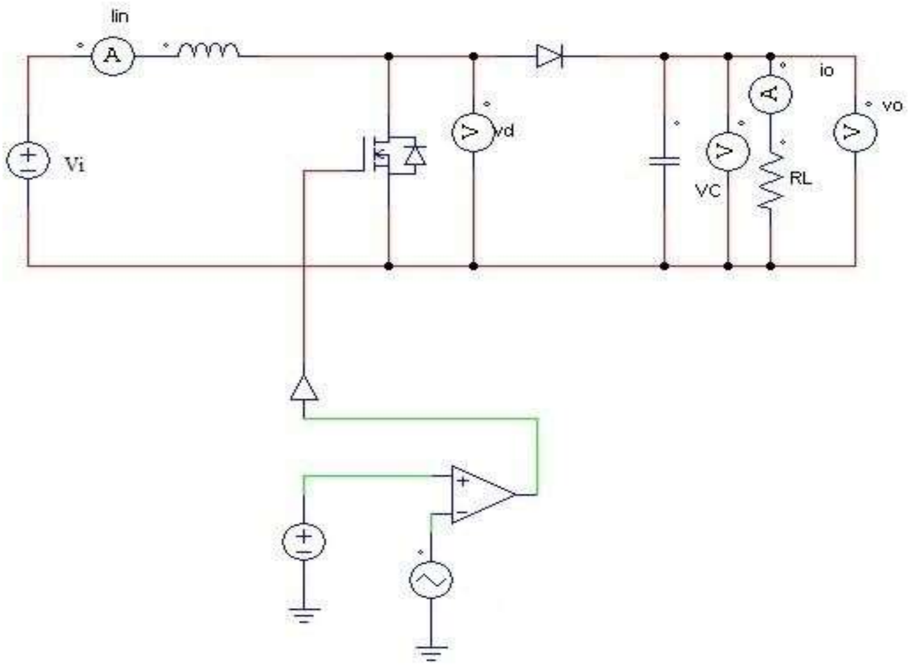


Figure 1: The DC-DC Boost converter. The circuit diagram consist of DC supply (V_{IN}), Inductor in series (L), MOSFET as a switch, Diode (D), Capacitor (C) and Load resistance (R_L). (The simulation is carried out in the PSIM Software Environment)

CHAOS AND BIFURCATION PHENOMENA IN POWER ELECTRONICS

In real-time systems, stability and linearity are two major factors. In a controlled setting, stability is achieved, but this is not possible in real-time operations. Linearity and predictability are also impossible to achieve at every moment. We presume that stable and linear system behaviour is possible under controlled or constant starting conditions, but the question arises when the starting conditions are changed. Chaos has entered the picture in this framework. Chaos is described as an unforeseen event or instability in which a deterministic system generates unpredictable effects when a parameter is changed. When an internal system parameter is changed, the system's behaviour fundamentally alters, which is known as bifurcation [3].

The chaotic impact also affects power electronics. The chaos is caused by switches, feedback, and storage elements like as capacitors, inductors, and memristors, which are both lumped and dispersed [11- 12]. Bifurcation phenomena are classified into two types: smooth bifurcation phenomena and boundary collision bifurcation phenomena. The system stability diminishes without structural change in smooth bifurcation and with structural change in border collision bifurcation [24]. There are several ways for managing chaos in the literature, including slope compensation [25], modulated off-time current mode control technique [26], linear state-feedback control method [27], self-inductor current feedback method [28], and dynamic feedback control method [29].

STUDY OF BIFURCATION PHENOMENA IN BOOST CONVERTER

Poincaré was the first to create bifurcation theory [3]. It explains the qualitative change in system behaviour caused by changing one or more parameters. These system parameters are sometimes referred to as system state variables. State control space refers to the graph of state space variables and controlled variables. Bifurcation points are sites in this state control space where bifurcations occur [3, 13, 30]. The boost converter is essentially a nonlinear system with intricate steady-state behaviour, which is sometimes referred to as chaos [3, 30]. The current through inductor (IL) is used as a state variable in the investigation of the bifurcation of a single stage boost converter. The IREF is thought to be a controlled variable [3, 30]. The pictures below depict the fluctuation of input voltage (VIN) and load resistance (RL), as well as the influence on bifurcation diagrams of a single stage boost converter.

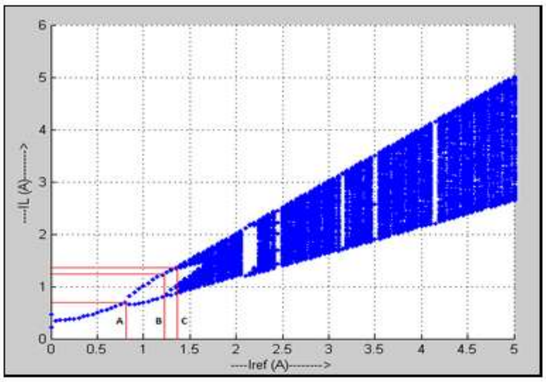
Variation of Input Voltages

In this case the input voltage is varied and other parameters are kept fixed. The detail parameter declaration is depicts in table 1.

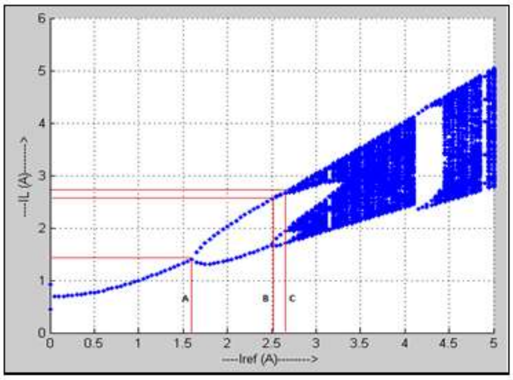
Table 1: Parameter for Case No- 1 (Variation of Input Voltage V_{IN})

Sr. No	Parameter	Values
1.	Inductor (L)	1 mH
2.	Capacitor (C)	5 μF
3.	Load Resistance (RL)	10 Ω
4.	Switching Frequency (F)	10 KHz

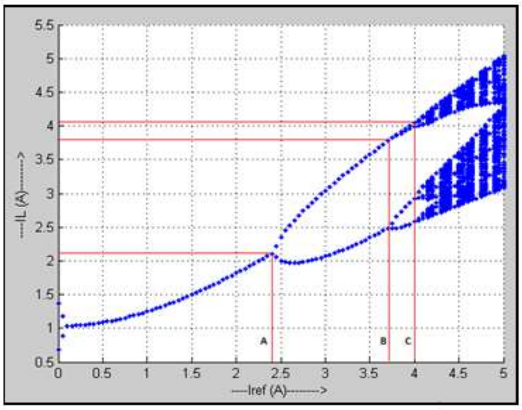
a) V_{IN} = 5 V



b) V_{IN} = 10 V



c) V_{IN} = 15 V



d) V_{IN} = 20 V

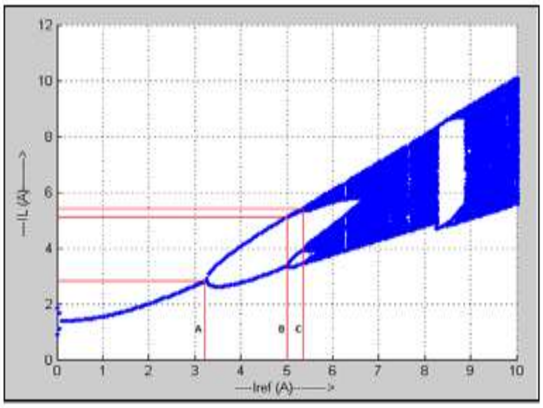


Figure 2 (a, b, c and d): Bifurcation diagram for Inductor Current (IL) with reference current (IREF) as the control Variable. Here the input voltage (VIN) is varied and other parameters are kept fixed. In this case current through inductor (IL) is considered as state variable and the reference current (IREF) is considered as a controlled variable. The graph of IL and IREF is called as state control space. The red solid line in the figure respect to A, B and C represent the period- 1 bifurcation, period- 2 bifurcation and period- 3 bifurcation respectively.

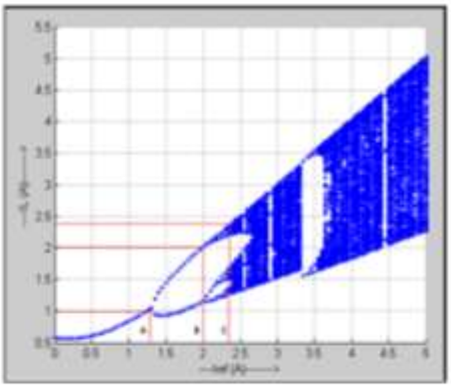
Variation of Load Resistances

In this case the load resistance is varied and other parameters are kept fixed. The detail parameter declaration is depicts in table 2.

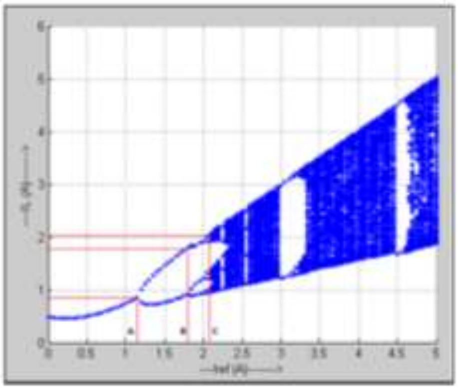
Table 2: Parameter for Case No- 2 (Variation of Load Resistance)

Sr. No	Parameter	Values
1.	Inductor (L)	1 mH
2.	Capacitor (C)	5 µF
3.	Input Voltage (V)	10 V
4.	Switching Frequency (F)	10 KHz

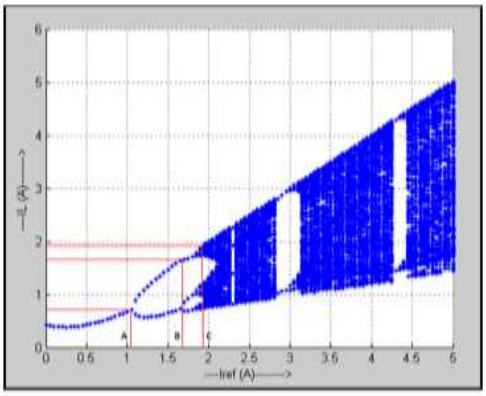
a) RL= 15 Ω



b) RL= 20 Ω



c) RL= 25 Ω



d) RL= 30 Ω

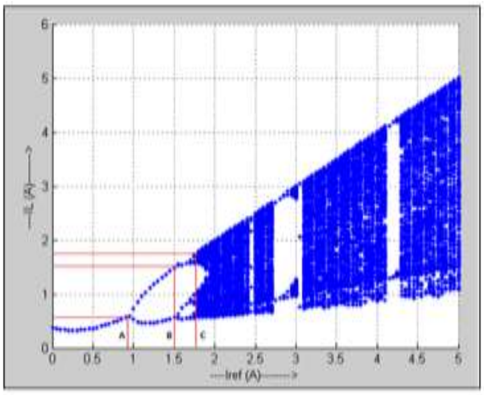


Figure 3 (a, b, c and d): Bifurcation diagram for Inductor Current (IL) with reference current (IREF) as the control Variable. Here the load resistance (RL) is varied and other parameters are kept fixed. In this case current through inductor (IL) is considered as state variable and the reference current (IREF) is considered as a controlled variable. The graph of IL and IREF is called as state control space. The red solid line in the figure respect to A, B and C represent the period- 1 bifurcation, period- 2 bifurcation and period- 3 bifurcation respectively.

ANALYSIS OF NONLINEAR DYNAMICS IN BOOST CONVERTER WITH RESPECT TO PARAMETER VARIATION

The bifurcation diagrams for Inductor Current (IL) as a state variable and IREF as the control variable are shown in Figures 2 and 3 (a, b, c, and d). Figure 2 depicts the influence of supply voltage fluctuations on the bifurcation diagram, whereas Figure 3 depicts the effect of load resistance variations on the bifurcation diagram. The supply voltage (VIN) is adjusted from 5 V to 20 V, and the result is shown in the same figures (fig.2). Load resistance changed from 15 Ω to 30 Ω on the same ground, and the corresponding effect is illustrated in the same figures (fig.3). The red solid lines A, B, and C indicate the period-1, period-2, and period-

3 bifurcations, respectively. As illustrated in fig. 2, as the supply voltage (VIN) rises, the corresponding bifurcation points change in increment order and become chaotic after three bifurcations in each case. According to fig. 3, when load resistance increases, the period- 3 bifurcation point shifts in a decrement pattern. As a result, for the boost converter to operate reliably, the load resistance in the circuit should be as low as possible. Table 3 depicts the numerical connection between period-bifurcation and the related IREF and IL as supply voltage varies (VIN).

Table 3 clearly shows that when the input supply voltage increases from 5V to 20V, the Period- 3 Bifurcation point shifts. The changing of Period-3 Bifurcation points implies a shift in the chaotic behaviour of the boost converter. After the Period-3 bifurcation points, the system becomes unstable or chaotic. These occurrences illustrate the chaotic behaviour of a boost converter in the presence of variable input voltage. Table 4 displays numerical data of period-bifurcation, reference current (IREF), and inductor current (IL) with load resistance changes (RL).

Table 3: Relation between Period-Bifurcation and Corresponding IREF and IL with Variations of Supply Voltage (V_{IN}).

Supply Voltage	Period-Bifurcation	I_{REF} in Amp.	I_L in Amp.
	Period- 1 Bifurcation	0.80	0.70
5 V	Period- 2 Bifurcation	1.25	1.20
	Period- 3 Bifurcation	1.35	1.30
	Period- 1 Bifurcation	1.60	1.50
10 V	Period- 2 Bifurcation	2.50	2.60
	Period- 3 Bifurcation	2.65	2.80
	Period- 1 Bifurcation	2.40	2.20
15 V	Period- 2 Bifurcation	3.70	3.80
	Period- 3 Bifurcation	4.00	4.10
	Period- 1 Bifurcation	3.20	2.90
20 V	Period- 2 Bifurcation	5.00	5.20
	Period- 3 Bifurcation	5.40	5.60

Table 4: Relation between Period-Bifurcation and Corresponding I_{REF} and I_L with Variations of Load Resistance (R_L)

Load Resistance	Period-Bifurcation	I_{REF} in Amp.	I_L in Amp.
	Period- 1 Bifurcation	1.30	1.00
15 Ω	Period- 2 Bifurcation	2.00	2.00
	Period- 3 Bifurcation	2.35	2.40
	Period- 1 Bifurcation	1.15	0.90
20 Ω	Period- 2 Bifurcation	1.70	1.85
	Period- 3 Bifurcation	2.10	2.05
	Period- 1 Bifurcation	1.10	0.80
25 Ω	Period- 2 Bifurcation	1.60	1.80
	Period- 3 Bifurcation	1.90	1.95
	Period- 1 Bifurcation	0.90	0.60
30 Ω	Period- 2 Bifurcation	1.50	1.50
	Period- 3 Bifurcation	1.70	1.80

Table 4 depicts the influence of load resistance variation on period bifurcation (RL). It is discovered that when load resistance increases, the period-bifurcation points shift away from the origin value. The region above the period-3 bifurcation is regarded as a chaotic boost converter zone. In the event of load resistance fluctuation, the region above the period-3 bifurcation is simply handled as an unstable portion of the boost converter.

CONCLUSIONS

This research investigates nonlinear dynamics in boost converters. Figures 2 and 3 clearly show the period-bifurcation diagram and chaotic consequences. Figure 2 (a, b, c, and d) and table 3 clearly show that for steady functioning of any boost converter, the input supply voltage must be high yet within the permitted range. It is also obvious from fig. 3 (a, b, c, and d) and table 4 that the load resistance of any boost converter must be as low as possible for stable functioning. Because the primary concept of the boost converter is to boost the supply voltage, there are certain practical limitations in delivering the supply voltage, but reducing the load resistance to a minimum is the obvious option in terms of stability.

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