BIFURCATION ANALYSIS OF DC-DC CONVERTERS BY USING NON-LINEAR METHODOLOGIES

A PROJECT REPORT

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Bifurcation analysis of dc-dc converters by using non-linear methodologies**" which is submitted by **AVINASH KUMAR**, Roll No's –**2K20/PES/07, Department of Electrical Engineering**, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

Power electronic systems display a variety of complex behaviors in Switched mode DC-DC converters for example rapid adjustments, in the operation, and bifurcation followed by chaotic performance. This unanticipated behavior leads the power electronic converter to action outside the operating regime and oftenly attributed to random external influences, which may causes sensor failure, Electromagnetic interference, reduction of converters efficiency and in the worst situation, a state of loss of control leads to a converter failure. The swiftly growing DC-DC power conversion market wants more cheap operations. To attain this objective, power electronic converters must work reliability in all loading circumstances including border conditions. For the past ten years, these boundary conditions have gotten a lot of attention from scientists. These boundary conditions in power electronic converters, result in various analytical and theoretical approaches. The most intriguing results, on the other hand, are built on mathematical structures that are abstracted, which is it can't be used straightly in the development of effective industrial application systems.

In the thesis, the discrete time analysis method of DC-DC Flyback converters and cuk converters are used to determine the full dynamics of non-linear behavior. The stability of the system can be demonstrated by deriving a state space and discrete iterative mapping which includes complete information about the closed loop control and DC converter parameter. Discrete iterative mapping could be used for additional analysis of stability, under the effects of nonlinear loads, parasitic parameters, and could also be extended to different functional converters. After analyzing the results, some modern control algorithms may develop to ensure the adequate functionality of the converter and to avoid complex behaviors like as rapid and slow-scale bifurcations. The flyback converter and cuk converter are theoretically derived and analyzed experimentally for doublet and chaotic bifurcations.

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d	Duty cycle
A	State matrix
eig	Eigenvalues
B	System matrix
C	Capacitor
D	Diode
f	Switching frequency
g	Mapping Functions
f	Vector field
K_D	Derivative coefficient
K_p	Gain of proportional
K_i	Gain of integral
I_{ref}	Reference current
I_L	Inductor current
I	Identity matrix
L	Inductance
n	Normal form
n	Number of variables
P	Output power
R	Resistance
V_o	Output voltage
R	State space
V_i	Input voltage
S	Switching device
T	One clock switching period
u	External input
V_{con}	Control voltage
Σ	Hyper-surface or switching manifold

List of Symbols

Φ	Fundamental solution matrix
μ	Vector parameters
φ	Flow
x	State vector (State variables)
v_p	output of the integrator
$h = 0$	Switching condition or hyper-surface or switching manifold”

CHAPTER 1

INTRODUCTION

1.1 Detailed background in power electronics

Power electronics and systems is a branch of the use of electronics in the control of, conversion, and transfer of electric power, that is used in static and dynamic equipment. This is used various areas, including transportation, aerospace telecommunications, commercial, residential, and utility applications (Transmission and distribution). This consists of the study of working of solid-state devices and power conversion. After 40 years of research and evolution, Power electronics has evolved to become one of the most important technologies in the world of Electrical engineering. The main reason for Improvements in power semiconductor technology that fueled this evolution is circuit topologies, control approaches, and packaging strategies. In power electronics and systems, power converters are created with the goal of matching the input and output requirements. So, Power converters can convert AC input values to DC output values or vice versa in a controlled manner. They are also built to change DC to AC, AC to AC, and DC to DC as Figure 1.1 illustrates.

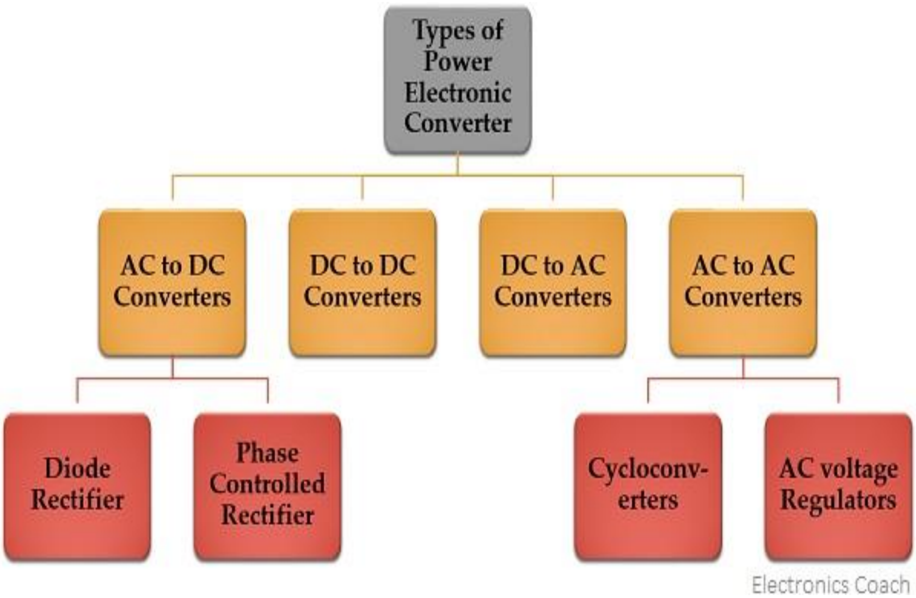

Figure 1.1 Different kinds of power converters

DC-DC power electronic converters are designed to be applied in wide applications, and many of them are created without considering the effect of action if switching. DC-DC power electronic converters are undoubtedly inherent nonlinear and piece-wise smooth systems. This is because they exhibit nonlinearity phenomena such as bifurcation that leads to sub-harmonic harmonics and chaos when any parameter is varied keeping others constant. So, the challenge for engineers and researchers is to keep in mind the effect of these complex behaviors in the process of product design. It is often seen that without complete knowledge of the practical circuit, in practical applications, experience-based trial-and-error processes are used to confirm that the circuits perform in prescribed operating range [1]. So, circuit parameters, components, and circuit designs are varied accordingly to fulfill the given criteria based on the results achieved from previous experience rather than using a methodical design that is suited to methodology.

1.2 Switching Power converters Nonlinear phenomena

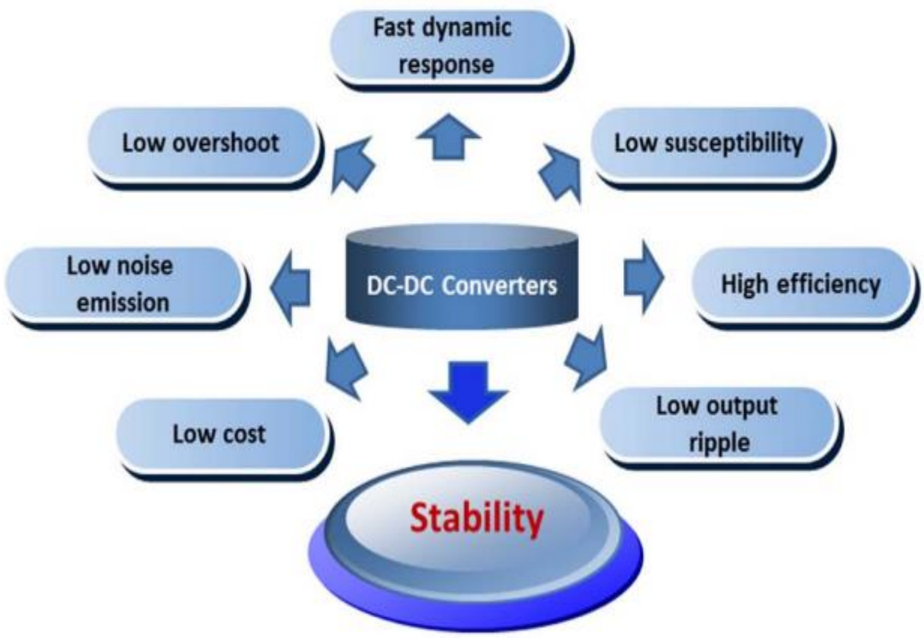

Figure 1.2 Requirements for high-performance power DC-DC converters in general

The requirement of the DC-DC converter is as shown in Fig.1.2. Some of the benefits include low cost, high efficiency, high conversion efficiency, low overshoot, low susceptibility, low output voltage ripple, stability, and debauched dynamic response. The stability of the system is the most crucial among them, as this parameter decides whether a converter can run reliably. The inherent switching conditions cause the converter, to have the steady state point of period oscillation around a predetermined value of the DC-DC converter. When the converter starts operating outside the operating regime such as bifurcation or chaos, the voltage, and current parameters will vary drastically, which causes increases in losses and sufficiency decreases. In addition, this causes an increase in EMI and causes the converter to malfunction or be complete damage to the converter.

A power electronic converter consists of power switches, passive components, diodes, etc. to control the output power of the power electronic converter, the semiconductor switches are utilized to control the electrical power, and they are managed by feedback-controlled circuits. While during the course of the operation of the converter, each of the subintervals of the linear circuit can be used to describe the operation. The power switching circuit makes the converter highly nonlinear which makes it substantially more difficult to solve Analytically. Practically, many powers electronic engineers employ the technique using the background of linear systems theory, for linearizing and averaging to analyse power converters., so discontinuities generated by the circuit's switching operation are ignored. The action of switching is forcefully associated with the system's fast scale stability. Due to an absence of information on the nonlinearities caused by switching, some converter equipment is chosen to ensure the system run but the system's stability is greatly affected, resulting in a bigger, costlier, and less efficient product.

Non-linearities in power electronics circuits have seen significant research attention in recent years. The actual research work in non-linearity and chaos power electronics started approximately in the 1980s. the first person who coined the term bifurcation and chaos in power electronics was *Brockett and Wood* [2] who studied nonlinearity in buck converter. *Hamill et al* [3] then studied nonlinearity further in detail by using a discrete iterative mapping approach [4], in this the buck converter's chaotic operation was studied and verified via simulation. Later, *Krein and Bass* [5] studied in a simple power electronics circuit like the non-linearity and chattering, unboundedness, and chaos. Further investigation of the complex behavior of power electronic converters has been studied by [6,7]. *C.K Tse* [8] further non-linearity in a boost converter operating under a simple feedback loop under the discontinuous mode of conduction. They exhibit a given specific operating condition, a common period doubling approach to chaos. The analytical study of the buck converter dynamics was studied *by Fossas and Olivar* [9], they identified the chaotic attractor topology and investigated the trajectories evolution when nearby to the attractors. *S. Banerjee* [9] studied the co-existing attractors in the voltage control mode of buck converters. The border collisions, rather than typical transitions, cause rapid jumps from periodic solutions to chaos. Bifurcation like period doubling and saddle node were explained by *Di Bernardo* [11,12]. After that many researchers in simple DC-DC converters have continued this work, such as buck [13-15] converters, boost [16-18] converters, Cuk [22-24] converters, parallel converters, and forward converters [25,26]. The, resonant converters [33,34], AC-DC power factor converters [30-32], Inverters [35-37] and interleaved converters [38-40]. In these, a variety of studies have been conducted such as border collisions, attractors, bifurcation, and chaos.

CHAPTER 2

LITERATURE REVIEW

2.1 non-linearity in power switching converters

Figure 2.1 depicts some of the most used DC-DC converter stability study methodologies. These methods are used to investigate and assess the inherent stability of these power electronics. One of the most widely used methods by engineers and inventers to estimate the stability and dynamic behavior of the power electronic converters is the state-space averaging technique [41, 42,27, 28]. In this method, to yield a linear model the steady-state operating point is used to linearize a nonlinear system. The advantage is that it provides a straightforward and realistic model but the disadvantage is that it is slow on a timescale and the prediction of nonlinear fails behavior at a faster timescale. So, Non-linear behaviors can be divided into two categories in general, the slow and the fast timescales. A slow timescale is defined as the dynamic behavior which is significantly sluggish compared to the switching frequency under investigation, whereas a fast timescale is defined as the dynamic behavior the switching frequency was explored. For example, fast timescale instability can be referred as the bifurcation on period-doubling and slow timeframe instability are examples of nonlinear processes which can be referred to as nonlinear behavior such as Hopf bifurcation. The traditional method of averaging was by taking into account the effect of fast-scale dynamics in frequency-dependent averaged models [43]. To recover the standard state-space averaging models, a simulation of dynamic behaviour was done using a multi-frequency averaging technique [44-46]. The frequency selective averaging method [47] was used to manage DC–DC converters using pulse width modulation (PWM). An analysis method supported to extract the ripple components of state variables from the averaged model, the *Krylov-Bogoliubov-Mitropolsky* (KBM) algorithm [48] was devised. However, this method fails to determine the exact chaotic dynamics effectively.

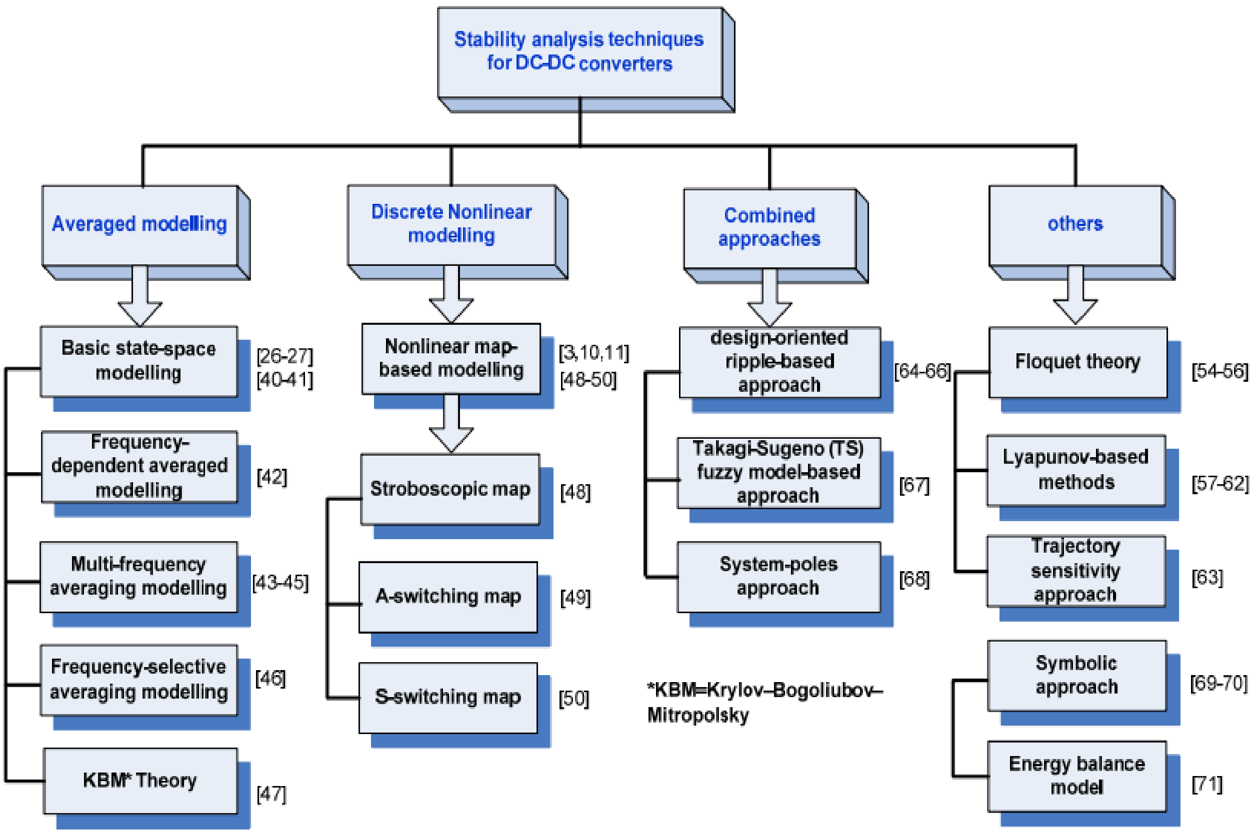

Figure 2.1 Approaches for determining the stability of power switching converters

So, the most extensively used method is discrete nonlinear modeling to address fast-scale nonlinearities. In the early stages, Nonlinear mapping -based modeling [49--51] and a few applications in [4, 11, 12, 35,] which was created using sampling data modeling [52-54] for the investigation of system stability, using an iterative map produced by synchronously sampling the state variables of the converter with clock signals generated by PWM. For the investigation of system stability, using an iterative map a method is produced called the Poincaré map approach and the resulting maps are classed as stroboscopic, S-switching, and A-switching maps on the basis of to the different sampling moments. The eigenvalues are used to find the Stability and are indicated by the Jacobian map's fixed point Because of the transcendental structure of the system's equations, the map itself cannot always be derived in closed form as a result, so the map must be calculated numerically. For the nonlinear analysis of power converters, other methods such as Lyapunov-based methods [58-63], Floquet theory [18, 55-57] and the trajectory sensitivity.

technique [64] have both been successfully implemented. In Floquet theory, the development of perturbation is investigated directly to forecast system stability by calculating the absolute value of the complete cycle solution matrices of eigenvalue. Piecewise-linear Lyapunov functions are searched for and created in Lyapunov-based approaches to define system stability. Systems are linearized around a nominal trajectory rather than an equilibrium 6 points in the sensitivity approach, and stability can be established by watching the change in a trajectory due to tiny initial or parameter perturbations. State-space averaging and discrete modeling has also been merged in some approaches. The design-oriented ripple-based technique [65-67], and the system-poles approach [69] ,fuzzy model-based approach by the *Takagi–Sugeno* (TS) [68] are examples of these methodologies. Other individual methods, such as the symbolic approach [70, 71] and the energy balance model [72], have been developed to assess the nonlinearities of switching power converters in addition to the aforementioned approaches. Some of the ideas described have been detailed in a recent review study on stability analysis methods for switching mode power converters [73].

2.2 Non-linear control methods in power switching converters

To deal with nonlinear phenomena, many control strategies are proposed, which are based on the approaches as shown in Figure 2.2. These can be divided into two types. types: feedback and non-feedback-based techniques. A small time-dependent perturbation is made to transition the system from unstable periodic orbits (UPOs) to targeted periodic orbits in order to achieve stable control The *Ott-Grebogi-Yorke* (OGY) strategy, developed by *Ott et al* [74], was the first chaos control method that was used. This strategy has the advantage of being simple and it is simpler to execute and does not require experience analytical and detailed understanding of system dynamics. An extended delay feedback control technique was proposed by *Pyragas* [58, 75] to stabilize the UPOs in dynamical systems with a large parameter domain, and some others were also proposed [76, 77]. For the first time, the buck converter's time-delay stabilization technique by *Batlle et al* [78] was introduced. Then, in the realm of nonlinear dynamics, to stabilize UPOs, the linear Time Delayed Feedback Control (TDFC) method, or alternative chaos controlling approach, was proposed. In this approach to create a stabilization control signals algorithm, the present state and the previous one-period state are used. Washout filter-aided feedback control advantages and disadvantages have been summarized in [89]. In some of the filter-based noninvasive, there have also been suggestions for controlling chaos in power converters [15, 90, 91]. Some of the new methods were developed by combining approaches from the state-space averaging technique and discrete time modeling like the System-poles technique [59], *Takagi–Sugeno* (TS) fuzzy model-based approach [68], and design-oriented ripple-based approach [56-59]. Other methods like the It has been recommended that a symbolic method [70, 71] and an energy balance model [72] be used to analyze the Switching power electronic converter nonlinearities

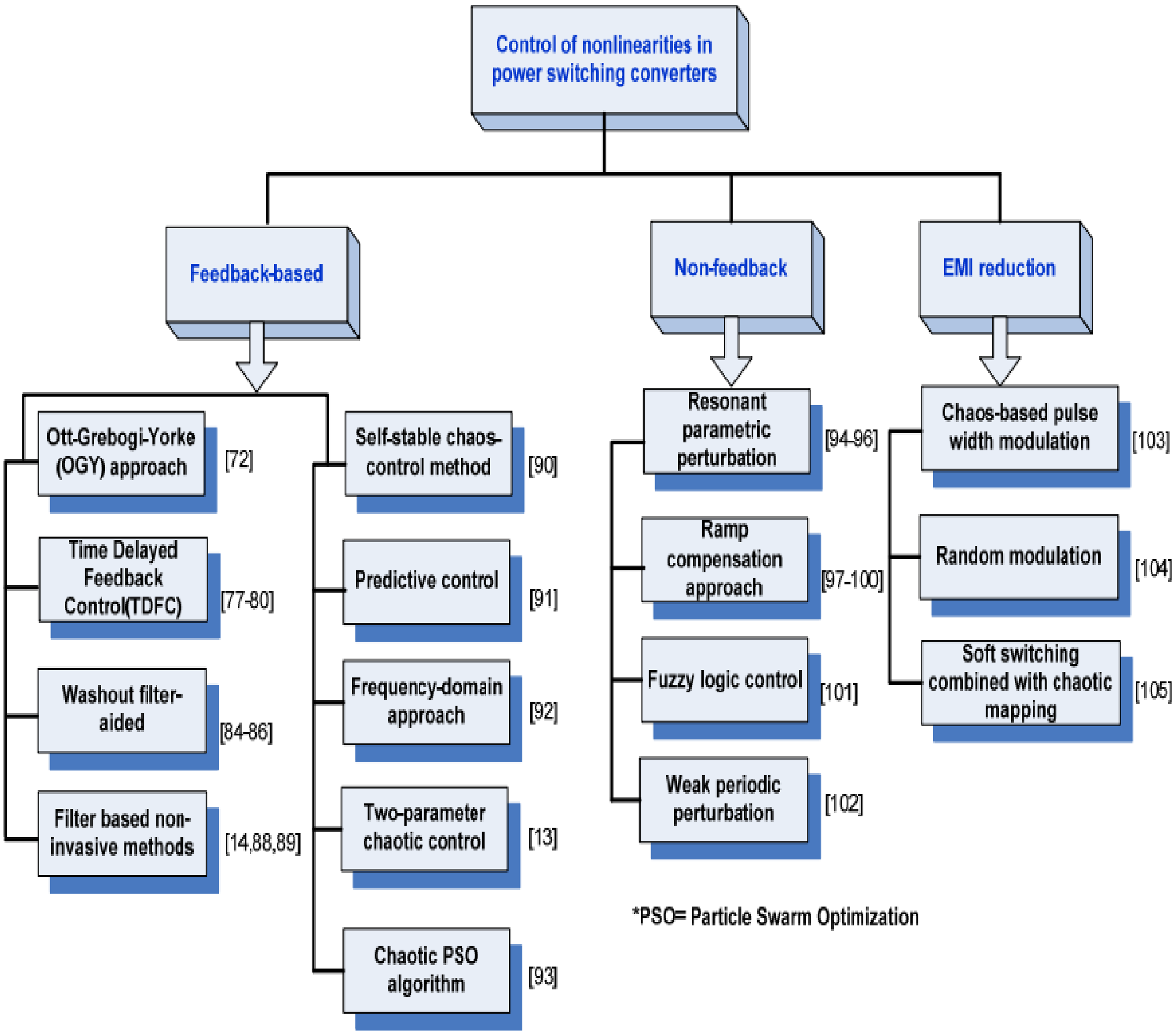

Figure 2.2 Non-linear techniques of control in switching power converters

2.3 thesis organization

The bifurcation and chaotic phenomena are very common in power electronics circuits and systems. In power electronics and systems, whenever any one of the parameters selected either input, output, load, etc. are changed, the system produces nonlinear behaviors, such as coexisting attractors, Hopf bifurcation, period-doubling bifurcation, and collision of boundary. The research in power electronics and systems when it comes to bifurcation behavior has already matured till now. Much research has been done to report various bifurcation behaviors. They have concluded many theoretical parameters that cause bifurcation and the side effects of bifurcation. In recent decade, research papers have concentrated to find suitable employment of the complex behavior existing in power electronics in the area of power electronics and systems for industrial applications. One of my research interests is to use methodology to reduce the phenomena of bifurcation behavior of devices used practically in power electronic and systems. The one of the most detailed bifurcation outcomes behaviors can be calculated by the abstract mathematical forms, which definitely cannot be applied directly on to the designing of the industrial systems with practical applications. That is why, the relatively more practically design-oriented approaches need to have experimented with in future study and research work. This thesis describes feedback control system details and stability analysis of expeditious nonlinear on time frame or timescale deportment in DC-DC power electronic switching converters, which is aiming to increment the cognizance of nonlinear modeling and reduce the gaps in practical application and research theoretically. The method of nonlinear analysis predicated on the Iterative mapping matrix is used. This research allows for a more thorough understanding of boundary operation conditions. It avails in the development of incipient control approaches that can be used to solve concerns of instability. This design-oriented strategy also offers an option for utilizable from the standpoint of design concept expeditious scale.

Chapter 1 discussed about the Detailed background in power electronics in which different types converters in which bifurcation can be observed.

Chapter 2 discussed non-linearity in power switching converters which tells about the types of non-linearity occurs in power converters.

Chapter 3 gives an overview of nonlinear dynamical analysis in general.

Chapter 4 and chapter 5 is the detailed discussion on flyback and cuk converter bifurcations.

CHAPTER 3

METHODOLOGY

3.1 Overview of power switching converter nonlinear dynamical analysis

In this section the general and an overview of background knowledge of power electronics systems, including methods of description in modeling strategies and dynamical systems. Stability analysis methods and approaches predicated on periodicity and equilibrium points solutions are discussed, with a focus on, the discrete iterative map derivation and steady state matrix. Moreover, the characterization of systems in terms of some quantifiable basis and nonlinear system comportment are discussed at the cessation of this chapter.

3.2 Details of switching power converters

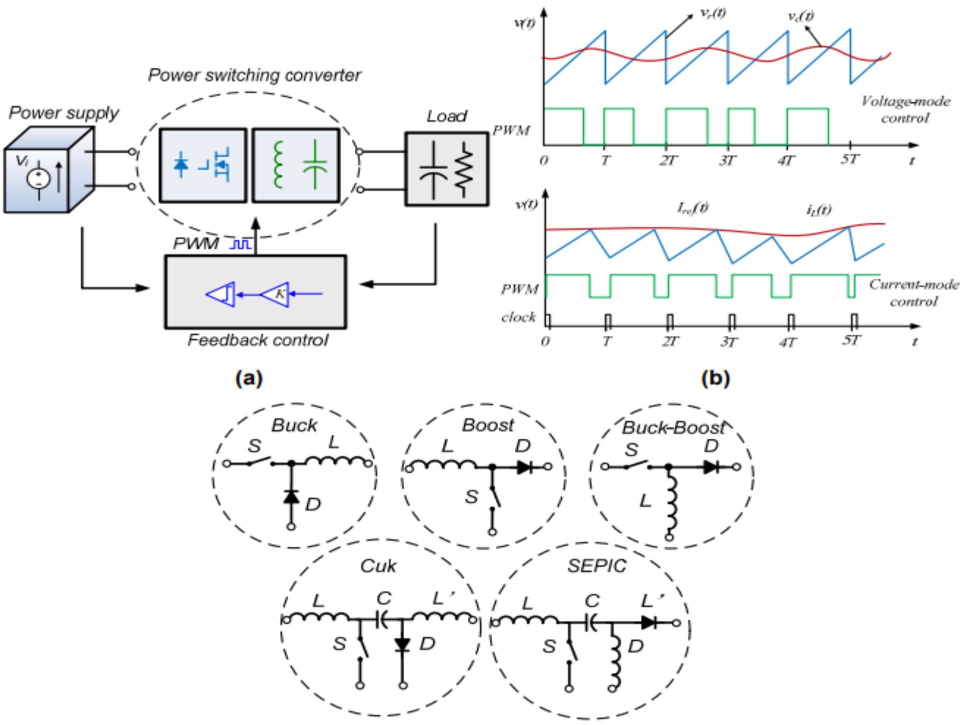

Fig 3.1 (a) Typical non-isolated DC-DC power switching converters (b) Voltage-mode scheme and current-mode scheme control (c) Diagram of a power electronic converter system

Power electronics converters contain diodes, power switches, and energy storing elements such as, capacitors, inductors, etc. they are used to control the varied loads with electricity and power with different techniques. Power electronics circuits mostly operate via toggling in between among different sets of topologies because of the switching function. Different controls can be employed such as voltage-mode scheme or current-mode control scheme shown in Figure 3.1 algorithm are used to maintain control the output power of the circuit and desired output can be obtained. A schematic diagram of a power electronic converter system can be seen in Figure 3.1 (a); and the different DC-DC power switching converter topologies, including buck (for low voltage), boost (for high voltage), buck-boost (for low and high), Cuk for low and high), and SEPIC (for low and high) converters, are shown in Figure 3.1 (c). In power electronic converters all the parameters such as capacitor voltages, inductor currents, and other time-dependent characteristics can all be expressed in the form of state space equations. External clock signals of definite periods in power electronics are required for pulse width modulation (PWM) it is essential. and systems. The state variables then became the switching frequency's purposes; So Non-autonomous dynamical systems make up the majority of power electronics systems.

3.3 Modeling of power electronic switching converters

Power electronic systems are modeled as linear equations and are used to approximate linear systems. Therefore, automatic the use control system for analysis, theory might be used for the systems.

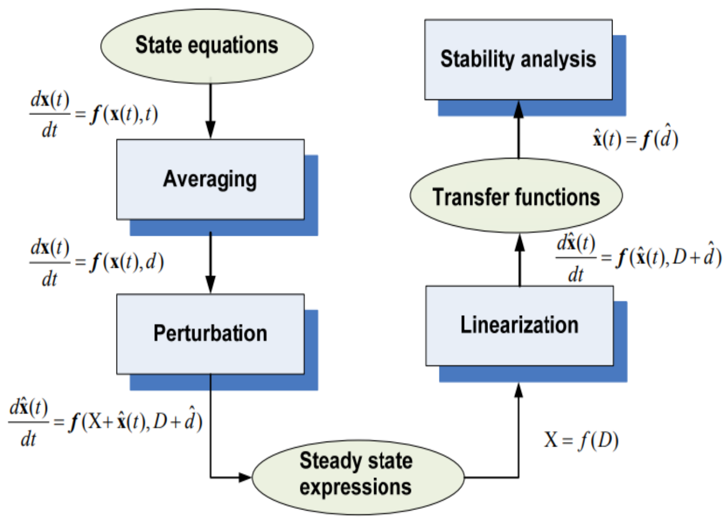

Figure 3.2 The state-space averaging approach's procedural scheme

The procedure for calculating the state space diagram is given in the above figure 3.2. The state equations can be obtained by steady state expressions via averaging and perturbations. In order to generate the transfer functions, the system is forced to linearize at this steady-state operation point. This also represents the small signal behavior of the system. since the system is linearized the stability of the system can be calculated by using frequency domain analysis which is the Bode plot and root locus in which we calculate the phase and magnitude plot and vary the open loop gain k respectively. But practically the systems are nonlinear in nature so the direct equations cannot be derived and have to follow nonlinear analysis mostly called mapping which is very complicated. By making the system linear the calculation of mathematics becomes very easy but, we lost the important information about nonlinearity which happen mostly due to approximations of the high power and exponentials. In power electronics converters, power switching devices such as MOSFETs, diodes, inductors, high-frequency transformers, feedback gain, and nonlinear components are the main source of nonlinearity [111]. The turn ON and turn of the power semiconductor switches are dependent on the response of the feedback signal, which then depends upon the state variables of the converters. the diodes operating in the semiconductor devices are highly nonlinear due to their V-I characteristics. The transformers, inductors, and choke coils also introduce high nonlinearity because of their saturation tendency. the OP AMPS, comparators, and digital controllers are therefore also highly non-linear components that produce further problems of nonlinearity. A continuous-time dynamical system is described by a differential equation. is as follows.

$$\dot{x} = \frac{dx(t)}{dt} = f(x(t), \mu, t) \qquad (3.1)$$

Where $x(t) = (x_1 , x_2, x_{3,} x_{3....} x_n)^T$ are known to be the system variables, $f = (f_1 , f_2, f_{3,} f_{4....} x_n)^T$ are called the connecting functions; and μ is called the vector of parameters. In the condition initially, $x(t_o) = x_o$ the dynamical system $x(t) = \emptyset(x_o, t)$ can produce the vector field of an n-dimension flow of, which can be the solution of the system. The generic solution's differential equation of power electronic converter can be written and is as follows:

$$x(t) = \emptyset(x_o, t)\, x(t_o) \qquad (3.2)$$

Where the fundamental solution matrix is the Φ( ). this describes how the system variables evolve and how it is tied to the initial circumstances. The following statement can be used to represent the relationship between the system state and discrete time for a discrete-time dynamical system:

$$x(n+1) = g(x(n), n) \tag{3.3}$$

where x(n) = $(x_{1n}, x_{2n}, x_{3n}, x_{4n} \ldots\ldots x_{mn})$ is representing a state variable at any time of tn where (n=1,2, K) and function g = $(g_1, g_2, g_3, g_4)^T$ is the mapping of the between the current state x(n) and the next following state x(n+1).

3.4 The equilibrium points solution's stability

The dynamical system stability is studied near to a point of equilibrium point as per Lyapunov's stability theory [110]. In mathematics, this is the constant solution as per differential equations of the system. A system's dynamical behavior of a power electronic system is inspected by iterating via computer simulations and the trajectory of the variables according to equation, vary from beginning conditions below. The linear system could be expressed in the following form as given below:

$$\dot{x} = A\,X + B\,E \tag{3.4}$$

where A and B are matrices that change over time or time dependent which is directly E represents the system's external input, and A represents the system's internal parameters. Whenever the magnitude of x becomes equal to zero, the system can be said to be in equilibrium, and the points are also known as fixed points or equilibrium points. From the equations above, the term B E tends to shift the current position to the points of equilibrium, as can be seen. The state matrix A ensures the equilibrium points' stability and also these points are determined for the same, that is, the eigenvalues and eigenvector of matrix Aare the key parameters to determine the stability of the system. The eigenvalues could be determined by equating the below given questions:

$$|\,A\,I - \lambda\,| = 0 \tag{3.5}$$

Since nonlinear systems have several equilibrium points, there can be more than one as the behavior of the vector field as different parts of the state space may be displayed differently. The notion of modest perturbation injection is used to investigate the stability of a nonlinear system. Specifically, the system is When the trajectory converges after a modest disturbance to the initial system, it is stable. By linearization near the fixed points, the system's local characteristics can be investigated.

3.5 dynamical systems characterization

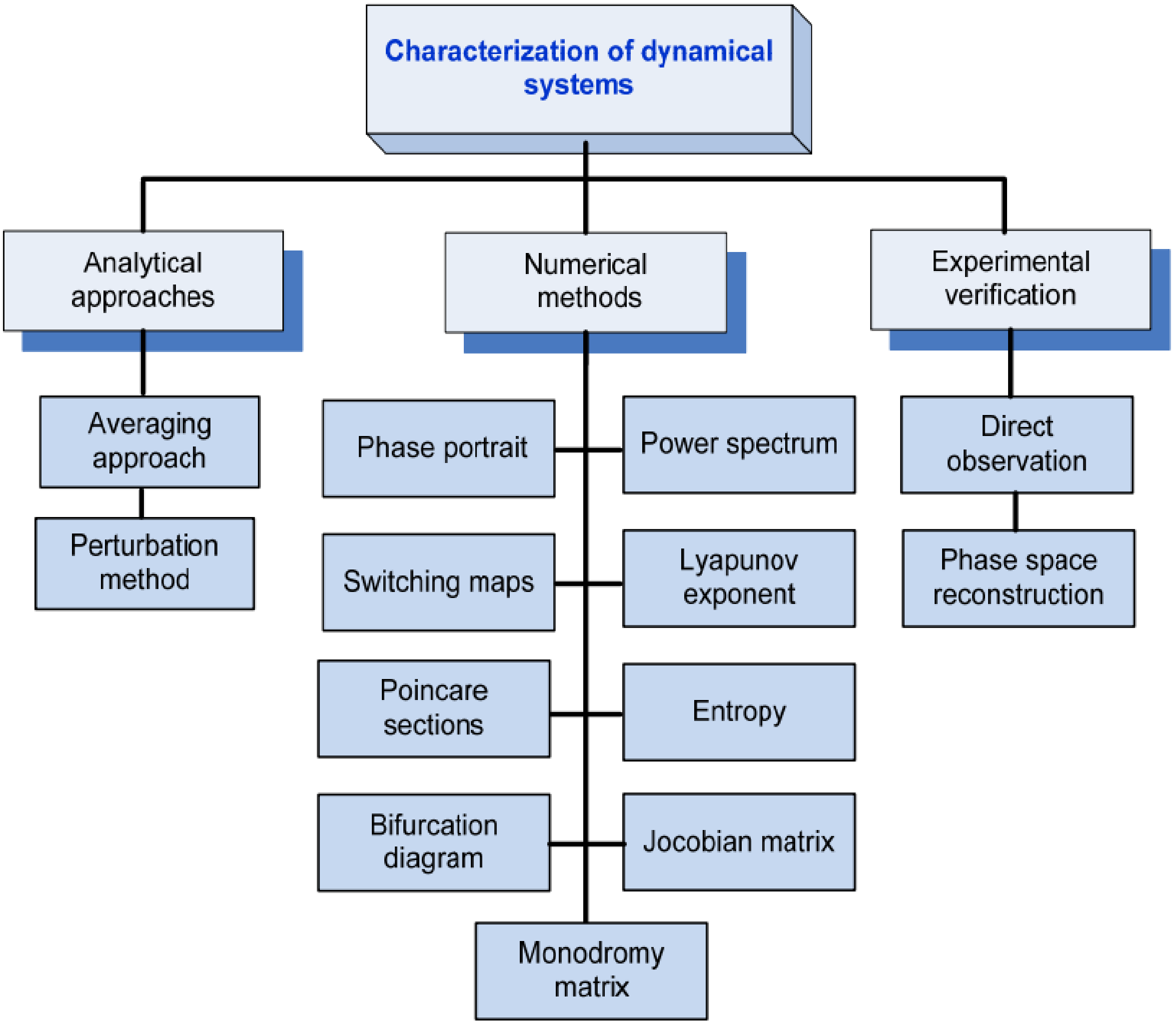

Figure 3.3 Typical characterization of dynamical system

The differential equations which are obtained by discrete iterative mapping for all continuous and discrete time operations of power electronics converters can be solved. by different analytical or numerical method technique. MATLAB or MATHEMATICA tools are mainly used for in the method of numerical nonlinear analysis, which explains how power converters work in terms of numbers of steady state equations. These are very powerful and effective methods that are used in displaying and researching nonlinearity behavior of the power electronic converters. Settings of the simulations also affect the results. Hence, experiments are also needed to verify the simulation results. However, in practical circuits the need of solving the complexity in the modelling process results in the assumptions and some approximations, which can diminish accuracy. Therefore, in the analysis of practical implementation of power converters both methods are normally used. The various Figure summarizes the techniques of analytical, numerical, and experimental approaches. The above figure 3.3 explanation focuses on the numerical approaches' and quantifiable features.

3.6 Capture and selection of complex behavior

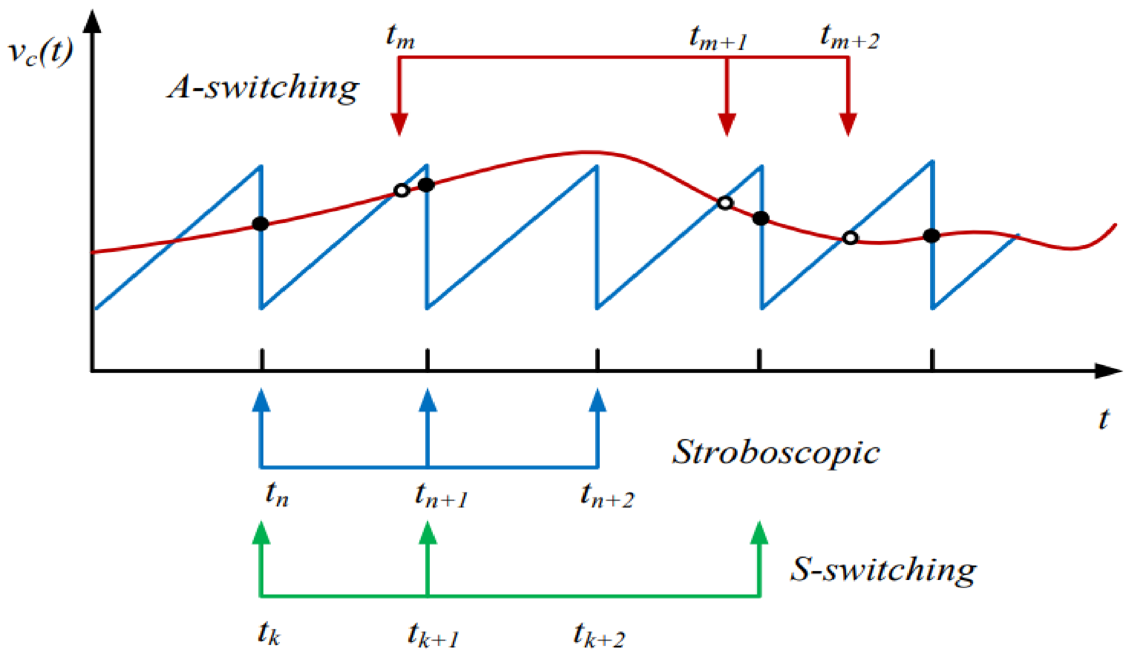

Figure 3.4 Under voltage-mode control, different sampling modes for sampled-data maps

To characterize a dynamic system, we mostly use switching maps technique. They are commonly used in stability analysis. Depending on the different sampling including stroboscopic maps, A-switching, S-switching, and, according to events as shown in Figure 3.4

[50]. The exact patterns of maps can be constructed by sampling the state at time instants. They exhibit the system's behavior under different sampling modes. In the periodically driven systems to indicate that the waveform is periodic the sampled data should remain at a constant value, and its period should be the same length as the sampling period. If the phase portrait is a geometric representation of the equilibrium solution for a dynamical system, the system may be in a quasi-periodic or chaotic state. shows no clear repetition. It refers to the projection of a trajectory from a higher order dimension to a two-dimensional phase plan in particular. Phase portraits, Poincaré parts and switching maps generally used formats for displaying system properties with fixed parameters. The bifurcation diagram is a type of graphical representation method for a system generally used to study the nonlinear phenomena with varying parameters. In this type of approach parameter is chosen and varied and this is plotted along one of the axes keeping others constant. The state variables are sampled then plotted and shown on the other axis as discrete points. The system is in period-1 if there is only one point corresponding to that parameter; period-2 if there are two points; chaotic if there are a large number of points that can be observed in response to the variation of that parameter. Figure 3.5 shows an example of a bifurcation diagram.

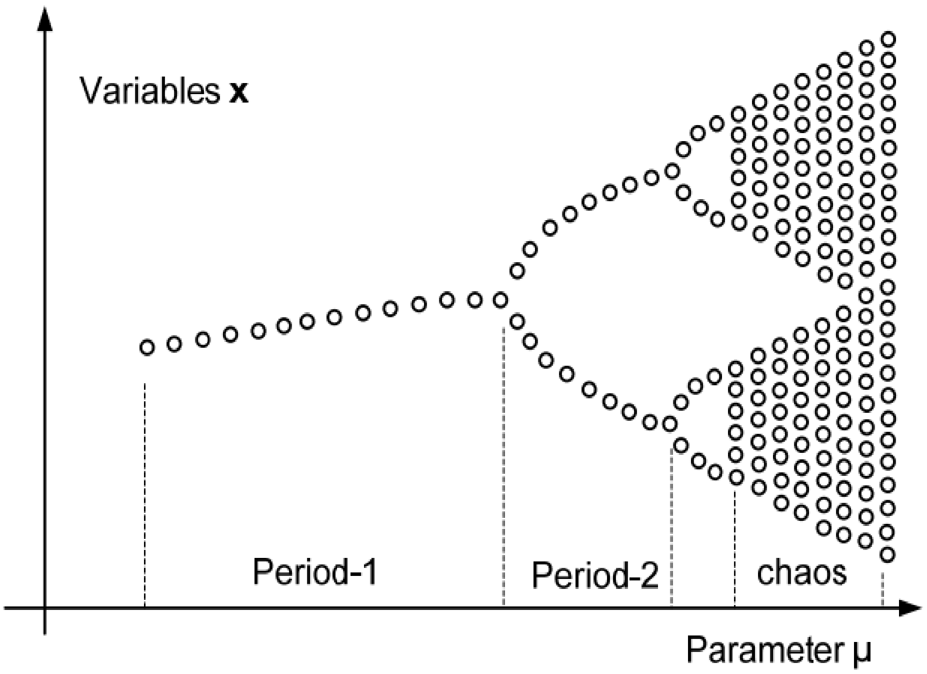

Figure 3.5 Diagram of a bifurcation plot

CHAPTER 4

4.1 Bifurcation analysis of cuk converter

This section discusses the nonlinear study and single-phase DC-DC control of cuk converters with simple resistance load. The theoretical analysis starts from a simple closed loop cuk converter with peak current control, which exhibits the typical nonlinear phenomena in operation. The transition's full derivation and discrete iterative mapping that contains complete information that is used to determine the system's stability. Finally, control the nonlinearity of the system to increase or improve the performance behavior, a new control algorithm can be developed and extending the region of stable operation.

4.2 Discrete iterative mapping of cuk converter

The parasitic elements have been neglected for the sake of easiness in calculation. In this section, some advanced algorithms have been derived to study complex behavior. The schematic diagram for cuk converter is as shown in Figure. 4.1.

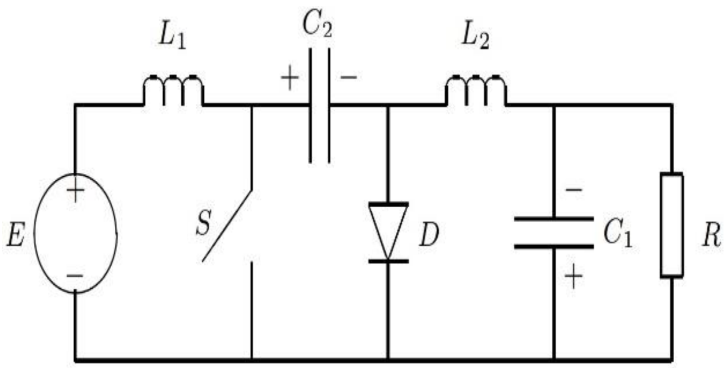

Fig.4.1 cuk converter schematic diagram

The state space equation for the cuk converter can be written as:

$$\dot{x} = A_1 X + B_1 E \text{ for } t_n \leq t < t_n + dT \quad (1)$$
$$\dot{x} = A_2 X + B_2 E \text{ for } t_n + dT \leq t < t_{n+1} \quad (2)$$

Where,

$$A_1 = \begin{bmatrix} \frac{-1}{RC_2} & 0 & \frac{1}{C_2} & 0 \\ 0 & 0 & \frac{-1}{C_1} & 0 \\ \frac{-1}{L_2} & \frac{1}{L_1} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} \frac{-1}{RC_2} & 0 & \frac{1}{C_2} & 0 \\ 0 & 0 & 0 & \frac{1}{C_1} \\ \frac{-1}{L_2} & 0 & 0 & 0 \\ 0 & \frac{-1}{L_1} & 0 & 0 \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{L_1} \end{bmatrix} B_2 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{L_1} \end{bmatrix} X = \begin{bmatrix} V_{c1} \\ V_{c2} \\ I_{L1} \\ I_{L2} \end{bmatrix}$$

and $t_{n+1} = t_n + T$

We have assumed C1 = C2 = C and L1 = L2 = L, to reduce the complexity of the differential equations. To calculate the general solutions for the switch on interval, the RHS of (2) can be integrated and substituted with t = $t_n{}'$. After substituting, this gives the end value of switch ON interval.'

$$V_{C1}(t_{n'}) = e^{\frac{-1}{RC_2}}\left(\frac{I_{L1}}{C_2}\right) + e^{\frac{-1}{RC_2}} V_{C1}(t_n) \tag{3}$$

$$V_{C2}(t_{n'}) = \frac{-I_{L1}}{C_1}(t - t_n) + V_{C2}(t_n) \tag{4}$$

$$I_{L1}(t_n') = \frac{t}{L} - \frac{t_n}{L} + I_L(t_n) \tag{5}$$

$$I_{L2}(t_n') = \frac{t - t_n}{L} + I_L(t_n) \tag{6}$$

Where, V_{C1}, V_{C2}, $I_{L1,}$ and I_{L2} are voltages across C_1, C_2, L_1 and L_2 respectively. To calculate the solution for the switch-off interval, apply the Laplace transformation to

$$\mathbf{X(s)} = [\mathbf{SI} - A_2]^{-1}\ [\mathbf{x}\ (t'_n) + B_2\mathbf{E(s)}] \tag{7}$$

$$\begin{bmatrix} V_{C1}(s) \\ V_{C2}(s) \\ I_{L1}(S) \\ I_{L2}(S) \end{bmatrix} = \frac{1}{H(S)} \begin{bmatrix} 0 & 0 & \frac{1}{L^2} - \frac{1}{LC} + \frac{1}{L^2C} & 0 \\ 0 & 0 & 0 & \frac{1}{L^2C} \\ \frac{-1}{LC^2} & 0 & \frac{-1}{LC}(s + \frac{1}{RC}) & 0 \\ 0 & \frac{-1}{LC^2} & 0 & 0 \end{bmatrix} \begin{bmatrix} V_{C1}(t_{n'}) \\ V_{C2}(t_{n'}) \\ I_{L1}(t'_n) \\ I_{L2}(t'_n) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{L} \end{bmatrix} \mathbf{E}(s)$$

Where,

$$V_{C1}(s) = \left(\frac{\frac{1}{L^2} - \frac{1}{LC} + \frac{1}{L^2C}}{H(s)} \right) I_{L1}(t'_n) \tag{8}$$

$$V_{C2}(s) = \frac{1}{L^2C} \left(\frac{I_{L2}(t'_n)}{H(s)} \right) + \frac{E(s)}{L} \tag{9}$$

$$I_{L1}(S) = \frac{-V_{C1}(t'_n)}{LC^2} - \frac{I_{L1}(t'_n)}{LC} \left(S + \frac{1}{RC} \right) \tag{10}$$

$$I_{L2}(S) = \frac{-V_{C2}(t'_n)}{LC_2} \tag{11}$$

On taking the inverse of the laplace of the above equations 8,9,10 and 11 and equate it with 3,4,5 and 6, the resultant equations are highly complex to simulate. By taking successive approximations, putting $t_c = d_n T$ and $t_d = (1-d)T$ and ignoring the higher degree polynomial, the final matrix is as follows

$$\begin{bmatrix} v_{c1(n+1)} \\ v_{c2(n+1)} \\ v_{c3(n+1)} \\ v_{c4(n+1)} \end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} & f_{13} & f_{14} \\ f_{21} & f_{22} & f_{23} & f_{24} \\ f_{31} & f_{32} & f_{33} & f_{34} \\ f_{41} & f_{42} & f_{43} & f_{44} \end{bmatrix} \begin{bmatrix} v_{c1(n)} \\ v_{c2(n)} \\ v_{c3(n)} \\ v_{c4(n)} \end{bmatrix} + \begin{bmatrix} g_{1(d_n)} \\ g_{2(d_n)} \\ g_{3(d_n)} \\ g_{4(d_n)} \end{bmatrix} E$$

$$f_{11} = \left[1 - \frac{t_d}{RC} + \frac{t^2{}_d}{2}\left(\frac{1}{C^2R^2} - \frac{1}{LC}\right)\right]\left[1 - \frac{t_c}{RC} + \frac{t_c{}^2}{2}\left(\frac{1}{R^2C^2} + \frac{1}{LC}\right)\right] + \left(\frac{t_d}{C} - \frac{t_d{}^2}{2C^2R}\right)\left(\frac{-t_c}{C} + \frac{t_c{}^2}{2RLC}\right) \tag{12}$$

$$f_{12} = \left[1 - \frac{t_d}{RC} + \frac{t_d^2}{2}\left(\frac{1}{C^2R^2} - \frac{1}{LC}\right)\right]\frac{t_c^2}{2LC} + \left(\frac{t_d}{C} - \frac{t_d^2}{2c^2R}\right)\frac{t_c}{L} \tag{13}$$

$$f_{13} = \left[1 - \frac{t_d}{RC} + t_d^2\left(\frac{1}{C^2R^2} - \frac{1}{LC}\right)\left(\frac{t_c}{C} - \frac{t_c^2}{2C^2R}\right) + \left(\frac{t_d}{C} - \frac{t_d^2}{2C^2R}\right)\left(1 - \frac{t_c^2}{LC}\right)\right] \tag{14}$$

$$f_{14} = 0 \tag{15}$$

$$f_{21} = \left(1 - \frac{t_d^2}{2LC}\right)\left(\frac{t_c^2}{2LC}\right) \tag{16}$$

$$\boldsymbol{f_{22} = \left(1 - \frac{t_d^2}{2LC}\right)\left(1 - \frac{t_d^2}{2LC}\right)} \tag{17}$$

$$\boldsymbol{f_{23} = (1\text{-} \frac{t_d^2}{2LC})\ (\frac{-t_c}{C})} \tag{18}$$

$$\boldsymbol{f_{24} = \frac{t_d}{C}} \tag{19}$$

$$\mathbf{f_{31} = \left(\frac{-t_d}{L} + \frac{t_d^2}{2LCR}\right)\left[1 - \frac{t_c}{RC} + \frac{t_c^2}{2}\left(\frac{1}{C^2R^2} + \frac{d1}{LC}\right)\right] + \left(1 - \frac{t_d^2}{LC}\right)\left(\frac{-t_c}{C} + \frac{t_c^2}{2LCR}\right)} \tag{20}$$

$$\boldsymbol{f_{32} = \left(\frac{-t_d}{L} + \frac{t_d^2}{2LRC}\right)\frac{t_c^2}{2LC} + \left(1 - \frac{t_d^2}{LC}\right)(1 - \frac{t_c^2}{LC})} \tag{21}$$

$$\boldsymbol{f_{33} = \left(\frac{-t_d}{L} + \frac{t_d^2}{2LRC}\right)\left(\frac{t_c}{C} - \frac{t_c^2}{2C^2R}\right) + \left(1 - \frac{t_d^2}{LC}\right)\left(1 - \frac{t_c^2}{LC}\right)} \tag{22}$$

$$\boldsymbol{f_{34} = 0} \tag{23}$$

$$\boldsymbol{f_{41} = \left(\frac{-t_d}{L}\right)\left(\frac{t_c^2}{2LC}\right)} \tag{24}$$

$$\boldsymbol{f_{42} = (\frac{-t_d}{L})(1\text{-}\frac{-t_c^2}{2LC})} \tag{25}$$

$$\boldsymbol{f_{43} = \left(\frac{-t_d}{L}\right)\left(1 - \frac{-t_c}{C}\right)} \tag{26}$$

$$\boldsymbol{f_{44} = 1 - \frac{t_d^2}{2LC}} \tag{27}$$

$$\boldsymbol{g_1 = 0} \tag{28}$$

$$\boldsymbol{g_2 = \left(1 - \frac{t_d^2}{2LC}\right)\left(\frac{-t_d^2}{2LC}\right) + \frac{t_d^2}{LC}\left(1 - \frac{t_c^2}{LC}\right)} \tag{29}$$

$$\boldsymbol{g_3 = 0} \tag{30}$$

$$\boldsymbol{g_4 = \frac{-t_d^2}{L}\left(1 - \frac{t_d^2}{2LC}\right) - \frac{t_d}{L}\left(\frac{-t_d^2}{2LC}\right) + \frac{t_c}{L}\left(1 - \frac{t_d^2}{2LC}\right)} \tag{31}$$

4.3 Feedback control loop for cuk converter

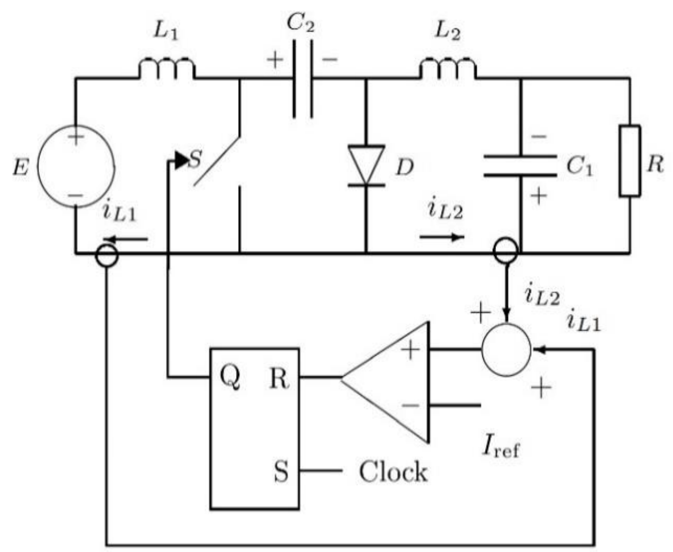

Fig.4.2 Current mode control of cuk converter

The cuk converter can be controlled in a number of ways. In this paper current mode control scheme was used to control output voltage as shown in figure 4.2. the advantage is that it has more reliability with, output short circuit and overload protection using fast cycle current sensing. So, a better study on transient can be done in current mode control. The equation for the feedback can be derived by observing the wave of open loop cuk converter in Figure 4.3.

$$I_{ref} - (i_{L1,n} - i_{L2,n}) = \left[\frac{E}{L_1} + \frac{v_{C2,n} - v_{C1,n}}{L_2}\right] d_n \quad (32)$$

$$d_n = \frac{I_{ref} - (i_{L1,n} - i_{L2,n})}{\left[\frac{E}{L_1} + \frac{v_{C2,n} - v_{C1,n}}{L_2}\right] T} \quad (33)$$

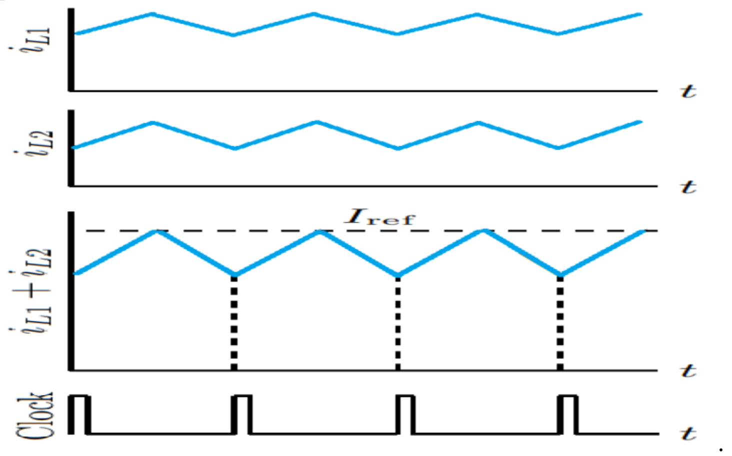

Fig.4.3 Current control cuk converter wave forms

4.4 BIFURCATION DIAGRAMS AND PHASE POTRAITS

The bifurcation diagram is plotted to know the maximum and minimum boundary conditions in which the converter can operate safely. It is also the graphical representation from which bifurcation can be studied. For this the computer simulations are an excellent way to determine the chaotic behavior. In the computer simulation any one parameter is varied keeping others as constant.

Table I. equipment values

PARAMETERS	VALUES
Switching period T	200 us
Inductance L1 and L2	16 mH
Capacitance C1 and C2	47 uF
Load resistance R	75 ohms
Input voltage E	5 V

Bifurcation w.r.t reference current

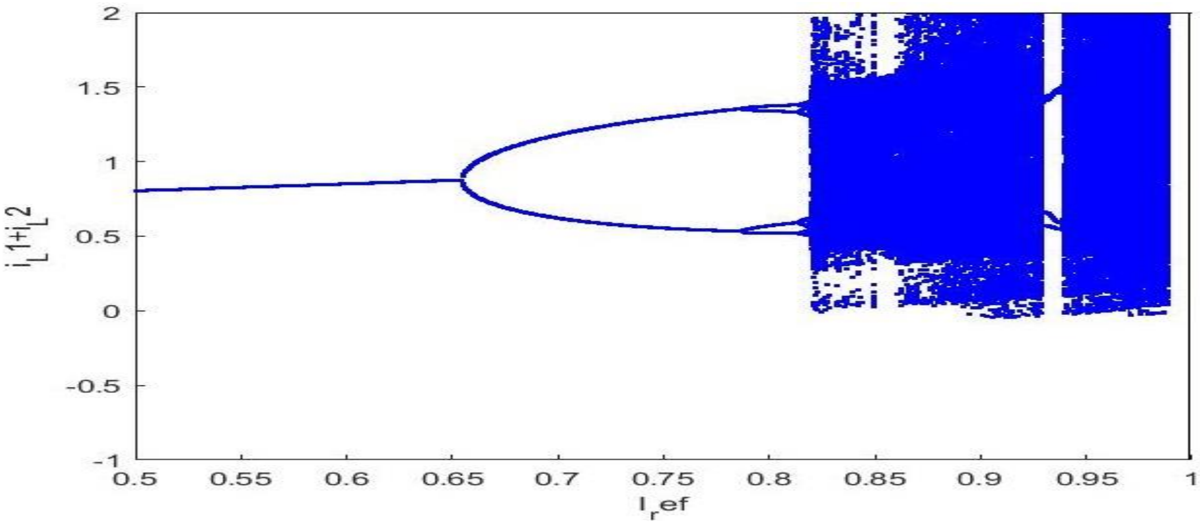

Fig.4.4 Diagram of Bifurcation w.r.t reference current Iref.

In the above figure 4.4 the bifurcation diagram of sum of input current (i_{L1}) and output currents (i_{L2}) w.r.t reference current (Iref) is plotted. In this figure it is observes that the system is behaving stably up to around 0.65 A. If the Iref is increased further the system loses its stability and bifurcates and the reason is two-time attractor. If the reference current is increased further, at 0.8 A the system again bifurcates to for 4 time periodic. The system enters chaos if reference current crosses 0.83 A. the bifurcation diagram can be validated through Time domain wave forms and Phase plots.

Time domain wave forms

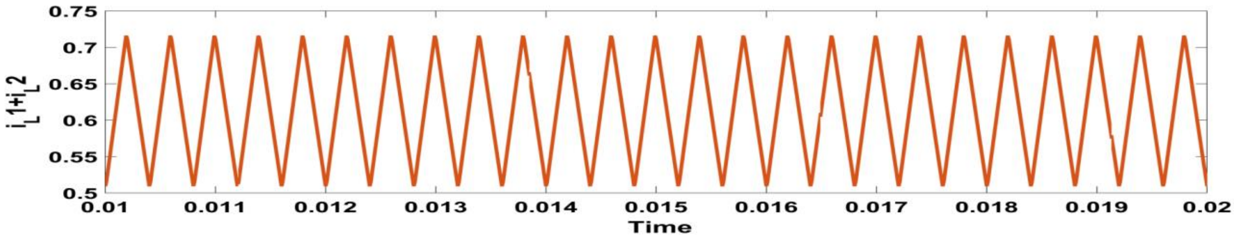

Figure.4.5 period-one waveform sampled at 5 ms intervals giving one Alternating fixed points at Iref = 0.55

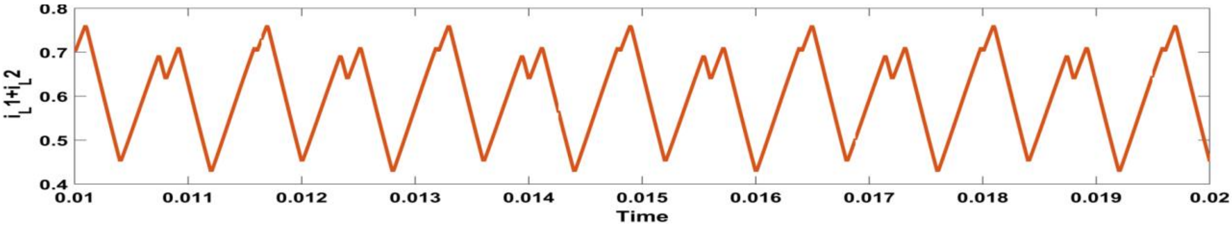

Fig.4.6 period-two waveform sampled at 5 ms intervals giving two Alternating fixed points at Iref =0.75

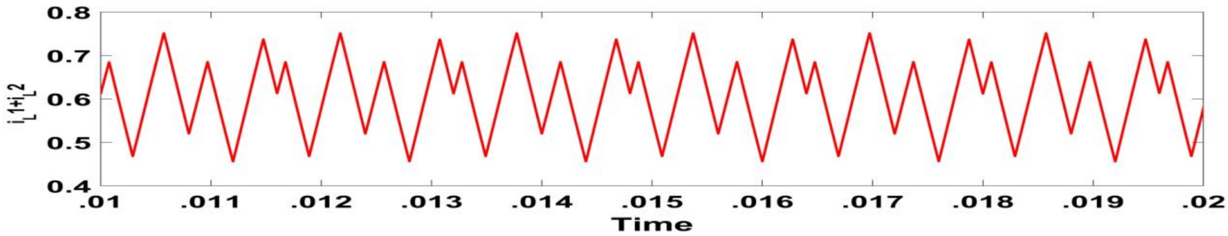

Fig. 4.7 period-four waveform sampled at 5 ms intervals giving four Alternating fixed points at Iref = 0.1

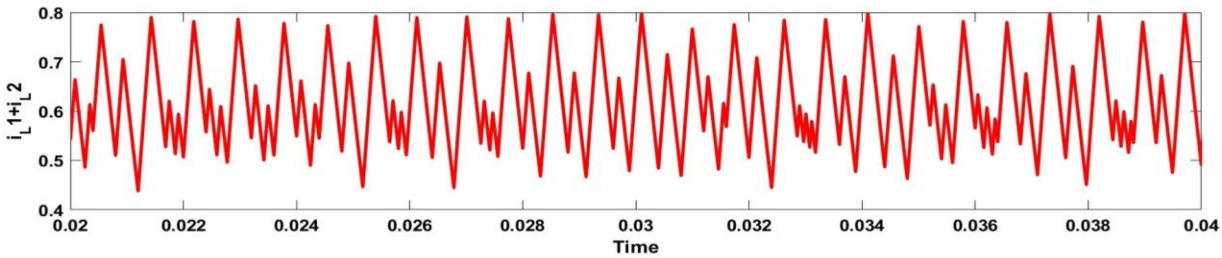

Fig.4.8 waveform at Chaos sampled at 5 ms intervals giving no Alternating fixed points at Iref = 0.1

The bifurcation diagram can be verified using Time domain waveforms. In this, the output current waveform has been taken. It can be observed from Fig.4.5 that the time domain waveform of output current repeats or mirrors itself at every 1 time period that is, the system is under stable operation. Also, Fig.4.6 showcases that the time domain waveform of output current repeats itself every two time periods that are the system has period-doubling bifurcations. Similarly, Fig.4.7 shows the time domain waveform of output current repeats itself at every 4-time period. That is, the system has 4T bifurcations. And in fig4.8 , the system has no period, which means the system has entered into chaos. The following section continues with the phase portraits of the bifurcation diagram.

Phase portraits

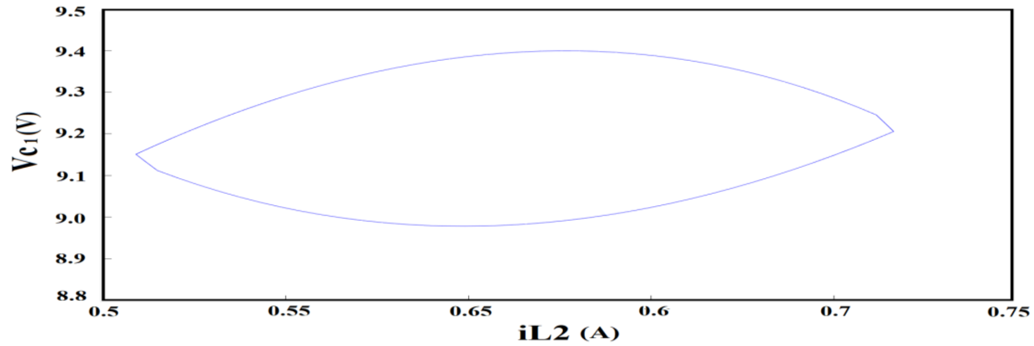

Fig. 4.9 output current and output voltage phase diagram at stable 1 period

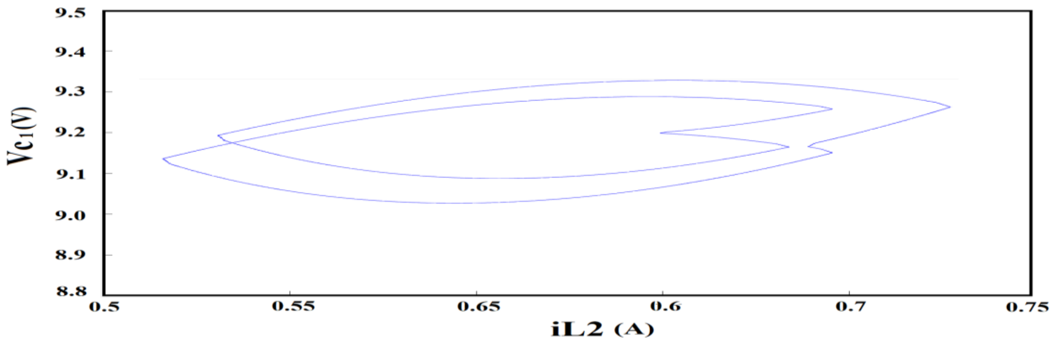

Fig. 4.10 output current and output voltage diagram at 2 time periodic.

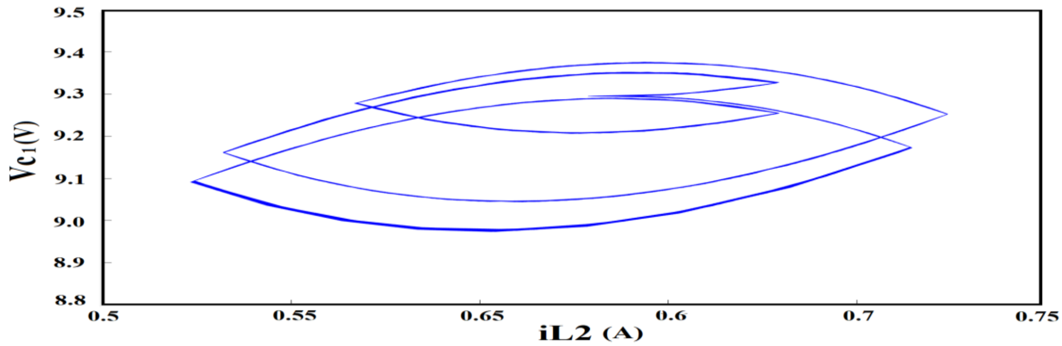

Fig. 4.11 output current and output voltage phase diagram at 4 time periodic

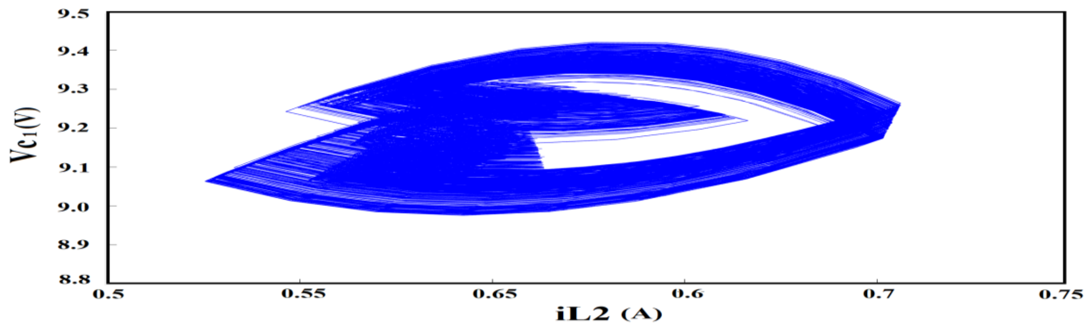

Fig. 4.12 output current and output voltage phase diagram at chaos

Figure 4.9, 4.10, 4.11 and 4.12 illustrates phase portraits of the output current vs output voltage in different stages (period 1, period 2 and chaos) of the system.

Diagram of Bifurcation w.r.t Load resistance

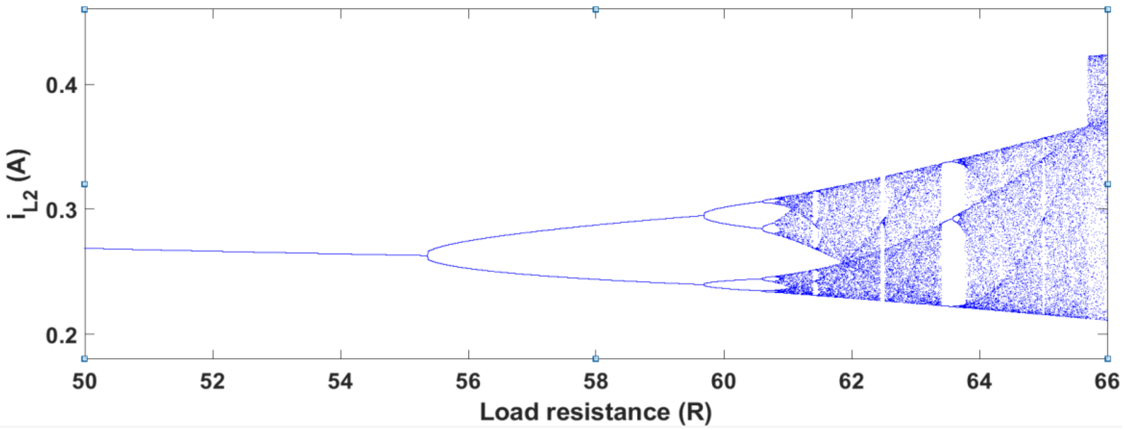

Fig. 4.13 Diagram of Bifurcation w.r.t Load resistance

In the above figure.4.13 the bifurcation diagram is plotted varying load resistance. It can be observed the system remains 1T periodic stable till R= 55 ohms, there after the system loses its stability there by causing a dynamic change and the system transforms from 1T to 2T periodic via period double bifurcations. Then the 2T periodic remains stable till R= 60 ohms. Then there after the system again loses its stability via 4T periodic. The system enters chaos after 62 ohms.

Diagram of Bifurcation w.r.t Input voltage

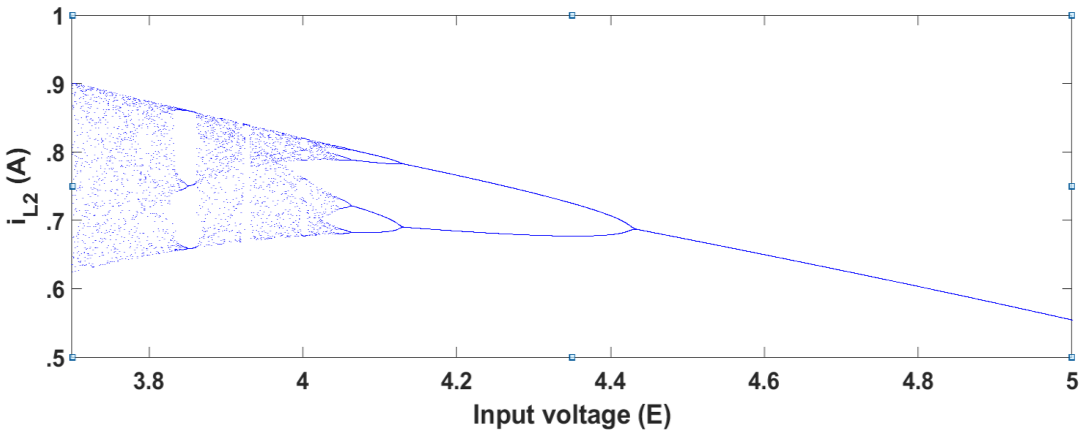

Fig.4.14 Diagram of Bifurcation w.r.t Input voltage

In the above figure. 4.14 the bifurcation diagram is plotted varying Input voltage. It can be observed that the bifurcation happens in reverse direction. The system remains 1T periodic stable E = 4.4 V, there after the system loses its stability there by causing a dynamic change and the system transforms from 1T to 2T periodic via period double bifurcations. Then the 2T periodic remains stable till E= 4.21 V Then there after the system again loses its stability via 4T periodic. The system enters chaos after E= 4 V.

CHAPTER 5

5.1 Bifurcation analysis of Novel Fly back converter

This section discusses the nonlinear study as well as DC-DC feedback control of Novel converters with simple resistance load. The theoretical analysis begins with a simple cuk converter operating in voltage control mode, which exhibits typical nonlinear behavior. The transition's full derivation and discrete iterative mapping that contains complete information that is used to determine the system's stability. Finally, control the nonlinearity of the system to increase or improve the performance behavior, It is possible to create a new control algorithm and extending the region of stable operation.

5.2 Discrete Iterative map derivation

The discrete iterative map technique is used for analyzing bifurcation behaviour. To simplify the calculations, all the parasitic elements in the circuit given below are assumed to be zero.

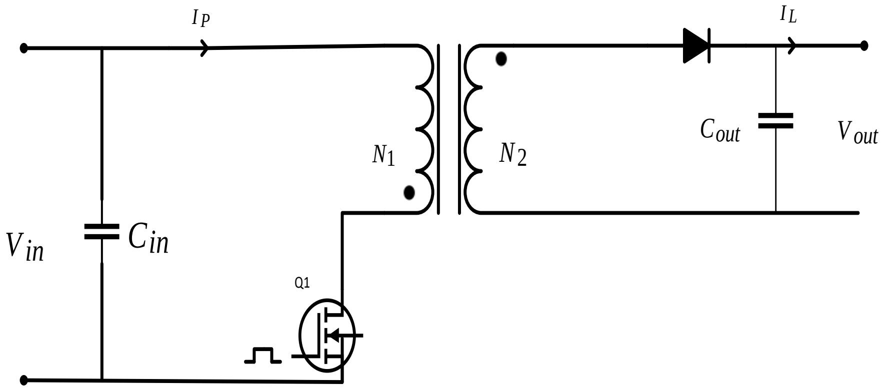

Fig.5.1 Flyback converter schematic diagram

The discrete iterative map for any Power electronic converter should be mapped as.

$$\boldsymbol{x_{n+1}} = \boldsymbol{f}(\boldsymbol{x_n}) \tag{1}$$

The switching converter is in continuous conduction mode, and its topological sequence is made up of two linear circuits that are defined by the state equations below.

$$\dot{\boldsymbol{x}} = \boldsymbol{A_1 X} + \boldsymbol{B_1 E} \quad \textbf{for } \boldsymbol{t_n \le t < t_n + dT} \tag{2}$$

$$\dot{\boldsymbol{x}} = \boldsymbol{A_2 X} + \boldsymbol{B_2 E} \quad \textbf{for } \boldsymbol{t_n + dT \le t < t_{n+1}} \tag{3}$$

Where,

$$x = \begin{bmatrix} V_c \\ I_L \end{bmatrix} \quad \text{and} \quad t_{n+1} = t_n + T \tag{4}$$

$$A_1 = \begin{bmatrix} \frac{-1}{RC} & 0 \\ 0 & 0 \end{bmatrix} \qquad B_1 = \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} \tag{5}$$

$$A_2 = \begin{bmatrix} \frac{-1}{RC} & (n)\left(\frac{1}{C}\right) \\ (-n)\left(\frac{1}{L}\right) & 0 \end{bmatrix} B_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{6}$$

Where $n = \left(\frac{N_1}{N_2}\right)$

Switch on time can be calculated by

$$t_n = \frac{L}{V_n}\left(I_{ref} - I_n\right) \tag{7}$$

In the general way, the switch-on interval can be easily computed by immediately integrating the RHS of (2) and putting t = $t_n{}'$ whi gives the value of x at the end of the switch-on interval.

$$Vc(t_n') = V_c(t_n)e^{-(d_nT)/CR} \tag{8}$$

$$I_l(t_n') = I_L(t_n) + \frac{E(dT)}{L} \tag{9}$$

Where, d_n = duty cycle at n_{th} cycle.

To find the solution for the switch-off interval, we apply the Laplace transformation to (10)

$$X(s) = [SI - A_2]^{-1} [x(t'_n) + B_2E(s)] \tag{10}$$

$$X(s) = \begin{bmatrix} s & n/c \\ -n/L & s + 1/RC \end{bmatrix} \begin{bmatrix} V_c(t'_n) \\ i_L(t'_n) \end{bmatrix} \Big/ H(s) \tag{11}$$

Where $H(s) = s^2 + \frac{s}{RC} + \frac{n^2}{LC}$ (12)

The Expressions for the capacitor voltage and inductor current in the s-domain can be written as

$$V_c(s) = \frac{s\,V_c(t'_n) + \frac{n}{c} i_L(t'_n))}{H(s)} \tag{13}$$

$$I_L(s) = \frac{\frac{-n}{L}(t'_n) + (s + \frac{1}{RC}) i_L(t'_n))}{H(s)} \tag{14}$$

On solving quadratic equation H(s), the roots are,

$$\boldsymbol{\lambda_1}, \boldsymbol{\lambda_2} = \frac{-1}{2RC} \pm \sqrt{\left(\frac{1}{2RC}\right)^2 - \frac{n^2}{LC}} \tag{15}$$

<u>CASE 1</u> $\frac{n^2}{LC} > \left(\frac{1}{2RC}\right)^2$**:**

$$\boldsymbol{\lambda_1}, \boldsymbol{\lambda_2} = -\boldsymbol{\sigma} \pm \boldsymbol{j\omega} \tag{16}$$

Where, $\boldsymbol{\omega} = \frac{n^2}{LC} - \left(\frac{1}{2RC}\right)^2$ **and** $\boldsymbol{\sigma} = \frac{1}{2RC}$ (17)

On applying Inverse Laplace, solving eq. 12 and 13, and putting and $t_{n+1} - t'_n = (1 - d_n)T$, we got the solution that was far too complex to get any result. Applying a second-degree series approximation as T/RC and σT are usually considered small [7].

$$\begin{bmatrix} v_c(t_{n+1}) \\ i_L(t_{n+1}) \end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} \\ f_{21} & f_{22} \end{bmatrix} \begin{bmatrix} v_c(t_n) \\ i_L(t_n) \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \end{bmatrix} E \tag{18}$$

$$f_{11} = 1 - \frac{(2-d_n)T}{RC} + \frac{1}{2}\left[\frac{T}{RC}\right]^2 \tag{19}$$

$$f_{12} = \frac{n(1-d_n)T}{C} - \frac{nR}{2}\left[\frac{(1-d_n)T}{RC}\right]^2 \tag{20}$$

$$f_{21} = \frac{n(1-d_n)T}{C} + \frac{n(1-{d_n}^2)T^2}{2LCR} \tag{21}$$

$$f_{22} = 1 - \frac{(1-d_n)T}{RC} \tag{22}$$

$$g_1 = \frac{n\, d_n T(1-d_n)T}{LC} \tag{23}$$

$$g_2 = \frac{d_n T}{L} - \frac{d_n T(1-d_n)T}{RLC} \tag{24}$$

<u>CASE 2:</u> $\frac{n^2}{LC} = \left(\frac{1}{2RC}\right)^2$**:** The approximate solution is

$$\begin{bmatrix} v_c(t_{n+1}) \\ i_L(t_{n+1}) \end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} \\ f_{21} & f_{22} \end{bmatrix} \begin{bmatrix} v_c(t_n) \\ i_L(t_n) \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \end{bmatrix} E \tag{25}$$

$$f_{11} = \left(1 - \frac{T}{RC}\right)\left(1 - \frac{(1-d_n)^2\, T^2}{2RC}\right) \tag{26}$$

$$f_{12} = \frac{n}{C}\left(1 - \frac{(1-d_n)T}{2RC}\right) \tag{27}$$

$$f_{21} = \frac{-n}{L}\left(1 - \frac{T}{RC} + \frac{1}{2}\left(\frac{T}{RC}\right)^2 - \frac{(1-d_n{}^2)T^2}{2LC}\right) \tag{28}$$

$$f_{22}=1 \tag{29}$$

$$g_1 = \frac{n}{C}\frac{d_nT}{L}\left(1 - \frac{(1-d_n)T}{2RC}\right) \tag{30}$$

$$g_2 = \frac{d_nT}{L} \tag{31}$$

<u>CASE 3</u> $\frac{n^2}{LC} < \left(\frac{1}{2RC}\right)^2$ **:** The approximate solution is

$$\begin{bmatrix} v_c(t_{n+1}) \\ i_L(t_{n+1}) \end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} \\ f_{21} & f_{22} \end{bmatrix} \begin{bmatrix} v_c(t_n) \\ i_L(t_n) \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \end{bmatrix} E \tag{32}$$

$$f_{11} = \left\{\left(1 - \frac{T}{RC}\right)\cosh\ \omega(1-d)\,T - \frac{\sigma}{\omega}\,\frac{(1-d)T}{RC}\sinh\ \omega(1-d)T\right\} \tag{33}$$

$$f_{12} = \frac{n}{wc} - \frac{(1-d)T}{C}\sinh\ \omega(1-d)T \tag{34}$$

$$f_{21} = \frac{-n}{wL}\left(1 - \frac{T}{RC}\right)\sinh\ \omega(1-d)T \tag{35}$$

$$f_{22} = \left(\frac{(1-d)T}{2RC}\right)\left(\cosh\ \omega(1-d)\,T - \frac{\sigma}{\omega}\ \sinh\omega(1-d)T\right) \tag{36}$$

$$g_1 = \frac{n}{\omega C}\frac{dT}{L}\frac{(1-d)T}{RC}\sinh\omega(1-d)T \tag{37}$$

$$g_2 = \frac{1}{\omega RC}\frac{dT}{L}\left(e^{-\sigma(1-d)T}\ \sinh\omega(1-d)T\right) \tag{38}$$

However, the most crucial parameter is case (1), which is almost equivalent to experimental conditions. So, the study of bifurcation will be based on this condition. This section has successfully provided the necessary equations and the steps to be followed to obtain the bifurcation diagram. The nest section enriches the control law for the feedback.

5.3 CONTROL LAW FOR FEEDBACK

A feedback mechanism is expected to control the output of voltage. In this paper, the feedback mechanism has been varied proportionally to reduce the complexity. The control law can be written as equation (39).

$$\boldsymbol{d_n} = \mathbf{H}\ (\mathbf{D} - \mathbf{k}\ (\boldsymbol{v_c} - \boldsymbol{v_{ref}})) \tag{39}$$

Where, D = duty cycle at steady state

k = feedback gain

v_c = capacitor voltage

$$H(x) = \begin{cases} 0\ for\ x = 0 \\ 1\ for\ x > 1 \\ x\ for\ else \end{cases}$$

5.4 BIFURCATION BEHAVIOUR AND PHASE PORTRAITS

The bifurcation diagram is a graphical way of representation and method for studying nonlinear processes in a system with several parameters. This method involves varying a parameter and plotting it alongside one of the axes. On the opposite axis, the monitoring variables of state that are sampled and plotted as discrete points.

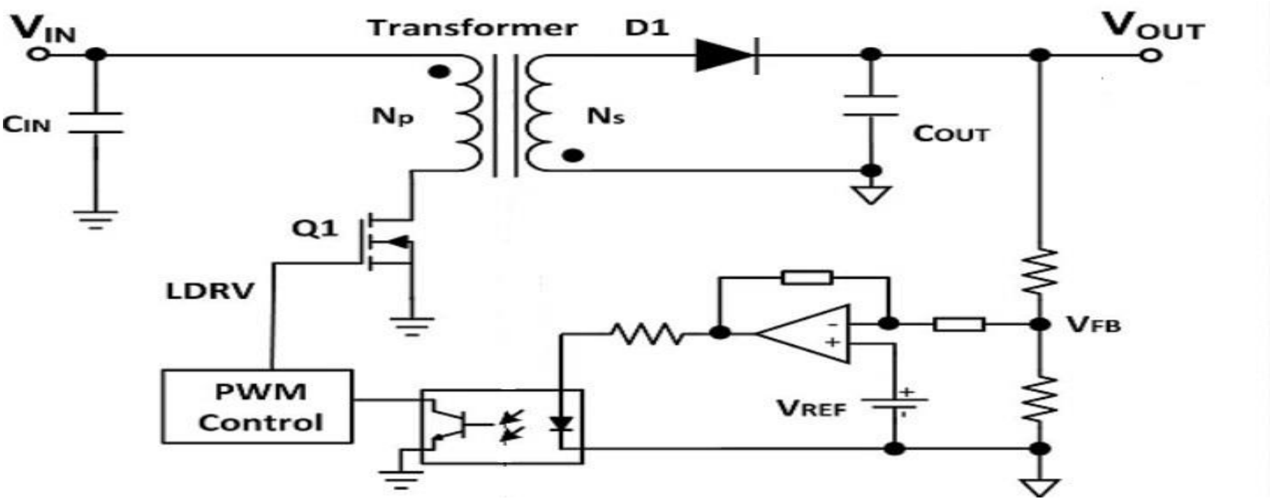

Fig. 5.2 closed-loop voltage control of flyback converter

Table.1 **circuit details of fly back converter**

Parameters	Values
Vin	22 mV
Inductor L	14.49 uH
Capacitor C	2 uF
Resistor R	2 Ohm
Switching Time T	330 u sec

The above figure 5.2 represents the flyback converter operating under closed loop condition. The feedback path consists of a voltage divider circuit, op amps and an optocoupler. The output of the optocoupler is connected to the PWM control. The PWM control consists of a reference current and a saw tooth generator which generates the PWM pulses. For the sake of convenience only proportional control have been implemented.

The following bifurcation diagram in the next page has been obtained by varying feedback gain and input voltage. The output accepted can be verified using phase plots and time-domain waveforms.

Bifurcation concerning feedback gain

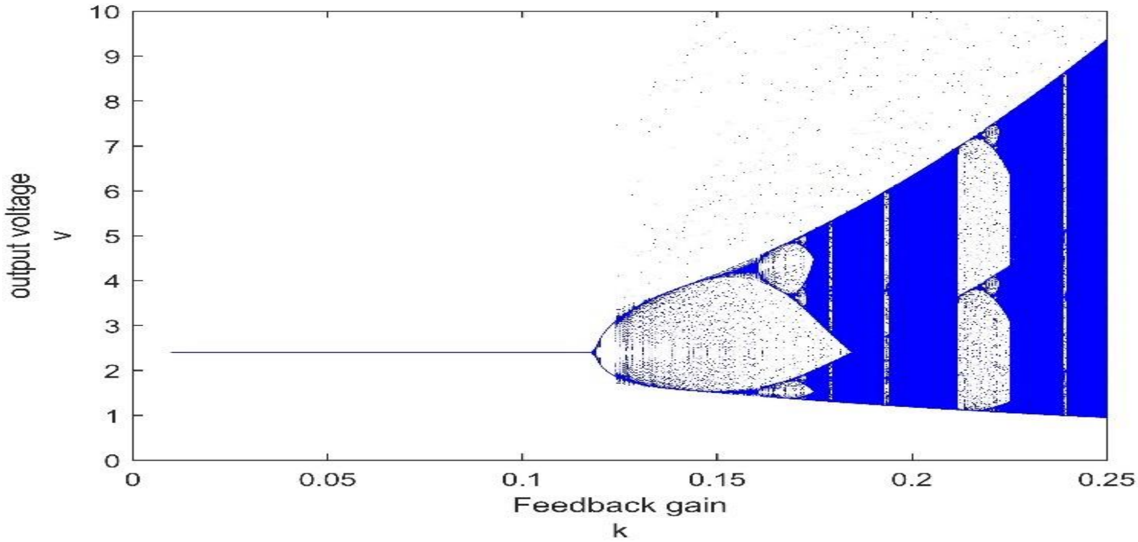

Fig.5.3 diagram of bifurcation with varying feedback gain

In Fig.5.3, the Diagram of bifurcation regarding feedback gain can be seen, and a stable period up to almost 0.12 can be observed. After k= 0.12, there occurs a period of double bifurcation or 2T. This occurs up to k= 0.16. And after k = 0.16, the output voltage bifurcates to period 4 or 4T, which continues to almost k = 0.175. This then finally enters into a chaotic region after around k = 0.19.

Time-domain waveforms

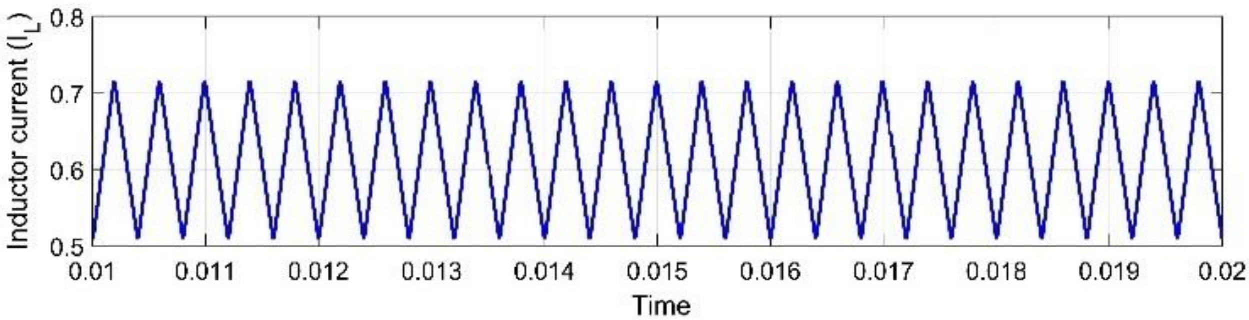

Figure .5.4 waveform at *period 1*- sampled at 5 ms intervals giving one Alternating fixed points at k = 0.1

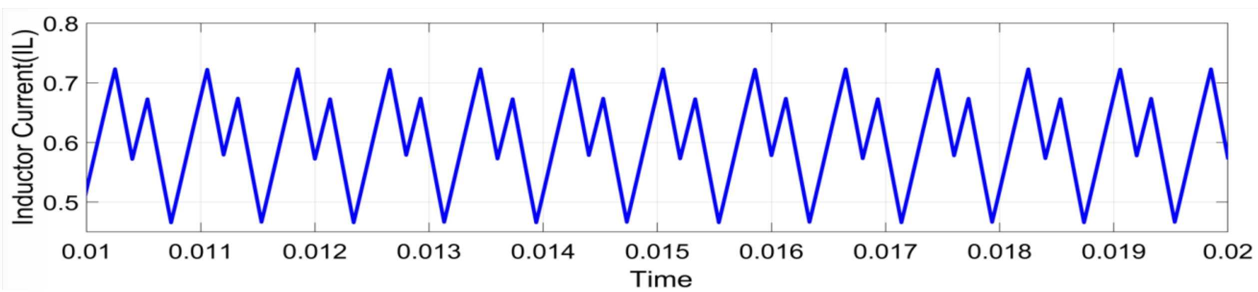

Fig 5.5 period-2 sampled at 5 ms intervals giving two (2) Alternating fixed points k = 0.14

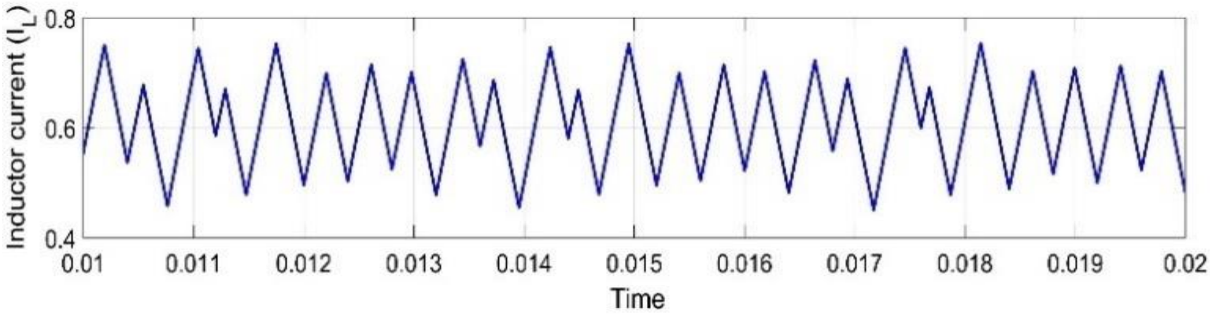

Fig.5.6 waveform *at period*-4 sampled at 5 ms intervals giving four (4) Alternating fixed points k = 0.17

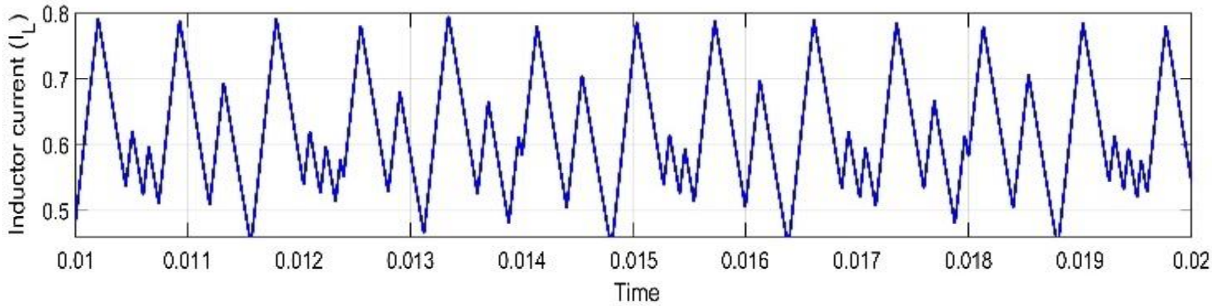

Fig.5.7 waveform at chaos sampled at 5 ms intervals giving no Alternating fixed points k = 0.2

The bifurcation diagram can be verified using Time domain waveforms. In this, the output current waveform has been taken. It can be observed from Fig.5.4 that the time domain waveform of output current repeats or mirrors itself at every 1 time period that is, the system is under stable operation. Also, Fig.5.5 showcases that the time domain waveform of output current repeats itself every two time periods that are the system has period-doubling bifurcations. Similarly, Fig.5.6 shows the time domain waveform of output current repeats itself at every 4-time period. That is, the system has 4T bifurcations. And in fig 5.7, the system has no period, which means the system has entered into chaos. The following section continues with the phase portraits of the bifurcation diagram.

Phase plots

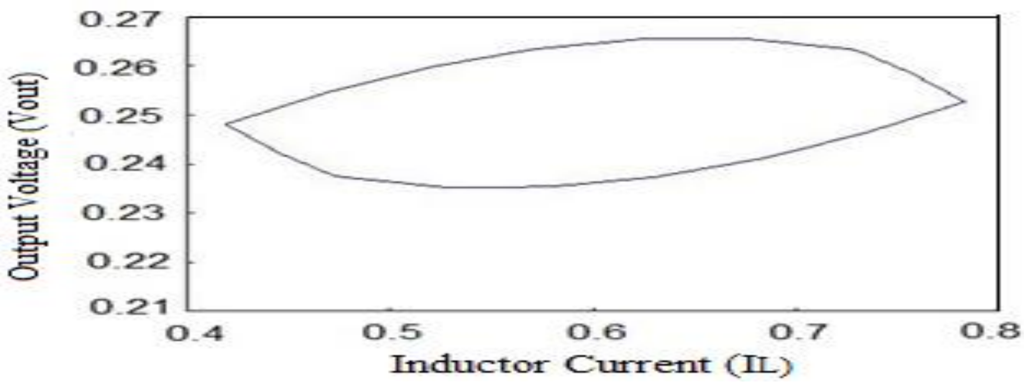

Fig. 5.8 output voltage and output current phase diagram at stable 1 period

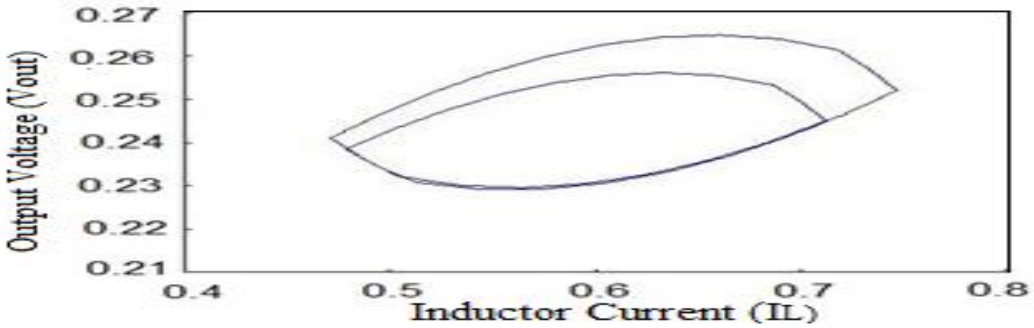

Fig 5.9 output voltage and output current phase diagram at period 2.

Fig. 5.10 output voltage and output current phase diagram at chaos

Figure 8,9 and 10 illustrates output voltage's phase portraits in different stages (period 1, period 2 and chaos) of the system.

Bifurcation concerning the input voltage

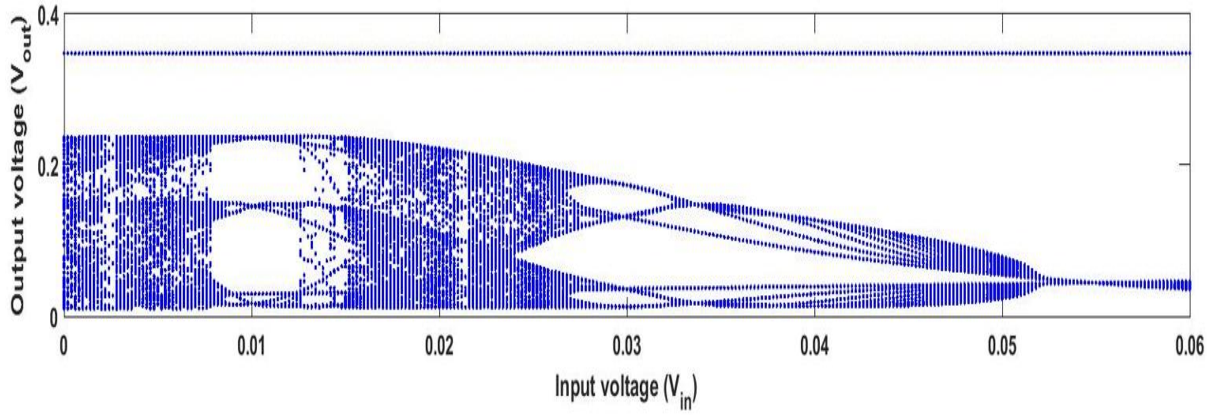

Fig. 5.11 bifurcation diagram with varying input voltage

In the figure.11 the bifurcation diagram with reference to input voltage can be seen. It has been observed that the bifurcation occurs in a reverse manner.A stable one period is observed up to almost 0.05 volts. Before 0.05 volts there occurs a period double bifurcation or 2T. This continues up to about 0.04 Volts. the output voltage again bifurcates to period 4 or 4T before

0.03 volts which continues to almost 0.02 volts. finally it enters into chaotic region before about V= 0.02. The time domain wave forms and phase plots can also be studied in similar manners

Bifurcation w.r.t reference current

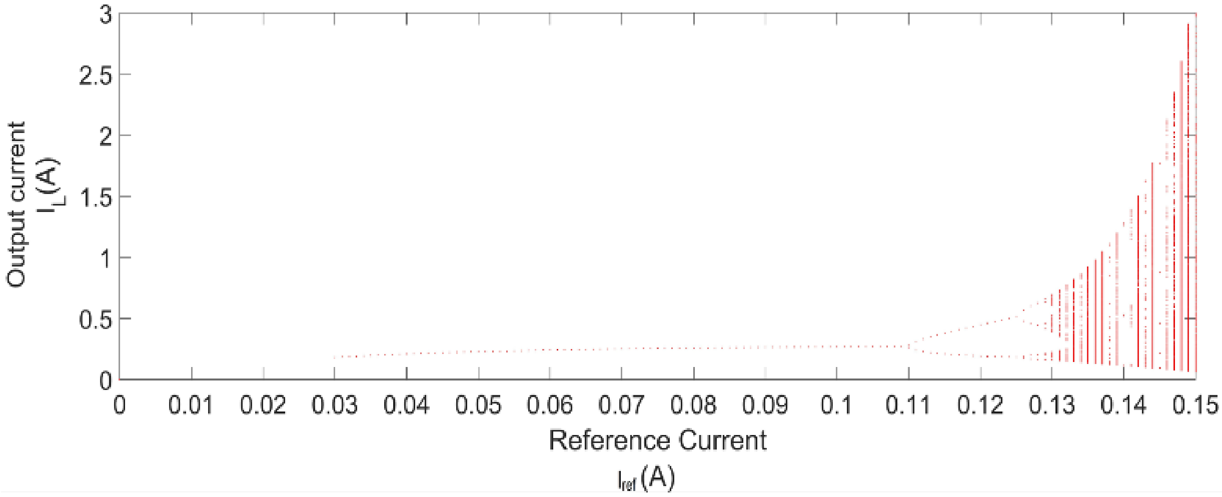

Figure . 5.12 bifurcation diagram with varying input voltage

In the Fig.12 the bifurcation diagram with reference-to-reference current is observed. A stable one period up to almost 0.11 amp is observed. After A= 0.11 there occurs a period double bifurcation or 2T. After 0.13A the output current bifurcates to 4T. similarly, after 0.135 A the output current shows the chaotic.

CONCLUSION

For the DC-DC converter control , converter's stability analysis and , a nonlinear analytic methodology based on the Discrete iterative mapping was used in this work. This derived matrix comprises all of the circuit characteristics and control coefficients, allowing system performance to be assessed with various input and output parameters. In the thesis, specific derivations of the Discrete iterative mapping are offered. In addition, new advanced control strategies have been proposed and developed to increase the stability performance of DC-DC converters based on the knowledge gathered from the Discrete iterative mapping . DC DC converters may now operate across a wider range of input voltages, and the approaches suggested here can be used to any other switching power converters such interleaved or multiphase converters. Furthermore, to increase the influence of the control parameters, the proposed control method was applied in a made by mixing digital controller. This method has never been reported before. Finally, the Discrete iteratieve matrix was used to assist in the decrease of DC-DC converter inductor size. The theoretical analysis and the efficiency of the established approaches have been proven by simulation and experimental data.

The paper gives an insight into the complex behaviour of switching power flyback converters. To analyze this complex behaviour bifurcation diagram, corresponding time-domain waveforms and phase portraits have been studied. Bifurcation is the most robust method to learn the chaos. Discrete iterative mapping was derived to get the next state voltage and current. A numerical method analysis has been carried out to obtain the desired results. Various methods like input voltage and feedback gain were varied in a closed-loop converter with a voltage control loop. Bifurcation has been studied. Also, two time periods, four-time periods, and chaos have been visually examined. The bifurcation diagram has been verified with Time-domain waveforms and phase portraits. The results provide information about the boundary conditions and maximum operating point.

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FUTURE WORK

Some potential future study fields can be recognized based on the work presented inside this thesis. Nonlinear analysis of additional sorts of non-isolated or isolated converters with higher order can be performed by using methods provided here. For example, how to create the Discrete Iterative mapping matrix while accounting for transformer nonlinearities. Furthermore, how many other control techniques can be produced using the given methods based on the new control legislation? The relationship between switching conditions and various control algorithms, as well as associated changes in the Discrete Iterative mapping matrix, can be investigated, for example. In terms of the expected benches execution, the existing platform can be improved to add more features and make it universal for testing other types of converters at different power ratings. Finally, to facilitate product design, a representation of system stability with detailed info about all system parameters and external situations can be constructed.

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