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Control of Chaotic Behaviour in Parallel-Connected DC-DC Boost Converters

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Abstract

Chaos control means to design a controller that is able to eliminating the chaos behaviour of nonlinear systems that experiencing such phenomenon. In this paper, a delayed feedback control mode is presented.
The paper describes the control of the bifurcation behaviour of a modular peak current-mode controlled DC-DC boost converter which is used to provide an interface between energy storage batteries and photovoltaic (PV) arrays renewable energy sources. The parallel-input/parallel-output converter comprises two identical boost circuits and operates in the continuous-current conduction mode. A comparison is made between waveforms obtained from a MATLAB/SIMULINK model for open-loop converter and the controlled one. The study shows the effectiveness of the designed delayed feedback control mode.

Keywords: Bifurcation and Chaos Theory; Boost Converter; Delayed Feedback Control Mode.

1. Introduction

Current-controlled DC-DC switch-mode converters are non-linear electronic devices and it has been observed that they may behave in a chaotic manner. The design of such converters, with a low harmonic content and low voltage ripple is a constant challenge; this has generated much interest, particularly in single-stage topologies such as the buck, boost, and cuk converters [1-7].

This paper investigates the control of chaotic behaviour in a two-module parallel input/parallel-output boost converter operating under a peak current-mode control scheme using a delayed feedback control

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strategy, which is based on the idea of stabilization of unstable periodic orbits that exist in the chaotic attractor [8], where each module has its own current feedback loop. The converter consists of two similar boost circuits operating in the continuous-current conduction mode. A non-linear map for the converter was derived using discrete time modelling and numerical iteration of the map produces bifurcation diagrams which indicate the chaotic operation.

In order to check the validity of the controller, a MATLAB/SIMULINK model for the controlled converter was developed. The waveforms for the open-loop model already produced by the MATLAB/SIMULINK model which integrates numerically the system state-variable equations for the converter. The results for the controlled model are compared with the open-loop model.

2. Bifurcation and Chaos Theory

Bifurcation theory, originally developed by Poincare, is used to indicate the qualitative change in behaviour of a system in terms of the number and the type of solutions, under the variation of one or more parameters on which the system depends [9-10].

The system state variables and the control parameters are defined and the relationships between any of these control parameters and a state variable is called the state-control space. In this space, locations at which bifurcations occur are called bifurcation points. Bifurcations of an equilibrium or fixed-point solution are classified as either *static bifurcations*, such as saddle-node, pitch fork, or transcritical bifurcations; or as *dynamic bifurcations* which are also known as the Hopf bifurcation that exhibits periodic solutions. For the fixed-point solutions, the local stability of the system is determined from the eigenvalues of the Jacobian matrix of the linearized system. On the other hand, with periodic-solutions, the system stability depends on what is known as the Floquet theory and the eigenvalues of the Monodromy matrix that are known in the literature as Floquet or characteristic multipliers. The types of bifurcation are determined from the manner in which the Floquet multipliers leave the unit circle. There are three possible ways for this to happen [9-10]:

i) If the Floquet multiplier leaves the unit circle through +1, then three possible bifurcations may occur: transcritical, symmetry-breaking, or cyclic-fold bifurcation.

ii) If the Floquet multiplier leaves through -1, the period-doubling (Flip bifurcation) occurs.

iii) If the Floquet multipliers are complex conjugate and leave the unit circle from the real axis, the system exhibits secondary Hopf bifurcation.

To observe the system dynamics under all the above possible bifurcations, a complete diagram known as a *bifurcation diagram* is constructed. A bifurcation diagram shows the variation of one of the state variables with one of the system parameters, otherwise known as a control parameter.

3. Converter Operation

A circuit diagram for the module boost converter is shown in Fig. 1. A simplified diagram for the proposed converter consists of two peak current-mode controlled DC-DC boost converters whose outputs are connected in parallel to feed a common resistive load. Each converter has its own current feedback loop comprising a comparator and a flip-flop. Each comparator compares its respective peak inductor current with a reference value, to determine the on-time of the switch.

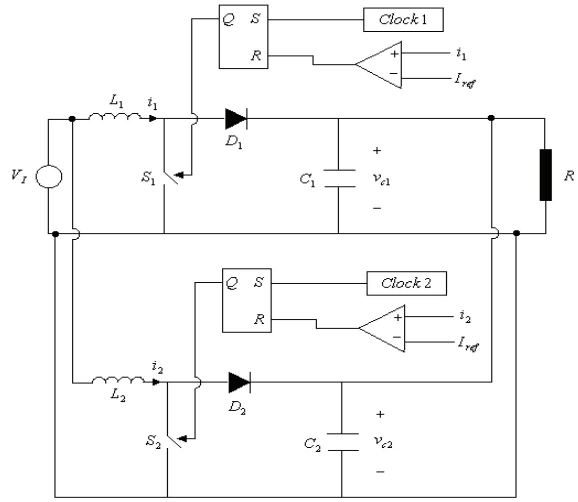

Fig. 1. Module Boost Converter Circuit Diagram

The iterative map describing the system takes the form:

$$x_{n+1} = f(x_n, I_{ref}) \tag{1}$$

where subscript n denotes the value at the beginning of the nth cycle and x is the state vector

$$x = \begin{bmatrix} i_1 \\ v_{c1} \\ i_2 \\ v_{c2} \end{bmatrix} \tag{2}$$

where:
i_1, i_2 are the currents through inductors L_1 and L_2, respectively.
v_{c1}, v_{c2} are voltages across capacitors C_1 and C_2, respectively.
So the iterative map:

$$i_{1(n+1)} = i_{2(n+1)} = e^{-kt'_n}\left[\frac{kLI'_{ref} + V_I - v_n e^{-2kt_n}}{\omega L}\sin\omega t'_n + I'_{ref}\cos\omega t'_n\right] + \frac{V_I}{2R} \tag{3}$$

$$v_{c1(n+1)} = v_{c2(n+1)} = V_I - e^{-kt'_n}\left[\frac{kv_n e^{-2kt_n} - kV_I - I'_{ref}/C}{\omega}\sin\omega t'_n + (V_I - v_n e^{-2kt_n})\cos\omega t'_n\right] \tag{4}$$

A MATLAB program was written to produce bifurcation diagrams for the two-module boost converter, with the nominal parameters given in Table 1.

Table 1. System Parameters

Circuit Components	Values
Switching Period T	$100\mu s$
Input Voltage V_I	$10V$
Inductance L_1	$1mH$
Inductance L_2	$1mH$
Capacitance C_1	$10\ \mu F$
Capacitance C_2	$10\ \mu F$
Load Resistance R	20Ω

Fig. 2 shows the bifurcation diagram for load current of the proposed system with the reference current as the bifurcation parameter.

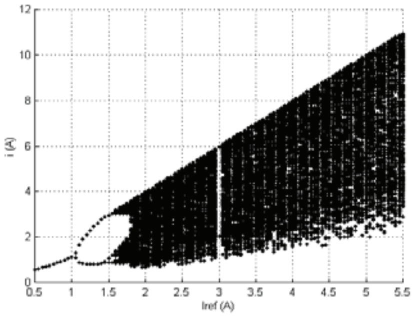

Fig. 2. Bifurcation diagram for the two-module converter

4. MATLAB/SIMULINK Simulation (Simulated Open-Loop)

MATLAB/SIMULINK model was developed based on the system equations:

$$\begin{aligned}
\frac{di_{L1}}{dt} &= \frac{1}{L_1}[v_{in} - v_C(1-u_{S1})] \\
\frac{di_{L2}}{dt} &= \frac{1}{L_2}[v_{in} - v_C(1-u_{S2})] \\
\frac{dv_{C1}}{dt} = \frac{dv_{C2}}{dt} &= \frac{1}{C}[-\frac{v_C}{R} + i_{L1}(1-u_{S1}) + i_{L2}(1-u_{S2})]
\end{aligned} \tag{5}$$

Where u_{S1} and u_{S2} take the value 0 or 1 depending on whether the switches 1 or 2 are closed or open. The result for chaotic regimes at $I_{ref} = 5A$ is obtained for the inductor current waveform and is given in Fig. 3. The inductor current at switch turn-on now have many values.

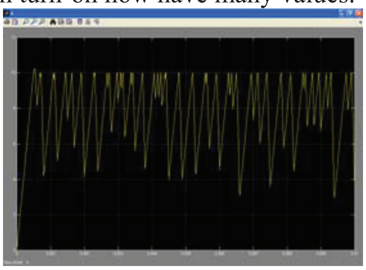

Fig. 3. Chaotic inductor current

5. Control of Chaos

The feedback control force *F(t)*, applied to the system is the difference between the current value of some system variable *y(t),* and its value τ seconds previously, multiplied by a constant *K*, where *K* is the feedback strength. The idea behind the scheme relies on the fact that a skeleton of a chaotic attractor is formed by an infinite set of unstable periodic orbits with different periods. If the value of the time delay τ is exactly equal to the period *T* of one of the orbits, then at the appropriate values of *K*, the orbit can become stable and chaos will be eliminated.

As the controller connected to the open-loop model, the inductor current at switch turn-on now does not have many values and the periodic regime is stable as shown in Fig. 4.

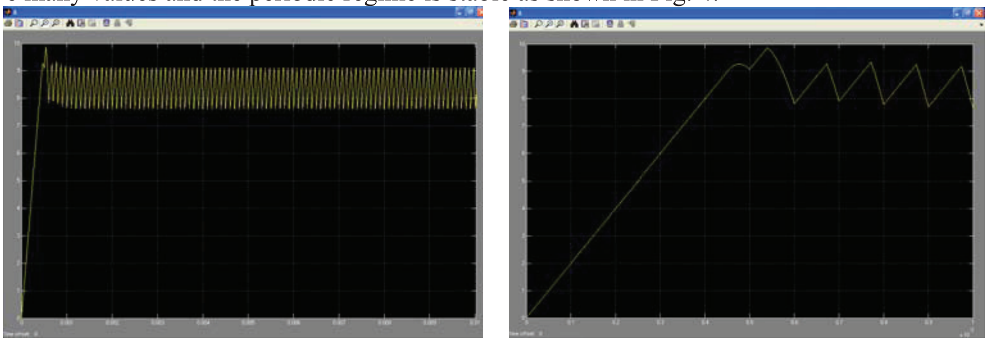

Fig. 4. Delayed Feedback Control

6. Conclusion

The simulated time waveforms for $i_L(t)$ at $I_{ref} = 5A$ with the converter connected to the delayed current feedback (the control circuit) showed the converter is operating in a "period-1" mode as required. The study shows the effectiveness of the designed delayed feedback control mode. The results indicated that delayed feedback control mode results in a greater range of stable period-1 operation, compared with the traditional method.

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