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Discrete time model of a multi-cell dc/dc converter: Non linear approach

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Abstract

By using a non linear discrete time model, this paper shows how to predict bifurcations in a two cells chopper and analyses the road to chaos. Equilibrium points and their stability are investigated in an analogical way to determine the nature of the bifurcations. The global behaviour is studied by using bifurcation diagrams showing collisions between fixed points and borderlines. The border collision bifurcations have their origin in the saturations of the PWM modulator.

Keywords: Multi-cell; Converter; Bifurcation; Chaos; Modelling

1. Introduction

For all industrial fields, power electronics converters play an essential role as well as variable speed drives or as power sources or for cleaning a power network. To meet the new needs, the structures of the converters evolve in order to reduce the stress of the components and to push back the operation limits to higher voltage or current levels. A growing activity currently relates to the multi-cell converters.

Multi-cell converters are developed to avoid or reduce the consequences of switches defects. Thus, they increase the reliability of the equipment. The multi-cell converters applications include the speed variation for medium and high voltage motors, the dynamic restoration of voltage and the harmonics filtering. Equipped with an appropriate control, these converters are well adapted to the conditioning of the renewable energy sources issued for example from windmills. Moreover, thanks to their modular structure, they can be associated very easily [2,3,5,10].

During last years, it has been observed that most static converters exhibit strange non linear phenomena. Apart from their normal operating mode, the multi-cell converters can also present sub-harmonic modes and sometimes chaotic behaviours. However, the linear average models do not make it possible to predict the bifurcation phenomena, the sub-harmonic oscillations, the chaos or the presence of multiple attractors. By nature, this type of model masks the essential non linearities of the real system by considering its average state on an operating period or by linearizing its dynamics around an operating point [1,11]. To analyze, to predict and control these strange behaviours, it is necessary to have non linear discrete time models [4,8,9].

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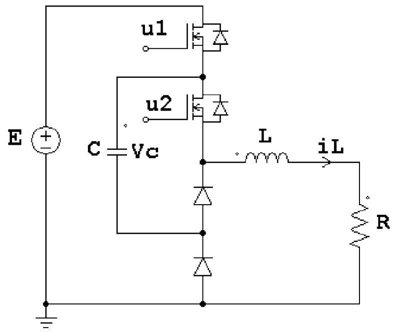

Fig. 1. Structure of a two cells chopper.

2. The converter

Fig. 1 shows the studied converter. It is based on a buck chopper modified in order to allow a higher input voltage by using two serial switches (transistors or diodes). A flying capacitor balances the switch voltages. Fig. 2 depicts the linear controller which drives the PWM modulator in order to control the output current and to stabilize the capacitor voltage near $E/2$. It is worth to note that the duty cycles d_1 of u_1 and d_2 of u_2 are defined with the off state. In normal operating mode, d_1 and d_2 lie between 0 and 0.5, if $I_r > E/2R$. During each period, the operating cycle is then split into four intervals as shown on Fig. 3.

Interval 1: $u_1 = 0$, $u_2 = 1$.
The capacitor is discharged through the inductive load.
Interval 2: $u_1 = 1$, $u_2 = 1$.
The inductor is charged and the capacitor remains stable.
Interval 3: $u_1 = 1$, $u_2 = 0$.
The capacitor is charged through the inductive load.
Inerval 4: The topology is the same as the one of interval 2 but the duration can be different.

3. Modellization

3.1. Open loop operation

The model is built in a dimensionless state space. The state vector is denoted $X = [i\ v]^t$. Voltages are scaled with the input voltage E and currents are scaled with the maximal current E/R. The time is scaled with the switching period T. The dynamic of each interval $k \in \{1, 2, 3, 4\}$ is described by a linear differential system with constant coefficients: $\dot{X} = A_k X + B_k$. The open loop model is obtained by integrating, in an analogical way, and by stacking up the solutions

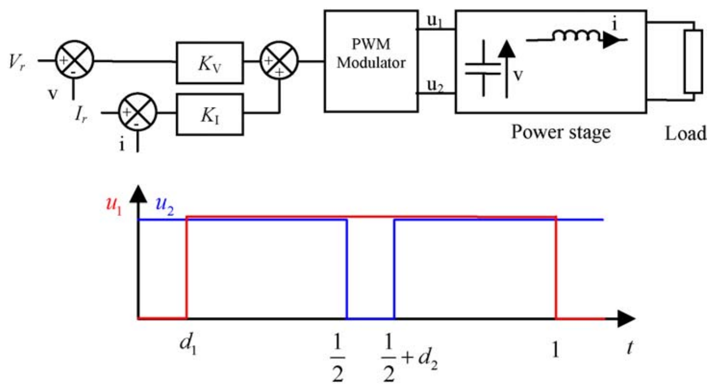

Fig. 2. Voltage and current controls of the converter.