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Chaotic behavior study for serial multicellular chopper connected to nonlinear load

P. Djondine, R. HE, M. Ghanes and J-P. Barbot

Abstract—In this paper, chaotic behavior investigation of two-cells chopper when it is associated with a nonlinear load is considered. The model of such system is described by a continuous time three dimensional non-autonomous system. The route to chaos is studied by using numerical simulations of two-cells chopper model. Moreover phase portraits; Poincaré section and first return map are analyzed to highlight the main characteristic of this particular chaotic behavior.

I. INTRODUCTION

Multicells converters have grown from an attractive theoretical concept to industrial applications, especially for use in higher power applications [7], [18], [15], [16], [13], [17] and they are well suited to packaging of renewable energy sources. Indeed, due to their modular structure, they can be combined easily [13]. In recent decades, it was discovered that most of static converters were the seat of unknown nonlinear phenomena in power electronics [6], [10], [12], [4]. It is for example the case of multicellular choppers that can exhibit unusual and sometimes chaotic behaviors. Obviously this may generate dramatical consequences (see for example the 1MW multicellular chopper [11]). However, the usual averaged models do not allow to predicting nonlinear phenomena encountered. By nature, these models obscure the essential nonlinearities [19]. To analyses these strange behaviors, it is necessary to use a nonlinear hybrid dynamical model.

The goal of this paper is to highlight the presence of chaotic behavior in the serial multicellular chopper [19] controlled by classical PWM method.

The paper is structured as follows. Section 2 deals with the modeling process. The electronic structure of the multicell converter is addressed and the appropriate mathematical model is derived to describe the dynamics of the chopper. In section 3, the proposed study of two cells chopper is presented. Phase portraits and Poincaré section and first return map are plotted to define the torus breakdown to chaos. Finally, some concluding remarks are reported in section 4.

II. MULTICELLULAR CHOPPER MODELING

Multicellular chopper consists of cells, where each one contains two complementary power electronics components and can be controlled by a binary switch (Fig. 1) [5], [9], [14], [2], [8]. The signal is equal to 1 when the cell upper switch is conducting and equal to 0 when the lower one is conducting. These cells are associated to capacitors and the chopper is connected in series with an

RL load [1]. Consequently the chopper has $p - 1$ floating voltage capacitors with p refers to cells number. The requested energy balance of the chopper is the following one ($v_{C_k} = k \frac{E}{p}$). This condition is necessary in order to guarranty that each cell cut off only $\frac{E}{p}$. In this case output voltage of the chopper takes one of the following values: $(0, \frac{E}{p}, \dots, \frac{(p-1)E}{p}, E)$. The chopper modeling is:

$$\left\{ \begin{array}{l} \frac{dV_{C_1}}{dt} = \frac{u_2 - u_1}{C_1} i_L \\ \frac{dV_{C_2}}{dt} = \frac{u_3 - u_2}{C_2} i_L \\ \vdots \\ \frac{dV_{C_{p-1}}}{dt} = \frac{u_p - u_{p-1}}{C_p} i_L \\ \frac{di_L}{dt} = \frac{u_2 - u_1}{L} V_{C_1} + \frac{u_3 - u_2}{L} V_{C_2} + \dots \\ \quad + \frac{u_{p-1} - u_p}{L} V_{C_{p-1}} + \frac{u_p}{L} E - \frac{R}{L} i_L \end{array} \right. \quad (1)$$

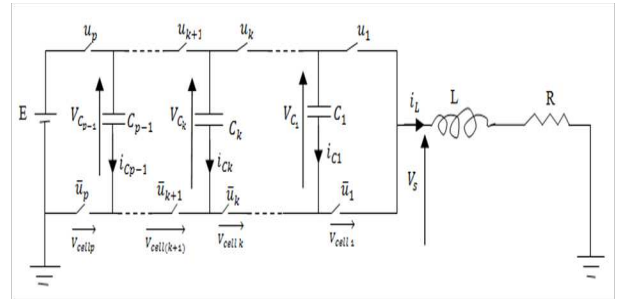


Fig. 1. p-cells chopper connected to RL load

Note that the chopper (Fig.1), which has a purely dissipative load, can not generate a chaotic behavior. Nevertheless, it is well known since from [3] that power converter when it is connected to nonlinear load may have a chaotic behavior.

III. CHAOTIC BEHAVIOR

A. Modelling

For the sake of simplicity, this investigation is carried out for a two cells chopper (Fig. III-A). A passive load in series with a nonlinear load composes the considered load. Moreover, the nonlinear load is connected with a capacitor in order to keep in mind the nonlinear properties.

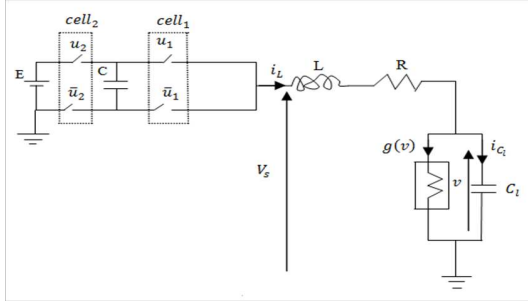


Fig. 2. 2-cells chopper connected to a nonlinear load

From equation 1 and taking into account the nonlinearity of the load, the two cells chopper modeling connected to nonlinear load is given by the following set of equations:

$$\begin{cases} \frac{dv_C}{dt} = \frac{u_2 - u_1}{C} i_L \\ \frac{dv}{dt} = \frac{(i_L - g(v))}{C_1} \\ \frac{di_L}{dt} = \frac{u_2 - u_1}{L} v_C - \frac{1}{L} v - \frac{R}{L} i_L + \frac{u_2}{L} E \end{cases} \quad (2)$$

where $g(v) = \frac{1}{2}v - (|v + 1| - |v - 1|)$

B. Chaotic behavior study

In this section, three indicators are used to identify the type of transition leading to chaos [20] of system (2) : Routes to chaos with phase portraits, Poincaré section and first return map. Chaotic systems are sensitive to initial values. Chaotic behavior of system (2) can be obtained only by varying the switching frequency f_s of the chopper. To be able to enter the chaotic behavior, the following parameters values of system (2) are chosen and assigned constants in the three indicators: $C = 0.1\mu F$, $C_1 = 40\mu F$, $R = 10\Omega$, $L = 50mH$, $E = 100V$.

1) *First indicator : routes to chaos*: For the sake of simplicity and the leak of space, only the phase portraits of v with respect to I_L are given in order to show the route to chaos and express the behaviour of the nonlinear load. The 3 dimensional phase portrait v_c with respect to v and i_L is given and analysed. As it is expected, a chaotic behaviour appears when the frequency of the converter decreases.

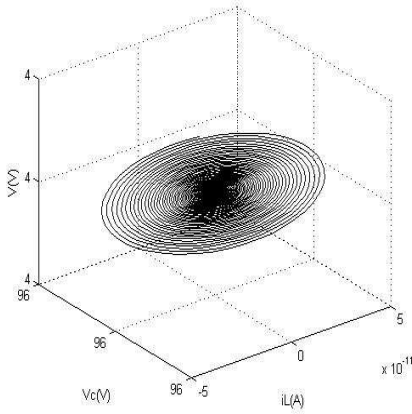


Fig. 3. $f_s = 0.25$.

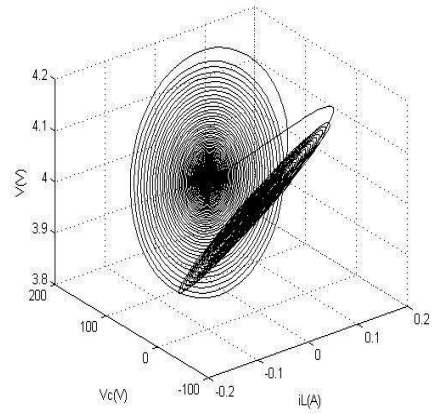


Fig. 4. $f_s = 1$.

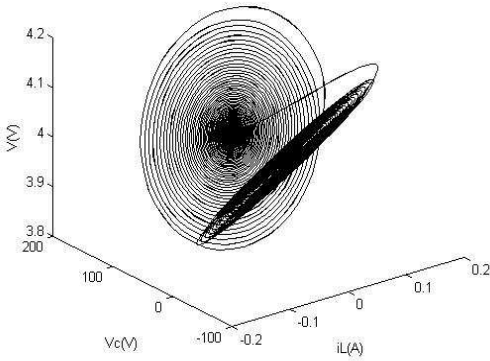


Fig. 5. $f_s = 10$.

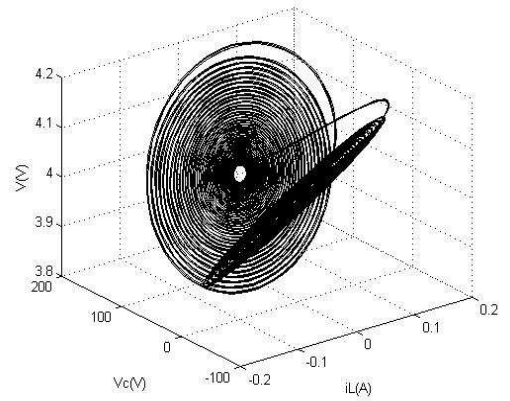


Fig. 6. $f_s = 20$.

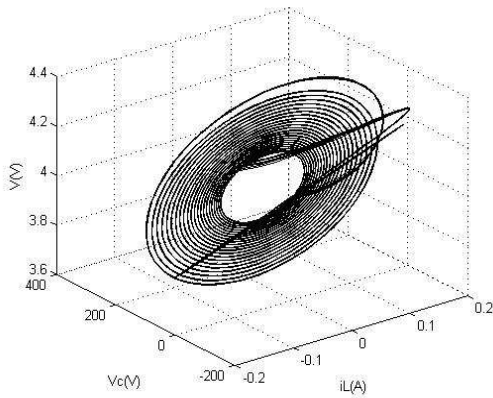


Fig. 7. $f_s = 50$.

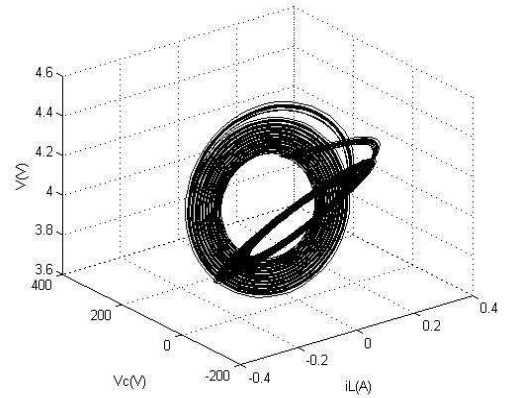


Fig. 8. $f_s = 100$.

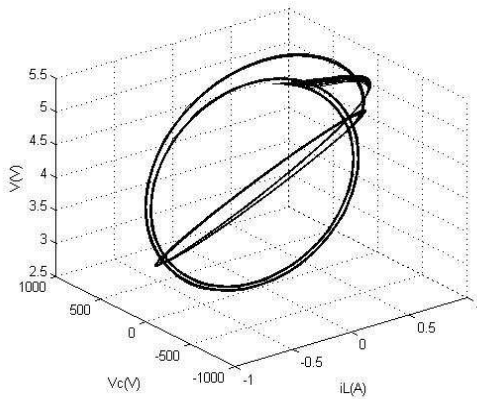


Fig. 9. $f_s = 500$.

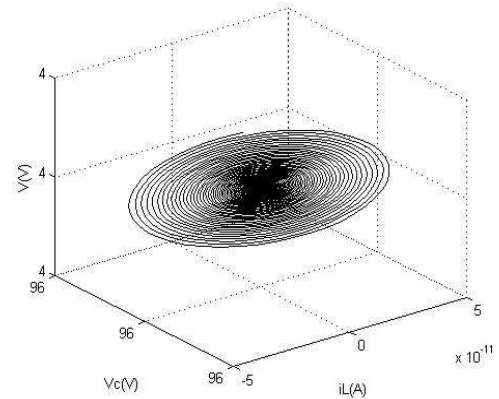


Fig. 10. $f_s = 100kHz$.

Case 1: Routes to chaos.

As it can be seen from figures (3- 10), when the frequency is very little ($f_s = 0.25hz$, Fig. 3), i_L is a point. As the frequency increase to $1Hz$, the chopper get into chaos. And gradually weaken since $30Hz$. When the frequency is $100kHz$, i_L become a point again.

2) Poincaré section analysis: $f_s = 20Hz$:

The Poincaré section is computed for $i_L = 0$ when the frequency is $20hz$ and the load voltage is stable in $4V$. From figures (11-12) it can be seen that the symmetry is around the nominal voltage capacitor V_{cn} that is $50V$.

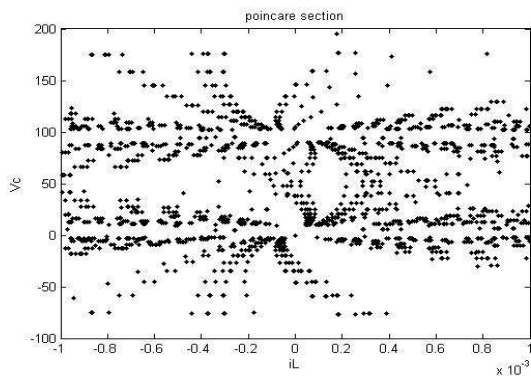


Fig. 11. Poincaré section

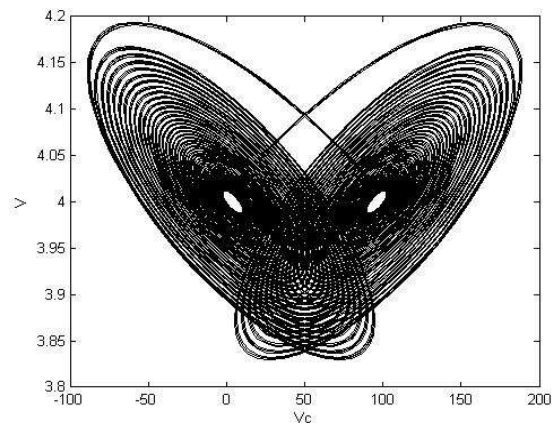


Fig. 12. Phase portrait of v over v_c

3) First return map: The first return (13) map is computed by the voltage of nonlinear load (v) for each minimum of I_L which is detected with $\frac{di_L}{dt} = 0$ and $|i_L| < 0.1$. From bifurcation diagram (figure (14)) it can be seen that the system is in the chaos between $1Hz$ and $30Hz$. As the frequency increase, the system get into stable. But at the resonance

frequency 2253.6Hz , the load current i_L get the maximum value of 5A , the system get into unstable aera (figure (15)).

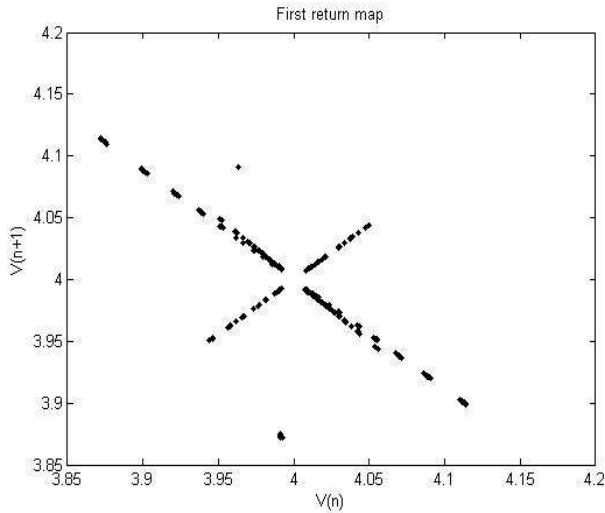


Fig. 13. First return map

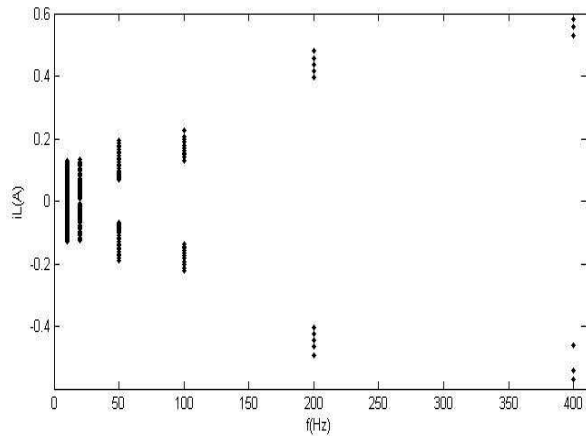


Fig. 14. Bifurcation diagram

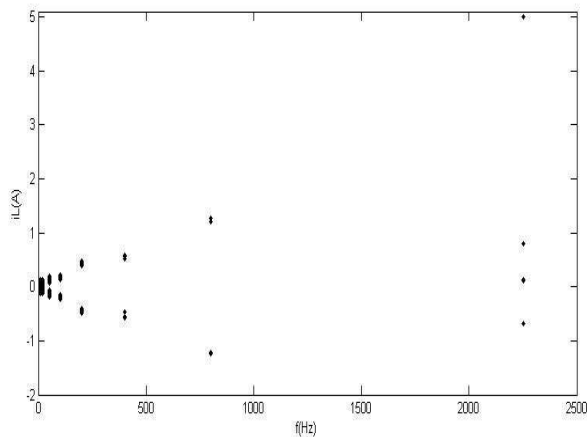


Fig. 15. Bifurcation diagram for a wide range variation of f_s

IV. CONCLUSION

In this paper, a study of chaotic behaviour in multicellular chopper (mainly 2-cells chopper) connected to a particular nonlinear load is investigated. The main contribution of this

work consists to draw the importance of the link between the switching frequency of the chopper and the resonance frequency of the circuit in chaos generation. The simulated results show that toroidal chaos occurs. Our on going work is first to implement the proposed method in experimental 2-cells set up with nonlinear load realization. Then we are planning to extend this investigation to choppers with cell number greater than two.

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