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SLIDING MODE CONTROL FOR A MULTICELL CONVERTERS

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ABSTRACT

In this paper, the sliding mode control is developed for a multicell power converter. The main purpose of this paper is to present the hybrid model and generate commutation surfaces based on a Lyapunov function. Simulations draw attention to the efficiency of the proposed strategy on a three-cell converter to assess the performances and the robustness of the synthesized controller.

Index Terms— multicell converter, sliding mode, robustness.

1. INTRODUCTION

The power electronics are well known important technological developments. This is carried out thanks to the developments of the semiconductor of power components and a new system of energy conversion. Many of those systems present hybrid dynamics. Among these systems, multicell converters built upon a series-association of the elementary cells of commutation cells. This structure, which appeared at the end of the 20^{th} century [6], makes it possible to share the constraints in tension and it also improves the harmonic contents of the wave forms[4]. Moreover, modeling is a very important step for control laws and observers synthesis. In literature, Several approaches have been considered to develop methods of control and observation of the multicell converter. Initially, models have been developed to describe their instantaneous [5], harmonic [6] or averaging [1] behaviors. These various models were used for the development of control laws in open-loop [12].

This control is very simple, to ensure the functioning of the converter with pulses delayed by 1/3 to the period relative to each other. But it can do more to ensure the stability of tension capacitors. It will be necessary to use a closed loop control that take into account the evolution of the capacitor voltages and can meet the requirement to control and maintain voltage levels defined [2].

In the other hand, the following model must be adequately simple to allow real time control but enough precise to achieve the desired behavior. Because it's based on continuous variables and discrete variables, Multicell converter modeling is claimed to be difficult [7] [8]. According to previous studies, three types of models could be found.

The average model consists of calculating average value of all variables during one sampling period. Nevertheless, this model cannot represent the capacitors terminal voltage natural balancing; The harmonic model consists of the calculation of the voltage harmonic phases and amplitudes by considering the charging current in steady-state operation; The instantaneous model deals with time-evolution of all variables including the switch states(discrete location). This model is hard to use as controllers and observers design is impossible since the converter is not a continuous system but the mixture of continuous and discrete systems [2] [3].

For a better exploitation of controller possibilities, hybrid modeling allows multicell converters using analysis and synthesis powerful tools [9]. The aim of this paper is to propose the hybrid modeling of a p-cells converter which will be afterwards controlled using sliding modes. This paper is organized as follows: after the presentation of the multicell converters in section 2, section 3 gives the proposed sliding mode controller. Simulation results are given in section 4.

2. CONVERTER STUDY MODE CONTROL

2.1. Multicellular converter description

The general structure of the studied multicell converter is presented in figure 1. It is composed of p-cells. Each cell contains two complementary power electronics components controlled by a binary switch .That means that if the upper switch of the k^{th} cell is closed $u_k = 1$ the lower switch is open.

The multicellular converter cells are associated in series with a RL load and the cells separated by capacitors that can be considered as continuous voltage sources [1][10].thus, the converter has $p-1$ floating voltage sources. In order to ensure normal operations, it is necessary to guarantee a balanced distribution of the floating voltages $V_{c_k} = k\frac{E}{p}$. The output voltage V_s

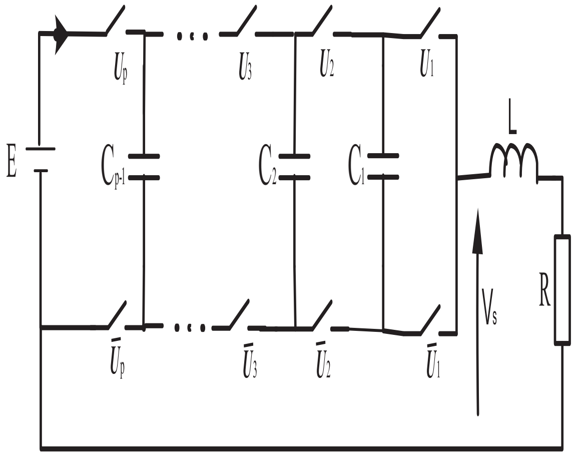

Figure 1. Studied p-cells converter.

can attend p voltage levels $\left(\frac{E}{p},...,(p-1)\frac{E}{p},E\right)$[10]. The general state space representation of the p-cells converter is given by the system 1:

$$\begin{cases} \frac{dv_{C_1}}{dt} = \frac{1}{C_1}(u_2-u_1)\,i_{ch} \\ \vdots \\ \frac{dv_{C_{p-1}}}{dt} = \frac{1}{C_{p-1}}(u_p-u_{p-1})\,i_{ch} \\ \frac{di_{ch}}{dt} = -(u_2-u_1)\frac{v_{C_1}}{L} - (u_3-u_2)\frac{v_{C_2}}{L} - \\ ... - (u_p-u_{p-1})\frac{v_{C_{p-1}}}{L} - \frac{R}{L}i_{ch} + u_p\frac{E}{L} \end{cases} \quad (1)$$

For this model the load current i_{ch} and the floating voltage V_{c_k} are used as space variables[7]such that:

$$\dot{X} = AX + B(X)u \quad (2)$$

Where $X = [v_{C_1}, v_{C_2}, .., v_{C_p}, i_{ch}]^T$ is the continuous state vector and $u = [u_1, ...u_p]^T$ the applied control input. The state matrix A is defined as follows 3:

$$A = \begin{bmatrix} 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \cdots & 0 & -\frac{R}{L} \end{bmatrix} \quad (3)$$

and the control matrix B expressed as 4:

$$B = \begin{bmatrix} -\frac{i_{ch}}{C_1} & \frac{i_{ch}}{C_1} & 0 & ... & 0 \\ 0 & -\frac{i_{ch}}{C_2} & \frac{i_{ch}}{C_2} & ... & 0 \\ .. & 0 & .. & .. & .. \\ 0 & ... & 0 & -\frac{i_{ch}}{C_{p-1}} & \frac{i_{ch}}{C_{p-1}} \\ \frac{v_{C_1}}{L} & \frac{v_{C_2}-v_{C_1}}{L} & ... & \frac{v_{C_{p-1}}-v_{C_{p-2}}}{L} & \frac{E-v_{C_{p-1}}}{L} \end{bmatrix} \quad (4)$$

2.2. linearization

The linearization method, proposed in [7], consists on adding a compensation term of duty cycle, which result from the comparison of the float voltage with the desired reference ,Figure 2 This method gives a directly control of the current. The average value of the current of the k^{th} capacitor is:

$$i_k = (u_{k+1} - u_k)\,i_{ch} \quad (5)$$

Moreover, the linearization method is determined by adjusting the difference of the duty cycle $(u_{k+1} - u_k)$. So, this gap on the voltage is filled in one pulse period. We thus obtain a second relationship

$$i_k = C_k \frac{\frac{kE}{p} - V_{ck}}{T} \quad (6)$$

From equations 5 and 6, we deduce the desired value

$$u_{k+1} - u_k = \frac{C_k}{Ti_ch}\left(\frac{kE}{p} - V_{ck}\right) \quad (7)$$

T is the switching period, C_k the k^{th} capacitor,i_{ch} current of load, p number of cell and V_{c_k} the floating voltage. for $k \in \{1, 2..., p-1\}$

Control of switching cells p gives us p degrees on duty cycles. But there is that $p-1$ floating voltages to enslave. We can then use the last degree by setting one of the values of duty cycle u_1 oru_p. This value can be chosen to be constant, or chosen so that the current continue a reference load. Several structures of control laws are possible: we set u_1 or u_p we deduce the rest of the vector u_i .

Figure 2gives a representation of the strategy.

Where:

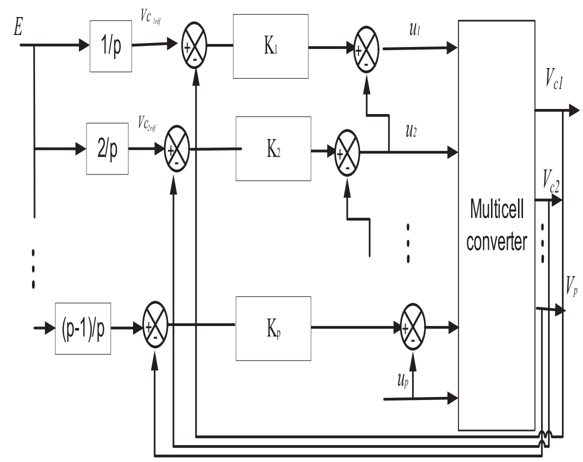

Figure 2. Strategy of linearization converter.

V_{c_k}: is the natural balancing as defined as flow $V_{c_k} = k\frac{E}{p}$

$V_{Ci_{ref}}$: the i^{th} desired references of the floating voltage
$K_i = \frac{C_k}{Ti_{ch}}$

The control validation is performed by simulation results with three cell converter.
Figures 3 and 4 represent the floating voltage $V_{c_{1,2}}$ and the load current i_{ch} , respectively.
Figure 4 shows that has a greater fluctuation in the dynamic current.

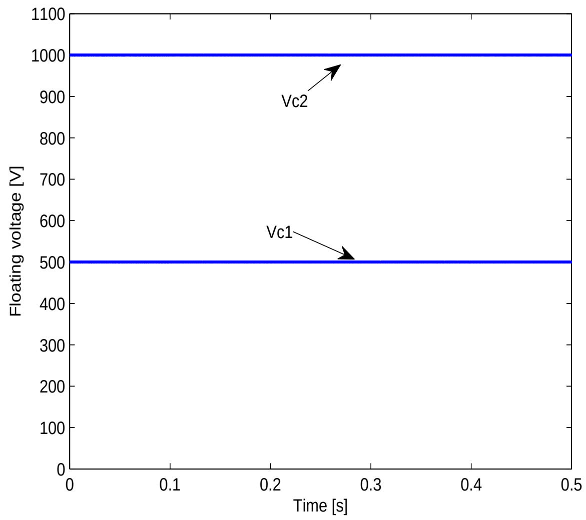

Figure 3. Floating voltage evolutions V_{C_1} andV_{C_2}

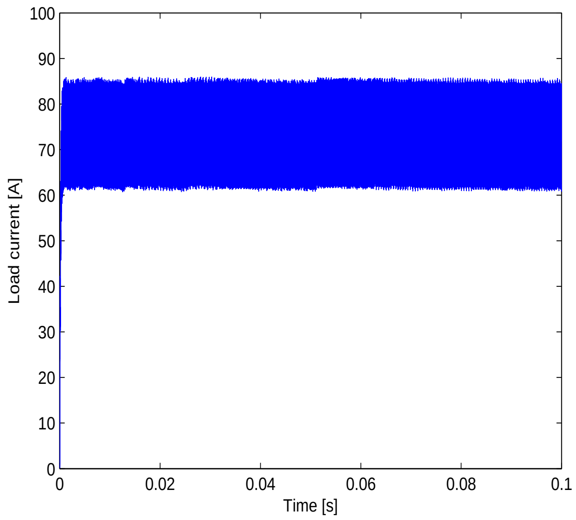

Figure 4. The current load evolution i_{ch}

The major problem of control is the sensitivity between the load and the current reference I_{ref}.
To resolve this problem, many researchers propose a robust control based on sliding mode control.

3. PROPOSED SLIDING MODE CONTROL FOR MULTICELL CONVERTER

Sliding mode control become more and more attractive to control for multi-cell converter. The proposed control approach is based on the use of model developed in [7], to control a two cells converter. For this study, we propose to generalize this control approach to p cells multicellular converter. Thus, we define p sliding surfaces as follows 8:

$$\begin{cases} S_1 = i_{ref} v_{c_1} - i_{ch} v_{ref_1} \\ S_2 = i_{ref} v_{c_2} - i_{ch} v_{ref_2} \\ \vdots \\ S_p = i_{ref}\left(E - v_{c_1}\right) + i_{ref}\left(E - v_{c_2}\right) \cdots i_{ref}\left(E - v_{c_{p-1}}\right) \\ -i_{ch}\left(v_{ref_1} + v_{ref_2} .... + v_{ref_{p-1}}\right) \end{cases} \tag{8}$$

where $e = \begin{pmatrix} i_{ref} - i_{ch} & V_{ref_1} - V_{c_1} & \cdots & V_{ref_1} - V_{c_1} \end{pmatrix}$ the tracking error is asymptotically stable . First, we define the control objective which to satisfy the sliding surfaces S as follow 9:

If:

$$\begin{cases} S_1 = 0 \\ S_2 = 0 \\ \vdots \\ S_p = 0 \end{cases} \tag{9}$$

And we use the $V_{ref_k} = k\frac{E}{p}$ Next, we get

$$\begin{cases} S_1 = i_{ref} v_{c_1} - i_{ch} v_{ref_1} = 0 \\ S_2 = i_{ref} v_{c_2} - i_{ch} v_{ref_2} = 0 \\ \vdots \\ S_p = i_{ref}\left(E - v_{c_1}\right) + i_{ref}\left(E - v_{c_2}\right) \cdots i_{ref}\left(E - v_{c_{p-1}}\right) \\ -i_{ch}\left(v_{ref_1} + v_{ref_2} ... + v_{ref_{p-1}}\right) = 0 \end{cases} \tag{10}$$

we deduce $\begin{cases} v_{c_1} = v_{ref_1} \\ v_{c_2} = v_{ref_2} \\ \vdots \\ i_{ch} = i_{ref} \end{cases}$ The closed loop control sequences are defined as:

$$u_i = \frac{1}{2}\left[1 - sign\left(S_i\right)\right] \tag{11}$$

for $i \in \{1, 2..., p\}$

4. SIMULATION RESULTS

In order to illustrate the performance of the proposed control, we considered a three-cell converter connected to an RL load.
$u_i = \frac{1}{2}\left[1 - sign\left(S_i\right)\right]$,

$i \in \{1, 2, 3\}$ The sliding mode surfaces are given by 12

$$\begin{cases} S_1 = i_{ref} v_{c_1} - i_{ch} v_{ref_1} \\ S_2 = i_{ref} v_{c_2} - i_{ch} v_{ref_2} \\ S_3 = i_{ref}\left(E - v_{c_1}\right) + i_{ref}\left(E - v_{c_2}\right) \\ -i_{ch}\left(v_{ref_1} + v_{ref_2}\right) \end{cases} \quad (12)$$

The control aims to insure the convergence of switching surfaces S_i to zero, to allow the reaching of the state variables to their references.
The parameters of the studied converter are given in table 1:

Table 1. Studied multicell converter parameters

Components	Rating values
E	$1500V$
L	$0.5mH$
$C1, C2$	$40F$
R	10Ω
f	$40Khz$
I_{ref}	$60A$

Figures 5 and 6 show respectively the floating voltages V_{C_1} , V_{C_2} and the load current i_{ch} evolutions. The floating voltages are set around their references.

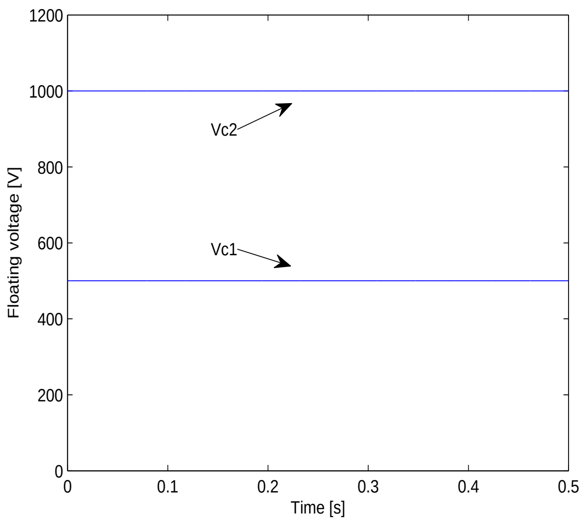

Figure 5. Floating voltage V_{C_1} and V_{C_2} evolutions obtained by application of the sliding mode control

Moreover, the load current reaches the desired reference.
Than, the proposed sliding mode control is robust and suitable for the studied converter. It rejects external perturbation and some controlled system parameters variations.

The robustness of the proposed SMC was tested with a load resistance variation of 50%.

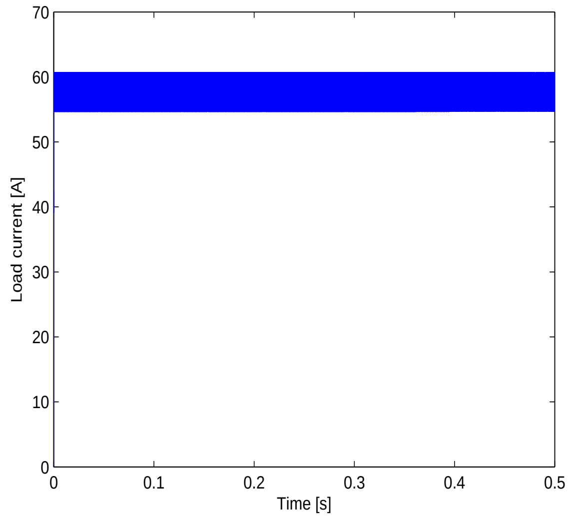

Figure 6. Load current i_{ch} evolution obtained by application of the sliding mode control and for $I_{ref} = 60A$

Figure 7 and 8 presents the voltages V_{C_1},V_{C_2} and the load current for a load resistance change from 10Ω to 15Ω at $t = 0.2s$. According to these results, it can be

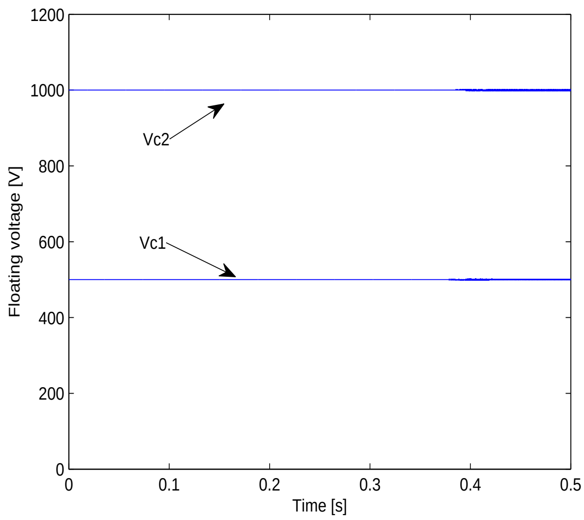

Figure 7. Floating voltages V_{C_1} and V_{C_2} for a load resistance change

noticed that the performances of the proposed control for load variation are satisfactory.
Figure 9 and 10 present, respectively, the variation of the floating voltages V_{C_1} and V_{C_2} evolutions and the current of load under change from $60A$ to $70A$ at $0.2s$. We can notice that the control keeps the floating voltages constant.

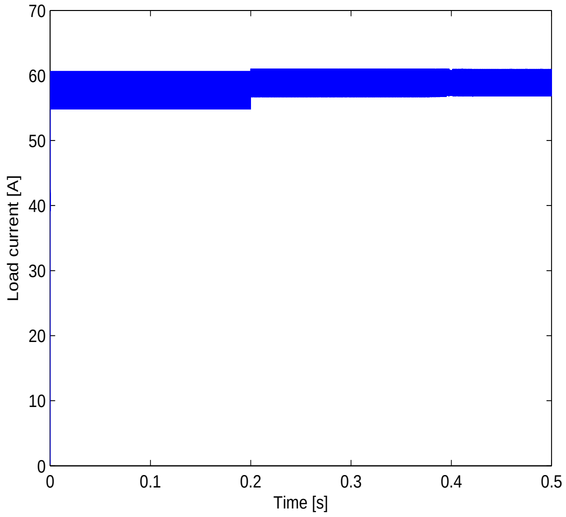

Figure 8. Load current i_{ch} evolution for a load resistance change

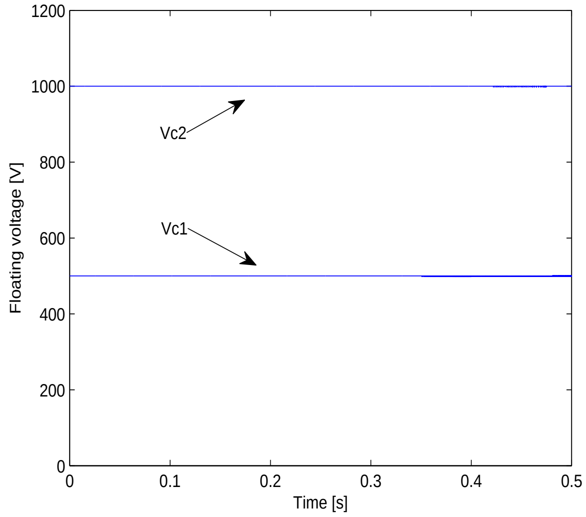

Figure 9. Floating voltages V_{C_1} and V_{C_2} evolutions under variation of current reference

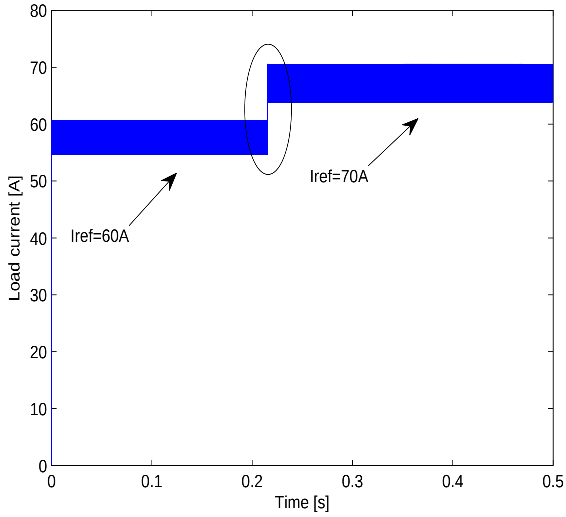

Figure 10. Load current i_{ch} under variation of current reference

5. CONCLUSION

In this paper, the hybrid sliding mode controller is proposed.The results show that the proposed method can perform an efficient for system...
Moreover this method present a robust control for the variations and uncertainties parameters In the literature, we can found many solutions for the control of the multi-cell converter. In this paper, we proposed the hybrid sliding mode controller. This mode of controller is suitable for this system. It has proven to be robust against controlled plant parameters variations and uncertainties.

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