

A Comparison Between PWM and Petri Nets Control Applied for Series Multi-cells Chopper

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Abstract— This paper proposes two control strategies for series multi-cells chopper. First, we study the open loop PWM control with triangular carriers, then a Petri Nets model for the same converter will be developed and tested .The simulation results show the efficiency and the robustness of Petri Net to control this type of converters.

Keywords — Series multi-cells chopper, PWM control strategy, Petri nets control strategy, Hybrid dynamic system, Hysteresis methodology

I. INTRODUCTION

Power electronics has shown a very well known important technological development [1]. This is realized due to the development of semiconductors, power components and new systems of energy conversion [2]. In the recent years researchers have given a great importance to the application of the new structures of the power electronics systems in the renewable energy such as wind and photovoltaic energy. Among the power systems, multicellular converters are based on the series association of elementary switching cells. This structure, which appeared at the beginning of the 1990's, allows the sharing of voltage constraints by all commutation series connected cells, which greatly improved the waveform harmonic content [3-5]. Many works proved high dynamic performance of this structure. In order to control this converter we must wisely choose the adequate model to allow the control synthesis and the precision to achieve the desired behavior. There are three types of models [6]; an average model, a harmonic model and an instantaneous model. The instantaneous model takes into account the evolution at every moment of all the variables including the state of switch. The most problematic factor is how to assure the balancing of capacitor voltage and a good tracking of load current. For this reason the choice of the controller is very important to ensure a well functioning of the converter. In this work two strategies are proposed to control the 2-cells chopper, where the performances are compared. There is a simple open loop required to ensure the stability of this converter and it is easy for implementation. Control is known as the PWM (modulation of width of pulse); voltage balancing is naturally assured with this method [7]; but this natural balancing

possess slows the dynamic properties. In the second part a Petri net model and control are proposed to minimize the number of commutations to one for certain cases. This is important for improving content of the output energy and the efficiency of the system by the reduction of the switching losses [8]. The paper is organized as follows: In section II, the multicellular chopper modeling is presented. Section III, deals with PWM and Petri nets control strategy for 2-cells chopper are shown .The simulation results are tested and analyzed in Section IV. Finally a conclusion is drawn in the last Section.

II. SERIES MULTI-CELLS CHOPPER MODELING

Fig.1 represents a p-cells chopper connected to the R-L load. It is based on the association of p commutation cells where each one is composed of pairs of complementary switches [9], between these latter we insert flying capacitors. Each cell is controlled by a binary function $u_k(t) \in \{0,1\}$, $k=1,\dots,n$, where $u_k=1$ indicates that the upper switch is closed and the lower switch is open.

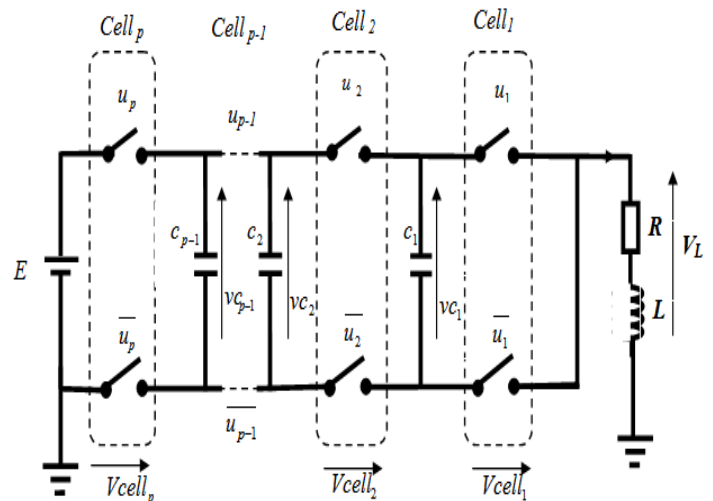


Fig.1 p-cells chopper structure

The system of equations (1) represents the instantaneous model of a multicellular chopper with a p-cells.

$$\begin{cases} \frac{dV_{C1}}{dt} = \frac{u_2 - u_1}{C_1} i_L \\ \frac{dV_{C2}}{dt} = \frac{u_3 - u_2}{C_2} i_L \\ \vdots \\ \frac{dV_{C_{p-1}}}{dt} = \frac{u_p - u_{p-1}}{C_{p-1}} i_L \\ \frac{di_L}{dt} = \frac{u_2 - u_1}{L} V_{C1} + \dots + \frac{u_p - u_{p-1}}{L} V_{C_{p-1}} + \frac{u_p}{L} E - \frac{R}{L} i_L \end{cases} \quad (1)$$

The cell voltage and output voltage are given by (2) and (3).

$$V_{cell_k} = V_{c_k} - V_{c_{k-1}} \quad (2)$$

$$V_L = \sum_{k=1}^p u_k V_{cell_k} \quad (3)$$

For 2-cells chopper ($p = 2$), this model becomes:

$$\begin{cases} \frac{dV_{C1}}{dt} = \frac{u_2 - u_1}{C_1} i_L \\ \frac{di_L}{dt} = \frac{u_2 - u_1}{L} V_{C1} + \frac{u_2}{L} E - \frac{R}{L} i_L \end{cases} \quad (4)$$

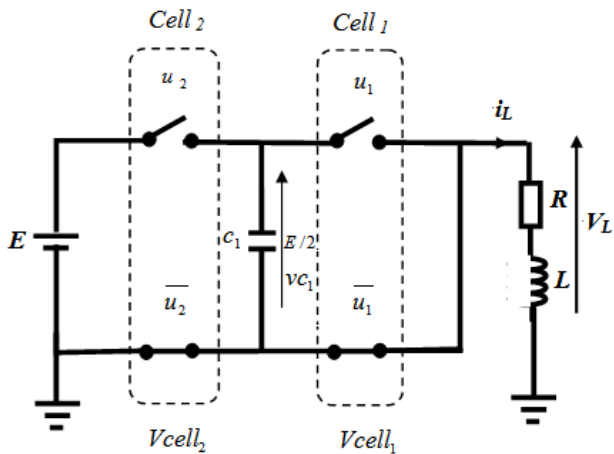


Fig.2 Two cells chopper connected to R, L load

Where V_{c1} , i_L represent respectively the capacitor voltage and the output current; u_1 and u_2 are the binary switches.

In order to ensure normal operations, it is necessary to guarantee a balanced distribution of the floating voltages $V_{c_k} = kE/p$, ($V_{c1} = E/2$ for 2 cells chopper).

III. CONTROL STRATEGIES

A. Pwm Control Strategy

With open loop, this control is simple for implementation; it ensures the stability of voltage to the capacitor terminals. The levels of control in each cell are generated by the intersection between a triangular carrier and signal modulating. In the case of the chopper, this signal is a constant [9],[10]. The control by PWM requires the same number of the triangular carriers as cells; the carriers shifted by $\delta = 2\pi/p$ angle. The functions t_{rk} used for generating triangular signal on the interval $[0, 1]$ for a two cell chopper are:

$$\begin{cases} t_{r1} = \frac{1}{2} \left[\frac{2}{\pi} \arcsin \left[\sin \left(\frac{2\pi}{p} f_p t - \frac{\pi}{2} \right) + 1 \right] \right] \\ t_{r1} = \frac{1}{2} \left[\frac{2}{\pi} \arcsin \left[\sin \left(\frac{2\pi}{p} f_p t + \delta - \frac{\pi}{2} \right) + 1 \right] \right] \end{cases} \quad (5)$$

With:

f_p : The triangular carrier frequency

$p = 2$ Number of cells

The principle of open loop control by pulse width modulation (PWM) for a 2-cells chopper is shown in Fig.3.

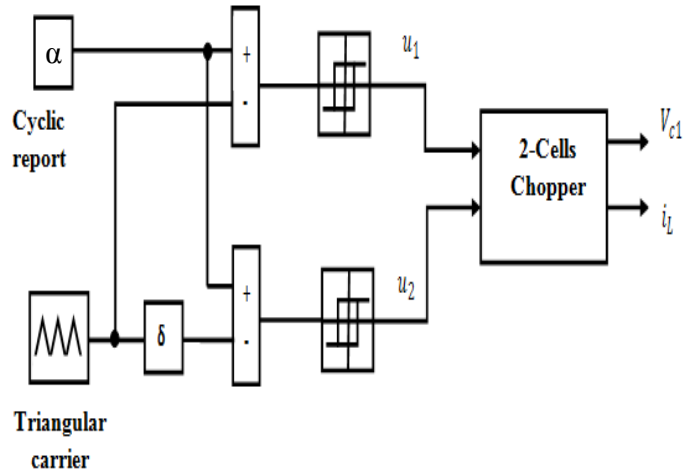


Fig.3 PWM control strategy for 2-cells chopper

B. Petri Nets Modeling and control Strategy

Petri nets are very effective and powerful tools for modeling hybrid systems. They are represented as a graph which has two types of nodes: places and transitions, interconnected by directed arcs. A transfer of tokens from one state to another depends on the transition conditions [11]. The multicellular chopper is among these systems, since it exhibits

both continuous and discrete behavior; load resistor, inductance and flying capacitors are the continuous parts which can be modeled by places. The physical commutations by the switches represent the discrete part which can be described by transitions; a Petri net control is proposed in this part (Fig.4). A transition will occur, only when its specific conditions have been met. Control strategy consists to regulate the voltage balancing V_{Cl} to value $V_{Clref} = E/2$ and the load current i_L to i_{Lref} value. To ensure this regulation, a hysteresis methodology is used [12]. An operating band $^+\delta$ (tolerance errors), is provided, in such a way that the load current and balancing voltage stay inside ($i_{Lref} - \delta_1 \leq i_L \leq i_{Lref} + \delta_1$) and ($V_{clref} - \delta_2 \leq V_{cl} \leq V_{clref} + \delta_2$).

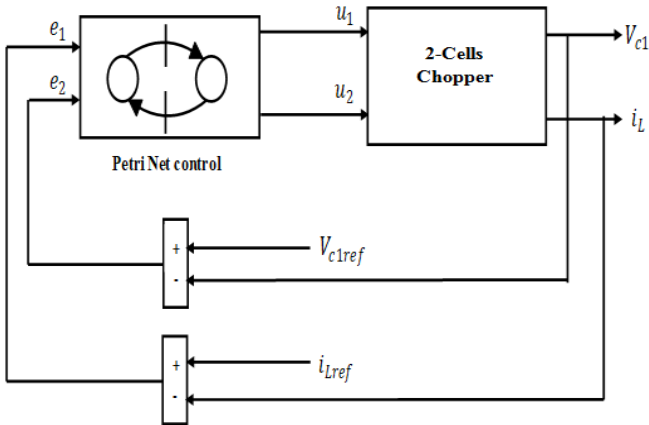


Fig.4 Petri Net control scheme for 2-cells chopper

Where e_1 and e_2 are the errors of current and capacitor voltage ($e_1 = i_{Lref} - i_L$ and $e_2 = V_{clref} - V_{cl}$). The states of the binary switches of cell1 and cell2 respectively (u_1, u_2) are modeled by two places P_1 and P_2 (Fig.5). Transitions from place to another depends on the admissible errors of output current and capacitor voltage as shown in table I.

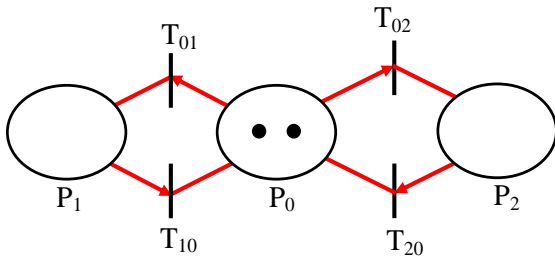


Fig.5 Petri net graph for a control switches of 2-cells chopper

For two cells chopper 4 transitions are possible, for example the T_{01} transition is firing if the load current error is superior or equal to the positive tolerance of the output current, i.e. $e_1 \geq \delta_1$, in this case the current must increase; u_1 switch is committed to open thus $T_{01}=1$. Or if the current is inside the hysteresis band, i.e. $-\delta_1 < e_1 < \delta_1$, then it depends on the capacitor voltage, if the capacitor voltage is less than the

negative tolerance error of the voltage i.e. $e_2 < -\delta_2$, the capacitor should be unloaded, and the transition T_{01} is reached.

TABLE I
TRANSITIONS

Transitions	Designations
T_{01}	$e_1 \geq \delta_1$ or $-\delta_1 < e_1 < \delta_1$ and $e_2 < -\delta_2$
T_{02}	$e_1 \geq \delta_1$ or $-\delta_1 < e_1 < \delta_1$ and $e_2 \geq \delta_2$
T_{10}	$e_1 \leq -\delta_1$ or $-\delta_1 < e_1 < \delta_1$ and $e_2 > \delta_2$
T_{20}	$e_1 \leq -\delta_1$ or $-\delta_1 < e_1 < \delta_1$ and $e_2 < -\delta_2$

IV. SIMULATIONS AND RESULTS

The proposed algorithms are validated through Matlab-Simulink software with the following parameters used in [9]:

- $E = 1500$ V
 - $R = 10$ Ω
 - $L = 0.5$ mH
 - $C_1 = 50$ μ F
 - $i_{Lref} = 75$ A
- For the PWM control:
- $f_p = 16000$ Hz
 - $\alpha = 0.5$ (The cyclic report).

Fig.6 and 7 show the evolution of the load current and the floating voltage for the PWM control.

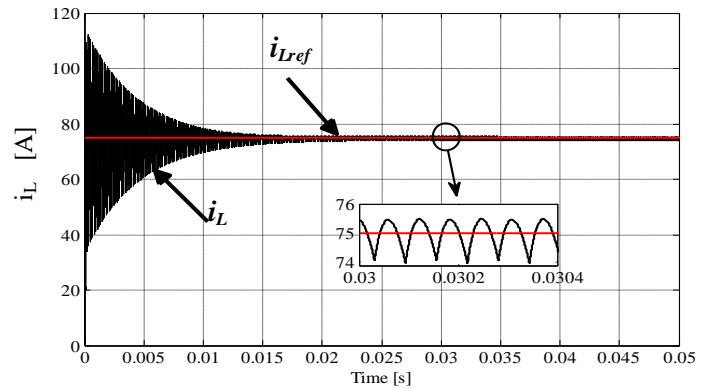


Fig.6 Load current for the PWM control

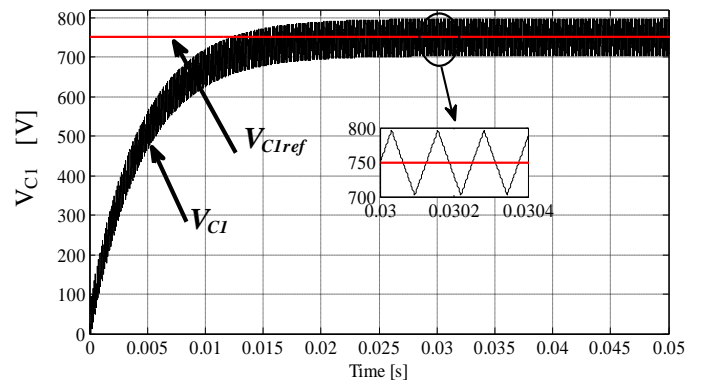


Fig.7 Floating voltage for the PWM control

Fig.8 and 9 show the evolution of the load current and the floating voltage for the Petri Nets control. The admissible tolerance error for load current and capacitor voltage has been selected as follows:

$$\delta_1 = 0.1 \text{ (the load current tolerance error)}$$

$$\delta_2 = 0.2 \text{ (the capacitor voltage tolerance error)}$$

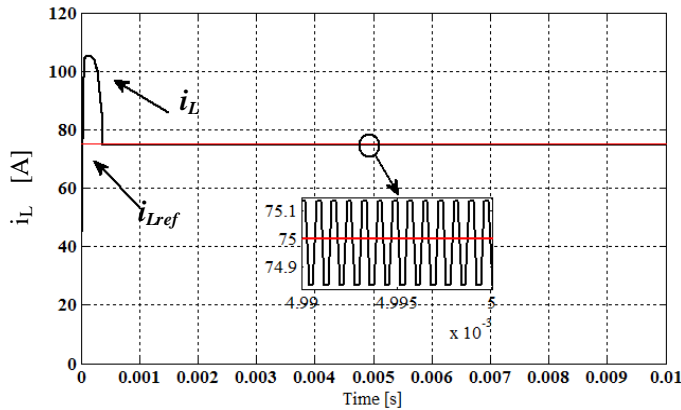


Fig.8 Load current for the Petri Nets control

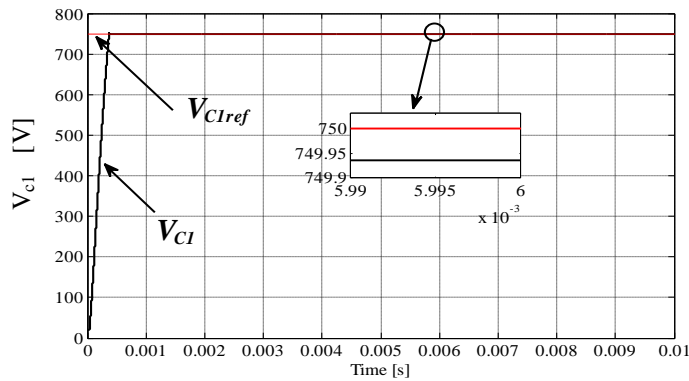


Fig.9 Floating voltage for the Petri Nets control

Compared with PWM control, it noticed that the Petri Nets control is more robust in terms of load current tracking and voltage balancing. The Petri Nets controller show a good tracking of load current in a short time ($4e-4$ s) and is perfectly maintained between the desired bands. It also showed that the floating voltage reach its desired value in a short time ($4e-4$ s) and is well balanced around the reference value with respect to the predefined tolerance error. For PWM control, the transition time is more important than the Petri Nets control (0.02 s) for both current and capacitor voltage. Indeed, a very large offset of load current during the transient time. It also showed a large undulation for the floating voltage. The study provides a substantial improvement in the capacitor voltage undulation and the offset for the load current by using the Petri Nets controller.

V. CONCLUSION

Two controllers have been proposed in this work in order to control 2-cells chopper. It is easy to use a PWM controller to find an appropriate natural balancing for capacitor voltage at the desired value, hysteresis methodology has been verified to regulate the output current and floating voltage by a Petri Nets controller, simulations results showed a best regulation for these latter by Petri Nets controller and they are more satisfactory than those obtained by PWM controller. This is very important to minimize losses in this converter and improves the quality of the output energy.

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