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Overview of Control Techniques for Multicellular Converter

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Abstract. The structure multicellular converters, which appeared at the beginning of the 1990s, makes it possible to share the constraints in tension and it also improves the harmonic contents of the wave forms. To benefit as well as possible from the large potential of the multicellular structure, an appropriate distribution of the voltages crossing each cell is needed. These converters are drastically used in industry as well as in research. One of the main limitations of these converters is unregulated supply of voltage and current. To overcome these problems there are various control techniques used in combination with these converters. In this review we summarized few of these control techniques. Some well known control techniques are PID, sliding mode control and Petri nets control. We have also paid attention on the advantages and disadvantages of these techniques with basic operating principle.

Keywords: multicellular converter, PID, sliding mode, Petri Nets control.

1 Introduction

Power electronics knew important technological developments thanks to the improvements of semiconductors, power components and systems of energy conversion. Among these systems, multicellular converters, which are built upon a series-association of elementary commutation cells, are more and more used in industrial applications. Indeed, they are characterized by their modularity and high efficiency. However, the major drawback of this kind of converter is their control complexity. This structure, which appeared at the end of the 20th 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 [10].

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].

Aim of this paper is to have an overview of all the control techniques used to facilitate the performance of various kinds of multicellular converters. We will briefly discuss the basic concept, advantages and disadvantage of each control technique throughout this review.

2 Research Methodology

2.1 PID control

The main objective of the PID control law is to regulate the output current and all voltages across the flying capacitors.

PID control is one of the oldest and classical control technique used for DC-DC converters. It uses one of its families of controllers including P, PD, PI and PID controllers (Figure 1). These different combinations will gives us various ways to regulate dc power supply in these converters. Due to the various advantages of PID it is widely used for industrial applications in the area of power electronics. One of the main causes for the use of this classical technique still in industrial applications is easy implementation of tuning method like Ziegler-Nichols tuning procedure by which we can easily optimize proportional, integral and derivative term of this control method needed to achieve a desired closed-loop performance. A proportional integral derivation controller is a generic control loop feedback mechanism widely used in industrial control system as well as in research. This approach is often viewed as simple, reliable, and easy to implement.

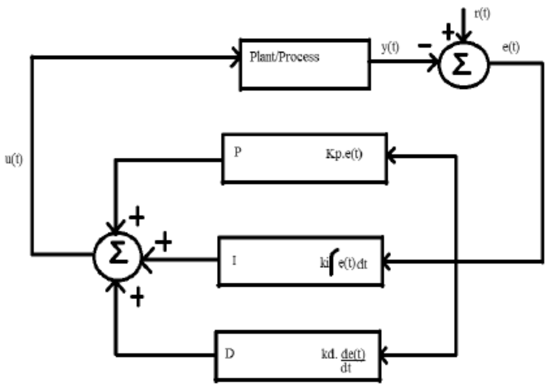

Figure 1 – Block diagram of PID controller

Some important advantages and disadvantages of PID control technique are:

Advantages of PID controllers:

– they are easy and simple to implement;

– easy to understand;

– reliable for linear systems.

Disadvantages of PID controllers:

– they do not reliable and satisfactorily in case of nonlinear systems;

– it shows longer rise time when overshoot in output voltage decreases;

– they suffer from dynamic response and produces overshoot affecting the output voltage regulation of converter.

Applied to a two cells converter [11], it results that the capacitor voltages and the output current reach the desired reference values without static errors (Figure 2). To test the robustness of the control the authors consider the variation of the input voltage and the load resistance. From these variations, we can deduce that the PID control law is suitable for the studied converter. Moreover, it rejects external perturbations and some controlled system parameters variations. Thus, we can confirm that the PID control applied to a multicellular converter is robust for the considered load variation.

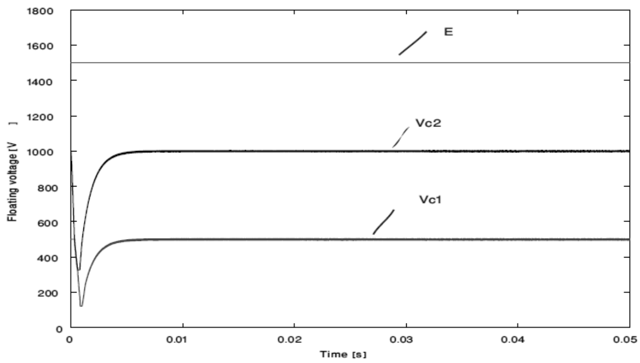

Figure 2 – Floating voltage V_{C1}, V_{C2} and E evolutions

2.2 Sliding Mode Control

SM controller is a type of non-linear controller. It is employed and adopted for controlling variable structured systems. It is very easy to implement as compared to other types of nonlinear and classical controllers. Two important steps in SM control is to design a sliding surface in state space and then prepared a control law to direct the system state trajectory starting from any arbitrary initial state to reach the sliding surface in finite time, and at the end it should arrive to a point where the system equilibrium state exists that is in the origin point of the phase plane. There are three important factors responsible for the stability of SM controllers, existence, stability, and hitting condition. Sliding Mode control principle is graphically represented in Figure 3.

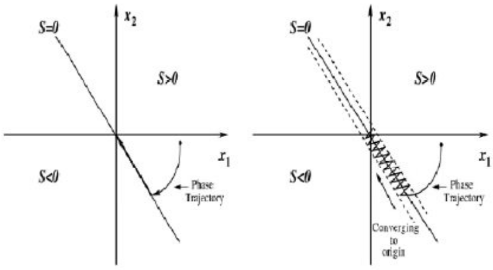

Figure 3 – Graphical representation of SM control

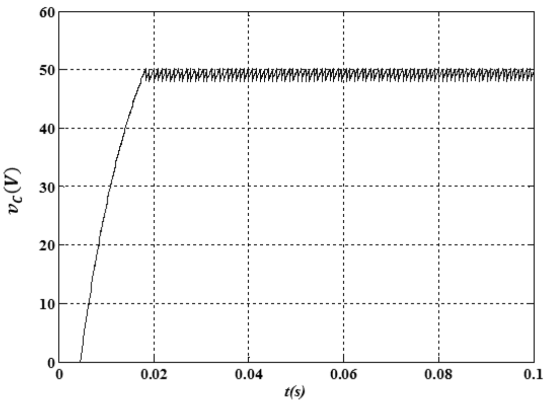

Figure 4 – Floating voltage V_C evolutions obtained by application of the sliding mode control

The sliding line divides the phase plane into two main regions shown in the figure. Each region is represent by a switching state and when the trajectory comes at the system equilibrium point, in this case the system is considered as stable system. A unique feature of an ideal sliding mode control technique is that it operates at infinite switching frequency. But practical SM controllers are operated at finite switching frequencies only which represent a quasi-sliding mode.

Advantages of SM controllers:

– they show good stability for large line and load variations;

– high robustness;

– fast dynamic response;

– simple and easy implementation.

Disadvantages of SM controllers:

– SM controlled converters suffers from switching frequency variation;

– these controllers are not available in integrated-circuit (IC) forms for their power electronic applications;

– there is no systematic procedure available for the design of sliding mode controllers.

Sliding mode control become more and more attractive to control for multi-cell converter. Applied to a two cells converter connected to a nonlinear load, the control keeps the load current constant at the desired I_{ref} value and the floating voltages change with the variation of the input voltage [12] (Figure 4). 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.

In [13] the robustness of the SMC was tested with a load resistance variation of 50 %. In this paper, the performances of the sliding mode control for load variation are satisfactory.

2.3 Petri nets control

The method applied to a two cells converter connected to a nonlinear load is illustrated in Figure 5

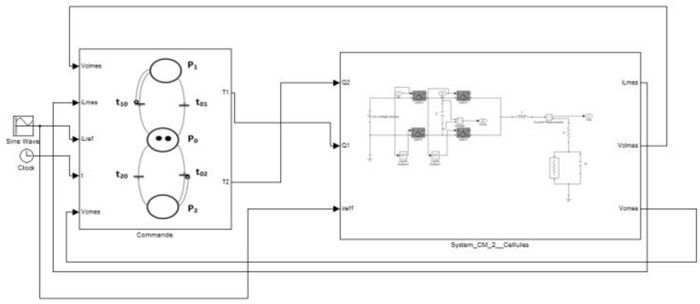

Figure 5 – Global structure of the Petri net control

The control consists of two parts, a continuous and a discrete. The first is based on a classical PI control loop for regulating the output voltage. This loop has as input the error $E_1 = v_{Cref} - v_C$ and i_{Lref} as output a current. The second control loop is done by a Petri net whose mission is the current regulation I_s to value i_{Lref} calculated by the PI. The current regulation is followed by a voltage balancing to ensure a better distribution of the latter in each cell. This algorithm is developed in order to control the system, in case it has an imbalance in the voltage of cells. The transition from one place to another is dependent on the voltage state, current i_{Lref} and chopper configurations. The closure of the switch of the cell (Celli) depends on the validation of the transition t_{i0} and the elapsed delay d_i.

This delay models the time allowed between two successive commutations, it is based on the technology used for making the switch. For our work we took the same delay ie $d = d_1 = d_2$. In the Petri the role of two arcs inhibitors, is to prevent the presence of more than one, token in places P_1 and P_2.

The imbalance of the cells voltage is one of the major problems of this type of converter, the de-balancing causes a failure of the voltage source if the string current exceeds the current permitted entry. Pollution of the power system harmonics reactions is one of the other consequences of this problem; we will show in the simulation result the contribution of this approach. In [14], the simulation results show the convergence of the current branch to a neighborhood of the value of the nominal operating current response times over (Figure 6). The evolution of the input current exhibited a remarkable performance of Petri nets control on pollution network lover converter input to the conventional control. Applied to a two cells converter associated to a nonlinear load, the floating capacitor voltage and the output current reach the desired reference values (Figures 6–7)

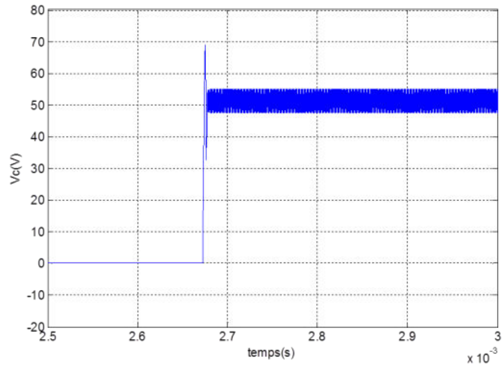

Figure 6 – Floating voltage v_C evolutions obtained by application of the Petri nets control

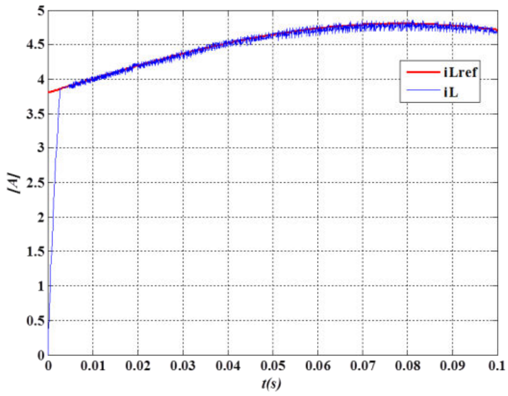

Figure 7 – Current load i_L evolutions obtained by application of the Petri nets control

3 Conclusions

In this review we provided an overview of control techniques used for multicellular converters. We briefly explained the basic concepts of each control techniques. We highlighted the advantages and disadvantages of each technique. We can conclude that each control techniques have their own limitations and drawback. It depends on our need that what kind of control technique is needed for particular purpose. There is still scope for the development of more reliable and efficient control technique.

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Огляд методів контролю багатокоміркового перетворювача

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Анотація. Конструкція багатокоміркового перетворювача, що з'явилася на початку 1990-х років, дає змогу розподілити обмеження напруги, а також покращує гармонічний вміст хвиль. Для максимально ефективного використання потенціалу багатоклітинної структури, необхідно забезпечити відповідний розподіл напруги для кожної комірки. Такі перетворювачі широко використовуються у промисловості й наукових дослідженнях. Одним із основних їх є нерегульоване постачання напруги та струму. Для подолання цих проблем існують різні методи керування, які використовуються для цих перетворювачів. У цій статті коротко описані деякі з цих методів керування. Деякі добре відомі методи керування – це застосування ПІД-регулятора, режиму ковзання, та управління мережами Петрі. Особлива увага приділена перевагам і недолікам цих методів із основним принципом роботи.

Ключові слова: багатоклітинний перетворювач, ПІД-регулятор, режим ковзання, управління мережею Петрі.