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A new hybrid control method for multi-cell choppers. Application to power renewable energy systems

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Abstract—The growing development of renewable energy opens new perspectives in the use of power converters, both in terms of technology and control. Unfortunately, conventional choppers set some serious problems, even those using "parallel or series multi-cell" technology. Indeed, the main problem in parallel multi-cell choppers is the possible imbalance of the currents in each cell. This may be due to the components imperfections (resistors, inductors) and/or to the circuits control (the signals have not exactly the same duty cycle).

In this paper we propose a new generation of parallel multi-cell choppers specially designed for renewable plants. A reconfiguration of the control is proposed in response to a variation between the current branches. Numerical simulation results are presented and discussed to validate the proposed model.

Index Terms—Power converter, Petri nets, hybrid dynamic systems, multi-cell chopper. wind power generation.

I. INTRODUCTION

Differential heating of the earth's surface by the sun causes the movement of large air masses on the surface of the earth, i.e., the wind. Wind energy conversion systems convert the kinetic energy of the wind into electricity or other forms of energy. Wind power generation has experienced a tremendous growth in the past decade, and has been recognized as an environmentally friendly and economically competitive means of electric power generation.

The characteristics of the wind resource are important in various aspects of the use of wind energy. The first step in any wind energy project is the identification of suitable sites and the prediction of the economic viability of the wind project.

More and more countries are ratifying the 1997 Kyoto Protocol, and wind power has become one of the most effective ways. The wind turbine technology is one of the most emerging renewable technologies. It started in the 1980s with a few tens of kW production power to today with Multi-MW range wind turbines that are being installed.

In classical power systems, large power generation plants located at adequate geographical places produce most of the power, which is then transferred towards large consumption centers over long distance transmission lines. The system control centers monitor and control the power system continuously to ensure the quality of the power, namely the frequency and

the voltage. This also means that wind power production in the beginning did not have any impact on the power system control but now due to their size they have to play an active part in the grid. The technology used in wind turbines was in the beginning based on a squirrel-cage induction generator connected directly to the grid. By that power pulsations in the wind are almost directly transferred to the electrical grid. Furthermore there is no control of the active and reactive power, which typically are important control parameters to regulate the frequency and the voltage. As the power range of the turbines increases those control parameters become more important and it is necessary to introduce power electronics [3] as an interface between the wind turbine and the grid. The power electronics is changing the basic characteristic of the wind turbine from being an energy source to be an active power source. The electrical technology used in wind turbine is not new. It has been discussed for several years [6]-[4] [11] but now the price pr. produced kWh is so low, that solutions with power electronics are very attractive.

First problems in the parallel multi-cell chopper is the possible imbalance of the currents in each cell. The imperfection of the converter can lead to an imbalance of the currents. These imperfections may be due to active components (resistors in conduction of switch) the passive components (inductors) or circuits control (the signals have not exactly the same duty cycle). A reconfiguration of the control is proposed in response to a variation between the current branches. This control is based in Petri nets. This type of control is an efficient solutions to this type of system. Finally simulation results are presented to validate the theoretical results. The paper is organized as follows: Section II, the modeling and analysis of system are presented. Section III is devoted to the Petri net control of the converter. To illustrate the theoretical results, simulation results are presented in Section IV. Finally a conclusion will be presented in Section V.

II. MODELLING

Wind farms are created when multiple wind turbines are placed in the same location for the purpose of generating large amounts of electric power Fig.1. Due to rising energy

prices and the resultant search for alternatives, there are now thousands of wind farms in many countries around the world. There is still a lot of controversy surrounding the pros and cons of wind power and its local impact.



Fig. 1. wind farm.

Wind turbines come with different topologies, architectures and design features. The schematic of a wind turbine generation system is shown in Fig.2. Some wind turbine topologies are cited in [5].

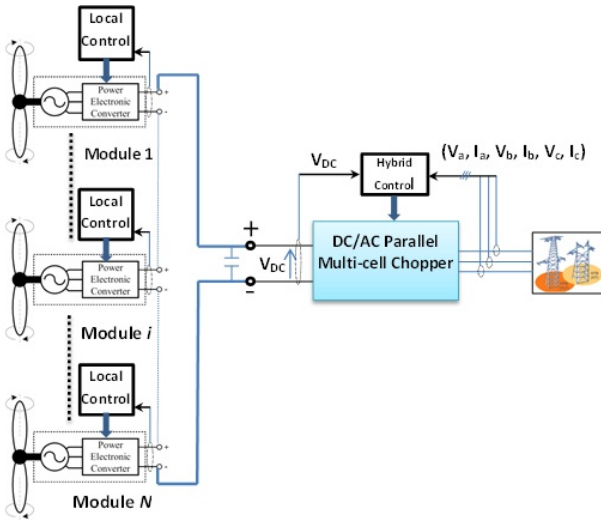


Fig. 2. Chain of production of wind energy.

A. Wind Speed

The wind speed usually varies considerably and has a stochastic character. The wind speed variation can be modelled as a sum of harmonics with the frequency range 0.110 Hz [8].

$$u = u_0[1 + \sum_n A_n \sin(\omega_n t)] \quad (1)$$

where u is the wind speed value subject to the disturbance, u_0 is the average wind speed, n is the kind of the mechanical eigenswing excited in the rotating wind turbine, A_n is the

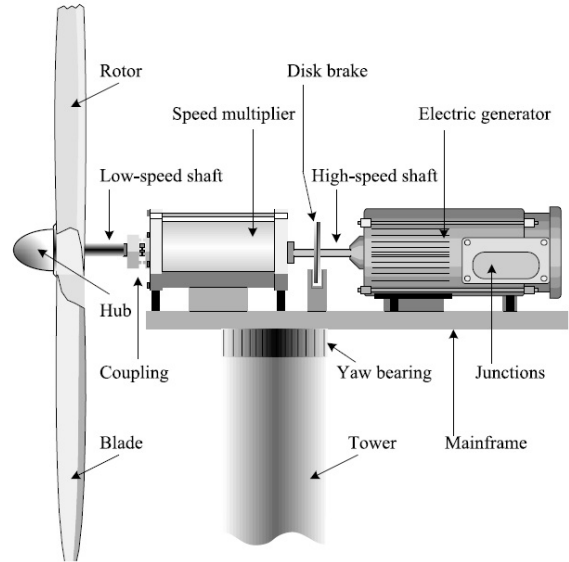


Fig. 3. Conversion from wind power to electrical power in a wind turbine.

magnitude of the eigenswing n , ω_n is the eigenfrequency of the eigenswing n . Hence, the physical wind turbine model is subjected to the disturbance given by the wind speed variation model [9],[10],[12]

B. Generator

Since the early time of developing wind turbines, considerable efforts have been made to utilize three-phase synchronous machines. AC synchronous WTGs can take constant or DC excitations from either permanent magnets or electromagnets and are thus termed PM synchronous generators (PMSGs) and electrically excited synchronous generators (EESGs), respectively. Whilst conventional power generation utilizes synchronous machines, modern wind power systems use induction machines extensively in wind turbine applications.

Typical asynchronous generator, Danish wind turbines

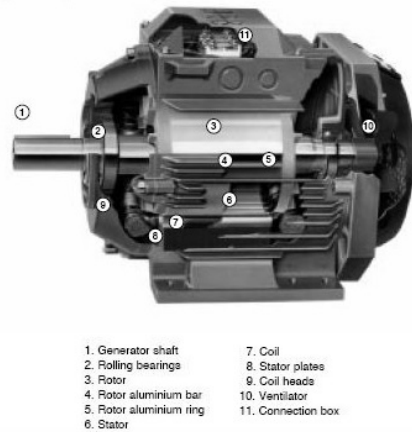


Fig. 4. Cutaway of a squirrel-cage induction generator.

These induction generators fall into two types: fixed speed induction generators (FSIGs) with squirrel cage rotors (sometimes called squirrel cage induction generators-SQIGs) [40];

1] and doubly-fed induction generators (DFIGs) with wound rotors Fig.3.

The generator considered in this paper is a PMSG. The equations for modelling a PMSG can be found in the literature [11].

C. Power converter model

A two-level VSI three-phase power converter has been selected for a clear analysis of a predictive control strategy with RL-Load. The topology of the inverter considered in this paper is represented in Fig.1. The circuit is operated by switching S11, S12, S21, S22, S31 and S32. The inverter uses two pairs of controlled switches in each inverter phase or leg, (S11, S12), (S21, S22) and (S31, S32) as shown in Fig. 1. Considering that the two switches in each inverter phase or leg operate in a complementary pair in order to avoid short circuiting the DC source.

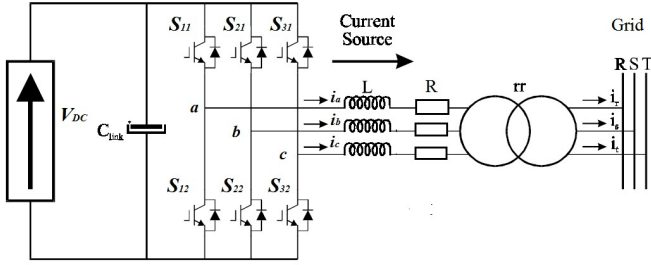


Fig. 5. Two-level voltage source inverter circuit topology.

In order to control the chopper in a current source Mode, it must be studied the relationship between V_{dc} and U_{ac} in the inductors:

$$\begin{cases} u_{ab} - u_{rs} = L \frac{d(i_a - i_b)}{dt} + R(i_a - i_b) \\ u_{bc} - u_{st} = L \frac{d(i_b - i_c)}{dt} + R(i_b - i_c) \\ u_{ca} - u_{tr} = L \frac{d(i_c - i_a)}{dt} + R(i_c - i_a) \end{cases} \quad (2)$$

Conduction of switches on the leading leg of the inverter (S_{11}, S_{12}) is phase shifted with respect to the conduction of switches on the lagging leg (S_{21}, S_{22}) resulting in a quasi-square excitation.

The following binary expression can know at any time the status of the bridge arms:

The output voltage and S_{jk} the j -phase control input which here value is expressed with the switching function

$$S_{jk}(t) = \begin{cases} 1, & S \text{ closed} \\ 0, & S \text{ open} \end{cases} \quad (3)$$

It is assumed that the inductance value (L) and the resistance value (R) are identical for all phases.

$$\begin{cases} u_a = S_{11}V_{dc} \\ u_b = S_{21}V_{dc} \\ u_c = S_{31}V_{dc} \end{cases} \quad (4)$$

$$\begin{cases} u_{rs} = u_r - u_s = \frac{U_{RS}}{m} \\ u_{st} = u_s - u_t = \frac{U_{ST}}{m} \\ u_{tr} = u_t - u_r = \frac{U_{TR}}{m} \end{cases} \quad (5)$$

III. HYBRID CONTROL OF CONVERTER BASED ON PETRI NETS

Dynamical systems are usually continuous or discrete or both. Dynamical Systems Continuous (SDC) have variables whose behavior continuous in time (voltage, current, speed, torque). they are often modeled by differential equations or equations of state and transfer functions. For discrete dynamical systems (SDS), the space of output variables is a discrete set of Boolean value (state opening closing of a switch, number of switches open closed in a simultaneous static converter, number of pulses for controlling switches)[13],[14],[15].

Systems including both continuous characteristics and discrete are called hybrid dynamic systems. In a very simplified one SDH has two sub sets, a continuous block, a block discrete:

- The continuous block symbolizes the dynamic evolution of the state continue in our case the RLC resonant circuit and HV transformer.
- The block has the discrete system is discrete event receives internal events, external conditions, the converter is the state of the switches of switching cells.

In this work, we were interested in modeling method and control systems hybrid event-based dominant the use of Petri nets.

In this section, we define the control scheme for a 2-level multicellular chopper. The proposed control scheme is based on PN and PID controller as shown in Fig. 6.

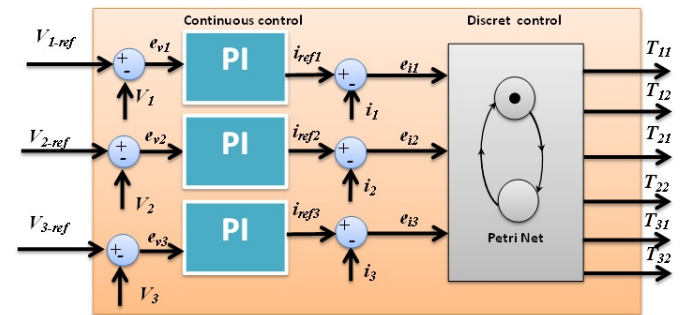


Fig. 6. Petri nets control scheme for output voltages and output currents.

For the output current regulation, a hysteresis methodology is used. An operating band, $\pm\delta_{a,b,c}$ is provided, such that the

output current i_a, i_b and i_c rests respectively inside (ie. $i_{refa} - \delta_a \leq i_a \leq i_{refa} + \delta_a, i_{refb} - \delta_b \leq i_b \leq i_{refb} + \delta_b$ and $i_{refc} - \delta_c \leq i_c \leq i_{refc} + \delta_c$).

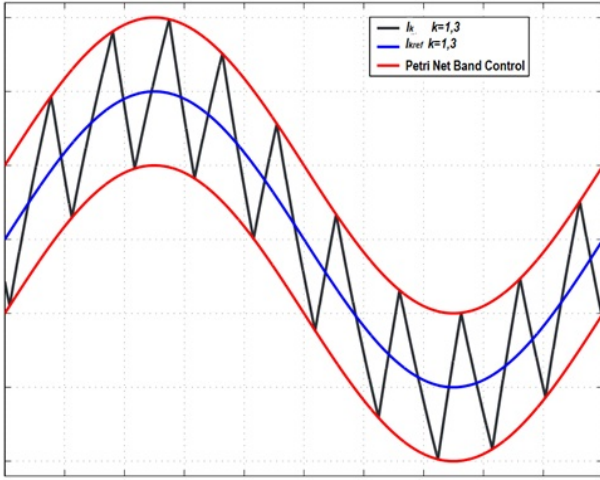


Fig. 7. Strategy of control using a hysteresis-type controller.

The PN that regulates the current, selects the appropriate voltage level to reach the current reference

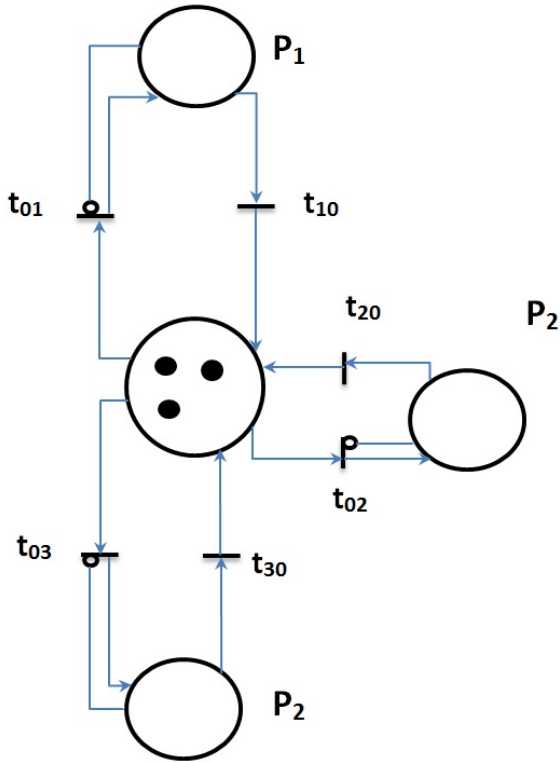


Fig. 8. Petri Net model controller of switch cell.

This algorithm is developed in order to control the output voltage of system. The transition from one place to another is dependent on the state current of converter. The closure of the switch of the cell ($Cell_i$) depends on the validation of the transition t_{i0} . The Petri net control is composed of arcs

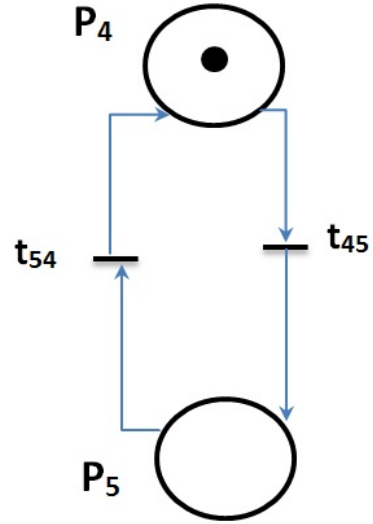


Fig. 9. Model PN controller of switch cell C_{ij} and her complementary.

inhibitors, their role is to prevent the presence of more than one token in places P_i [1],[14],[3]. The significance of all places and transition is shown in Table 3 and 4

TABLE I
SIGNIFICATION OF PLACES

Places P_i	Designations
P_0	Initial state
P_1	The switch of cell1
P_2	The switch of cell2
P_3	The switch of cell3
P_4	The switch C_{jk}
P_5	The switch \bar{C}_{jk} (Complementary of C_{jk})

TABLE II
THE TRANSITIONS

Transitions	Designations
t_{01}	$i_a \leq (i_{refa} + \delta_a)$
t_{02}	$i_b \leq (i_{refb} + \delta_b)$
t_{03}	$i_c \leq (i_{refc} + \delta_c)$
t_{10}	$(i_{refa} - \delta_a) \leq i_a$
t_{20}	$(i_{refb} - \delta_b) \leq i_b$
t_{30}	$(i_{refc} - \delta_c) \leq i_c$
t_{45}	if P_i is valid
t_{54}	if P_i is not valid

with :

- $-\delta_a$ = Undulation current through the first phase
- $-\delta_b$ = Undulation current through the second phase
- $-\delta_c$ = Undulation current through the third phase

IV. SIMULATION RESULTS

The simulation results are obtained using the parameters of converter as follows:

$$R = 10 \Omega, L = 100 \cdot 10^{-3} H, R_{load} = 10 \Omega, \delta_{a,b,c} = 0.1 A,$$

After application of the close control of the converter, simulation results are shown in the following figures:

The Fig.10 and Fig.11 show respectively a simulation of the evolution of the output currents i_s, i_b, i_c and output voltage V_a in both control.

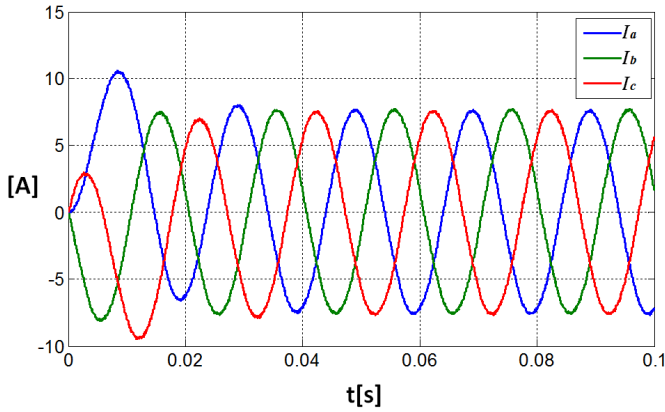


Fig. 10. Evolution of output currents i_s, i_b, i_c using a Hybrid control.

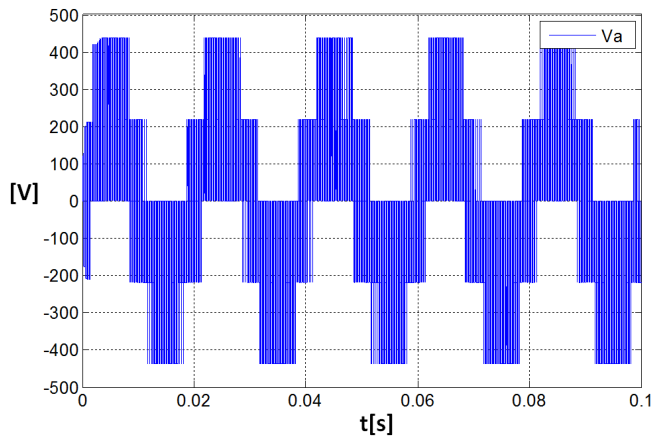


Fig. 11. Output voltage V_a variations using a Hybrid control.

The Fig.13 and Fig.14 represents the results obtained by using the PI PWM control. The result shows this control are not robust we can see the unbalancing of output currents i_s, i_b, i_c .

Peak Magnitude Spectrum called by Simulink

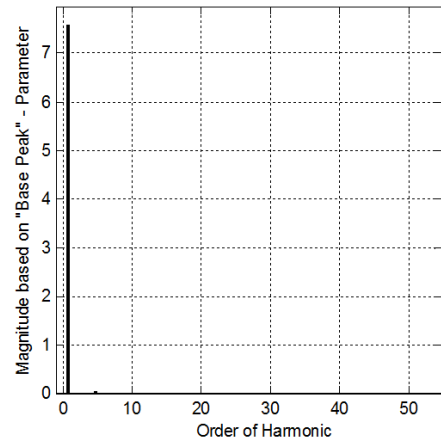


Fig. 12. Fourier analysis Hybrid Control.

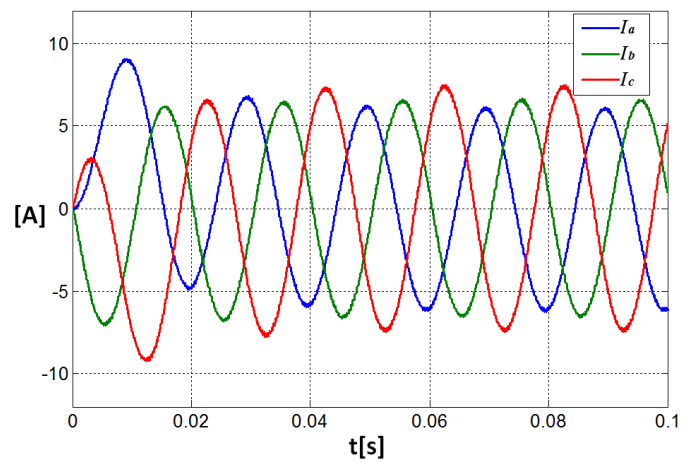


Fig. 13. Evolution of output currents i_s, i_b, i_c using a PI PWM control.

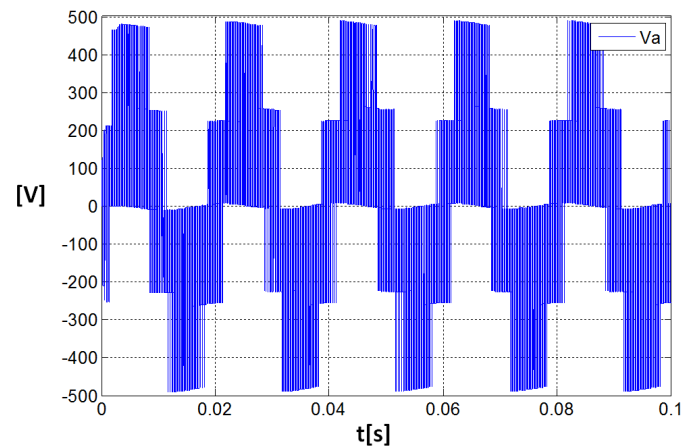


Fig. 14. Output voltage V_s variations in both control using a PI PWM control.

The total harmonic distortion, or THD, of a current used our approach equal to $THD = 1.8\%$. When we use the classical

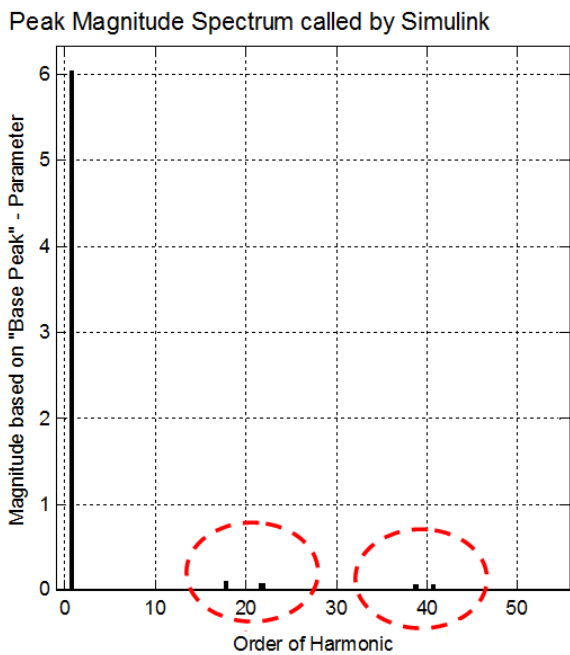


Fig. 15. Fourier analysis PI PWM control.

control the THD = 4%, we can see the efficacy of our hybrid control. The classical controller causes more harmonic due to the periodicity of the controller. The hybrid controller developed in this article ensures an instantaneous regulation of current branches.

V. CONCLUSION

This work consists of a modeling and control of multi-cell Converter used in chain of wind energy generator. Control scheme using Petri Nets has been proposed for controlling the output current and voltages for the multicellular chopper. Petri nets are among the powerful tools for modeling and control of such systems which have discontinuities in their mathematical models. The algorithm is based on the statements of output currents i_a , i_b and i_c , the current reference calculated by the PI and the configurations of switch cells. Finally simulation results show the convergence of output current $i_{a,b,c}$ to a neighborhood of the value of the reference $i_{a,b,c}$ in finite time. This study shows that PN can be used as a design tools for control of power electronics systems, and could lay the basis for future studies in the design of converter controllers using the formal analysis tool offered by Petri nets.

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