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Study and Control of a Power Electronic Cascade using Photovoltaic Cell-Multilevel Inverter

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Abstract

In this paper, we study the performances of the cascade of the photovoltaic cell with the multilevel neutral point clamped (NPC) voltage source inverter (VSI).

In the first part, we remind the model of the double stator induction motors (DSIM). Then, we develop knowledge and control models of this inverter using the connection functions of the semi-conductors. After that, we propose a PWM strategy to control this converter. In this part, the inverter is fed by constant input DC voltages. In the last part, we study the performances of the constituted by two photovoltaic cells – two three-level NPC VSI - DSIM. The results obtained confirm the good performances of the proposed cascade.

Keywords: Multilevel inverter; Generator Cells; Photovoltaic; Control; DSIM.

1. Introduction

Nowadays, the main energy supplier of the worldwide economy is fossil fuel. This, however has led to many problems such as global warming and air pollution. Therefore, with regard to the worldwide trend of green energy, solar power technology has become one of the most promising energy resources. The number of PV installations has had an exponential growth [1]. One of the most important types of PV installation is the grid connected inverter configurations. These grid connected PV systems can be categorized from two viewpoints: PV cell and inverter configurations. The PV cell arrangements fall into four broad groups: centralized technology, string technology, multi-string technology and AC-module and AC-cell technologies [2].

All approaches have advantages and disadvantages [2], [3]; and will compromise various attributes such as harmonic generation, complexity, efficiency, flexibility, reliability, safety, modularity and cost. However, for residential PV installations, the most suitable configuration seems to be the string or multistring technologies where one or more strings of PV cells are connected to a single inverter. Using this type of configuration, there will be no losses associated with the string diodes compared to centralized technology. Moreover, independent Maximum Power Point Tracking (MPPT) is possible for all strings which might be installed in different sizes and orientations. This also increases the overall efficiency under special circumstances like partial shadowing.

There are different approaches to implement string and multi-string topologies. Usually, these modules consist of a solar array and a DC to DC converter controlled by a MPPT algorithm. Afterwards, the outputs of the DC/DC converters build up a DC voltage which is then converted to AC by means of an inverter [4]. The other possibility is to use multilevel. PV systems categorized by different PV cell configurations and inverter types topologies which are able to generate better output quality, while operating at lower switching frequency. This implies lower switching dissipation and higher efficiency. Moreover, this topology utilizes switches with lower breakdown voltage; therefore, it can be used in higher power applications at lower cost. It is worth mentioning that although the number of switches in this approach is higher than other two level topologies, for a sufficient high number of levels, the output filter can be avoided which means less weight, cost and space.

On the other hand, even with the same size of filter at the output, the switching frequency can be decreased which means higher efficiency. In general, a greater number of switches in multilevel converters can be justified since the semiconductor cost decreases at a much greater rate than the filter components cost. This project the total cost of multilevel converters to be comparable or even lower than that of two-level converters.

This paper presents the performances of the cascade of the photovoltaic cells with the multilevel NPC inverter.

Simulation results obtained confirm the good performance of the proposed cascade.

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2. Model of the DSIM

The model of the double stator induction machines (DSIM) is given in figure1 [5], [6].

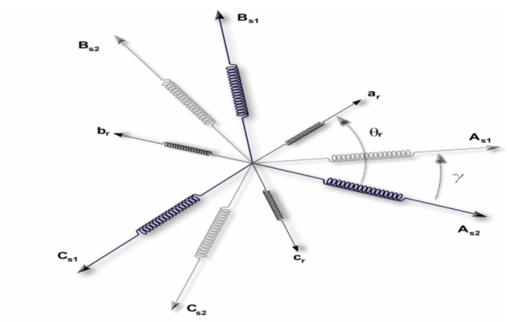

Figure 1. DSIM schema

Park model of the DSIM, with P pairs of poles, is defined by the following equations system [7], [8]:

$$\begin{cases} V_{sd1}=r_{s1}i_{sd1}+\dfrac{d\varphi_{sd1}}{dt}-\omega\varphi_{sq1} \\ V_{sq1}=r_{s1}i_{sq1}+\dfrac{d\varphi_{sq1}}{dt}+\omega\varphi_{sd1} \\ V_{sd2}=r_{s2}i_{sd2}+\dfrac{d\varphi_{sd2}}{dt}-\omega\varphi_{sq2} \\ V_{sq2}=r_{s2}i_{sq2}+\dfrac{d\varphi_{sq2}}{dt}+\omega\varphi_{sd2} \\ V_{rd}=r_r i_{rd}+\dfrac{d\varphi_{rd}}{dt}-\omega_{gl}\varphi_{rq} \\ V_{rq}=r_r i_{rq}+\dfrac{d\varphi_{rq}}{dt}+\omega_{gl}\varphi_{rd} \end{cases}$$

The electromagnetic torque is given by the following expression:

$$C_{em}=p\frac{L_m}{L_m+L_r}\left[\varphi_{rd}\left(i_{sq1}+i_{sq2}\right)-\varphi_{rq}\left(i_{sd1}+i_{sd2}\right)\right]$$

The model of the DSIM in the Park frame is given by figure2.

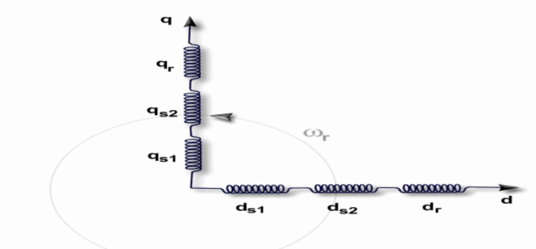

Figure 2. Representation of DSIM in the Park frame

3. Modelling of Three Level NPC VSI

3.1. The three-level NPC VSI structure

The three-level NPC VSI is constituted by three arms and two DC voltage sources [9], [10]. Every arm has four bi-directional switches in series and two diodes (Figure3) [7].

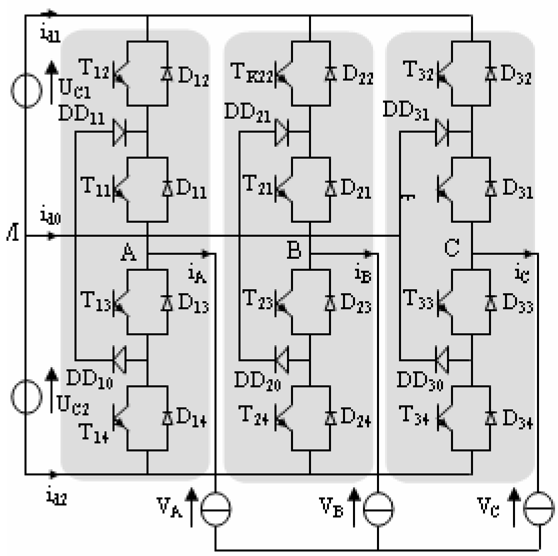

Figure 3. The three-level NPC inverter

3.2. Knowledge model

The switch connection function F_{ks} indicates the opened or closed state of the switch TD_{ks}.
We define two a half arm connection function F^{b}_{km} with:

k : arm number

$$m = \begin{cases} 0 \text{ for the lower half arm} \\ 1 \text{ for the upper half arm} \end{cases}$$

For an arm k of the three-phase three-level NPC, several complementary laws controls are possible. The control law which lets an optimal control of this inverter is:

$$\begin{cases} B_{K4} = \overline{B}_{K1} \\ B_{K3} = \overline{B}_{K2} \end{cases}$$

Where B_{Ks} represents the gate control of the switch Tks.
We define the half arm connection function F^{b}_{i1} and F^{b}_{i0} associated respectively to the upper and lower half arms.
Where i is arm number (*i*=1, 2, 3).

$$\begin{cases} F^{b}_{11} = F_{11}F_{12} \\ F^{b}_{10} = F_{13}F_{14} \end{cases}; \quad \begin{cases} F^{b}_{21} = F_{21}F_{22} \\ F^{b}_{20} = F_{23}F_{24} \end{cases}; \quad \begin{cases} F^{b}_{31} = F_{31}F_{32} \\ F^{b}_{30} = F_{33}F_{34} \end{cases}$$

The output voltages of the inverter relatively to the middle point M are defined as follows:

$$\begin{bmatrix} V_{AM} \\ V_{BM} \\ V_{CM} \end{bmatrix} = \begin{bmatrix} F^{b}_{11} \\ F^{b}_{21} \\ F^{b}_{31} \end{bmatrix} U_{C1} - \begin{bmatrix} F^{b}_{10} \\ F^{b}_{20} \\ F^{b}_{30} \end{bmatrix} U_{C2}$$

This system shows that the three-level can be considered as two two-level voltage source inverters in series. This characteristic lets us to extrapolate the strategies used

The input currents of the inverter are given as follow

$$\begin{cases} i_{d1} = F^{b}_{11} i_1 + F^{b}_{21} i_2 + F^{b}_{31} i_3 \\ i_{d2} = F^{b}_{10} i_1 + F^{b}_{20} i_2 + F^{b}_{30} i_3 \end{cases}$$

The current i_{d0} is defined by the following relation:

$$i_{d0} = (i_1 + i_2 + i_3) - i_{d1} + i_{d2}) \qquad ($$

4. PWM Strategy of the Five Level NPC VSI

The inverter is controlled by the space vector modulation strategy which uses two bipolar carriers.

This strategy is characterized by two parameters [8], [11]:

- The modulation index m is defined as a ratio between the carrier frequency f_p and the reference voltage frequency f:

$$m = \frac{f_p}{f}$$

- The modulation rate r is the ratio between the magnitude V_m of the reference voltage and three times of the carrier's magnitude:

U_{pm}: $$r = \frac{V_m}{U_{pm}}$$

Figure4 shows the signals of this strategy.

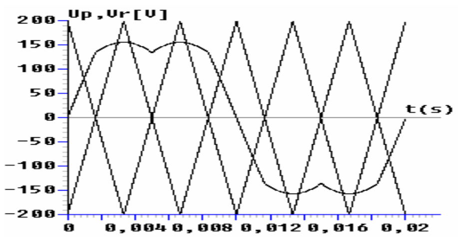

Figure 4. Space vector modulation strategy

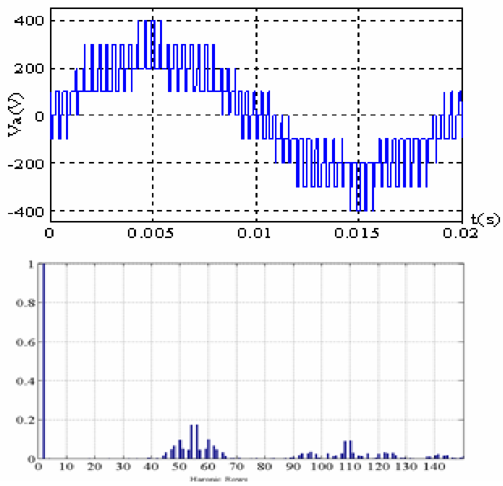

Figure 5. Simple voltage of the inverter and its spectrum

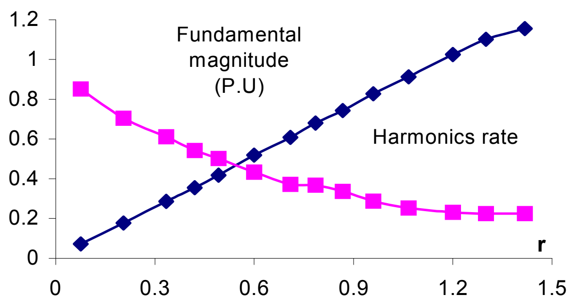

Figure 6 The adjusting characteristic of the output voltage of the inverter

For even values of m, the output voltages present symmetry relatively to the quarter of the period. Then, only odd harmonics exist. These harmonics gather by families centred around frequencies multiple of 4mf. The first family centred around frequency 2mf is the most important in view of its magnitude (Figure5).
The modulation rate r lets linear adjusting of fundamental magnitude from $r = 0$ to $r_{\max} = 1{,}15$ (Figure6).
The harmonics rate decreases when r increases (Figure6).

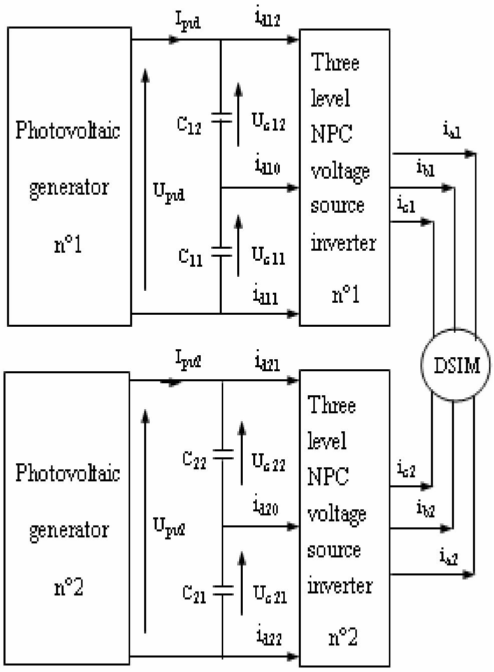

Figure 7. Two photovoltaic generator-filter-two three-level NPC VSI-DSIM cascade

5. Cascade of two Photovoltaic Generator – two Three-Level NPC VSI - DSIM

Until now, we have supposed the input DC voltages of the three-level NPC VSI constants. In this part, the authors study a generation input DC voltage technique. For this, we propose a cascade constituted by two photovoltaic generator-two three-level NPC VSI which feeds a DSIM (Figure7).

5.1. Modelling of Photovoltaic Generator

The building block of the PV array is the solar cell, which is basically a p–n semiconductor junction that directly converts light energy into electricity. Since the invention of solar cells, several models have been proposed to describe its function and behavior under different weather conditions (light and temperature) [12]. In this paper, we present the model with one exponential (diode) [13], [14]. The equivalent circuit is shown in figure8.

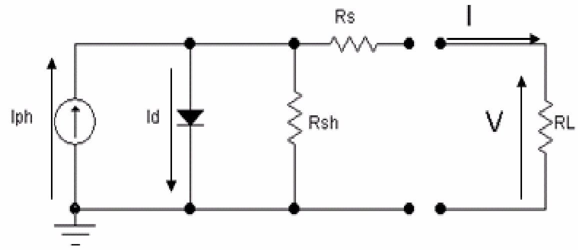

Figure 8. Electrical Scheme of a photovoltaic cell with one diode

To simulate a PV array, a PV simulation model which was obtained using Matlab/Simulink, was used based on the following equation:

$$I_g = I_{ph,g} - I_{s,g}[\exp\left(q\frac{V_g + R_{s,g}I_g}{AkN_{ms}T}\right) - 1] - \frac{V_g + R_{s,g}I_g}{R_{sh,g}}$$

where I is the PV array output current (A); V the PV array output voltage (V); Iph is the photocurrent depends on the solar radiation and the cell temperature; Is is the cell reverse saturation current varies with temperature; Rs is the series resistance; Rsh is the shunt resistance, q is the charge of electron = $1.602.10^{-19}$ C; K is the Boltzmanns constant K=$1.381.10^{-23}$ J/K; A is the pn junction ideality factor; T is the cell temperature (K) and g is the gap.

In our case, we have used photovoltaic generator MSX-83 composed by 36 cells in en series. The characteristics of a PV cell of changes in current and power based on the voltage of the PV cell is shown in figures 9 and 10(for a temperature T=25° and light E=1000W/m^2).

Figure 9. Current–voltage Characteristic PV

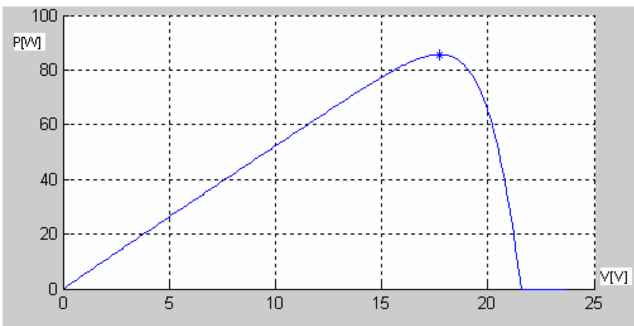

Figure 10. Power–voltage Characteristic PV

5.2. Modelling of Intermediates Filters

The model of these filters is defined by the following system:

$$\begin{cases} C_{K1}\dfrac{dU_{CK1}}{dt} = I_{pvK} - I_{dK1} \\ C_{K2}\dfrac{dU_{CK2}}{dt} = I_{pvK} - I_{dK2} \end{cases}$$

K: Number of the intermediate filters (K=1, 2).

5.3. Simulation Results

The parameters of the intermediate filter are: C_{11}=C_{12}=C_{21}=C_{22}=10mf.

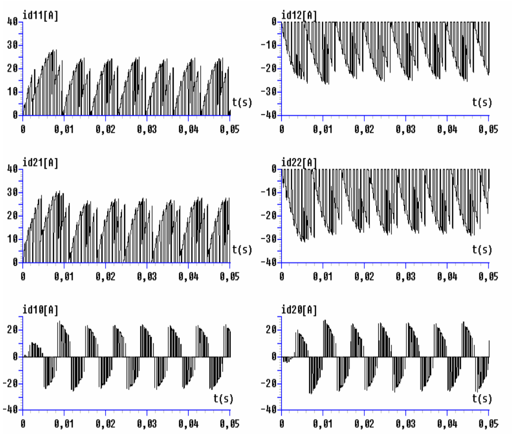

Figure11. Input currents of the two three-level inverter

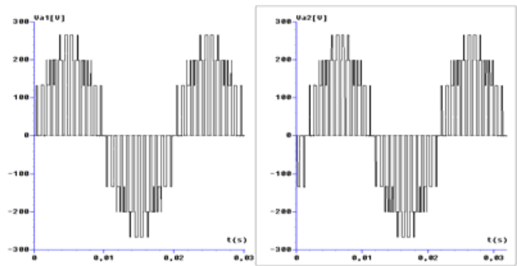

Figure 12. Output voltage of two three level inverter

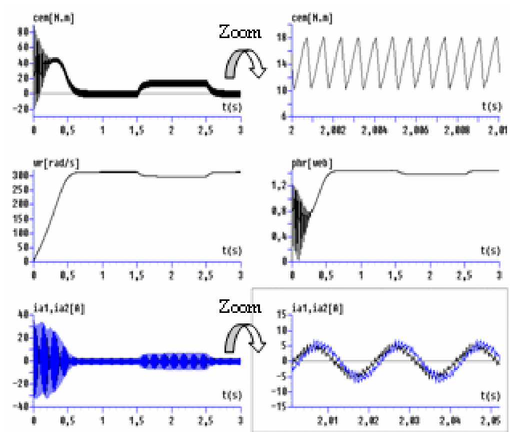

Figure 13. The DSIM performances

We note that the currents i_{d11} and i_{d21} are respectively the opposite of the currents i_{d12} and i_{d22}. The currents i_{d10} and i_{d20} have a mean value practically null (Figure11). The output voltages of inverter V_{a1} and V_{a2} are practically sinusoidal (Figure12). The performance of the speed control algorithm of the DSIM shows that the current of the machine nearly is sinusoidal; the speed follows quietly its reference. The speed and the torque effect for the charge variation between two instants t=1.5s and t=2.5s (Figure13).

6. Conclusions

After a brief introduction of different possible choices for inverters in Photovoltaic applications, it is shown that the Cascaded Multilevel Converter is a suitable choice for PV systems. The paper presents the performance of the cascade of the photovoltaic cell with the multilevel inverter.

The simulation results show that the performances obtained with this cascade are full of promise to be using this inverter in renewable energy.

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