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# Performance Evaluation and Comparison of Two Cascaded Configurations of PV Generators-Five Levels Inverter for a Stand-Alone Application in South Algeria

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**ABSTRACT**

In this paper two configurations of solar photovoltaic energy conversion using the NPC five levels inverter for stand-alone application in south Algeria are proposed and their performances compared. The first cascade uses four separate PV sources and the second configuration use only one PV generator. In these two cases and without DC/DC converter introduced between PV source and inverter and to get a stable AC voltage, authors in propose a proportional regulator of inverter modulation index. The SVPWM technique is used in order to get the best voltage waveform. For the second configuration proposed, we introduce in the control loops another algorithm which uses the redundant vectors of space vector diagram of inverter to stabilise the DC bus voltages. A real data of temperature and solar irradiation obtained by radiometric station in Ghardaïa city in south Algeria are used to test the performance of proposed controls. The simulation results show that the inverter output voltage is stable for the two configurations proposed despite the variation of solar irradiation, temperature and load. Also, the THD obtained is in the limits of international standards. Then, the PV cascade with separate PV sources is the best solution, seeing that we do not need to use another algorithm in the control loops.



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## 1. INTRODUCTION

Fossil fuels include coal and natural gas, as well as the more familiar fuels refined from crude oil including diesel, gasoline, and fuel oils. The burning of fossil fuels is a major source of pollutants which contribute to smog, climate change, acid rain, and other health, environmental and economic concerns. Solar energy is the energy provided by the sun. This Solar power is used to provide heat, hot water, light, electricity, and even cooling, for homes, businesses, and industry. Solar irradiation intensity on Algerian territory indicates that Algeria has a strong solar potential source (Figure 1) [1]. Ghardaïa is a dry and arid city in the south, where the sunshine is more than 3,000 hours per year and mean annual of the global solar irradiation measured on horizontal plane exceeds 20 MJ/m2 [2].

A solar PV inverter converts the direct current output of a photovoltaic solar panel into a utility frequency alternating current that can be fed into local, off-grid electrical network or used in commercial electrical grid. The multilevel inverter concept was established in the early 1980s when the Neutral Point

Clamped (NPC) structure, the capacitor clamped (or Flying Capacitor (FC)) structure and the cascaded H-bridge (CHB) structure were proposed [3]-[7].

Different cascades of PV conversion use one or two converters [8-9]. This study focuses on the application of the five levels NPC inverter in single stage conversion for off-grid electrical network. Many works in this field introduces a PI controller [10] or a complexe regulators such as fuzzy logic control [11] to set the output inverter voltage. Authors in this paper proposes a simple proportional regulator. Two configurations of photovoltaic energy conversion are proposed and their performances compared. The first cascade uses a separate PV sources and the second configuration use only one PV generator. In these two cases and without a DC/DC converter introduced between PV source and inverter, and to get a stable output inverter voltage, a proportional regulator of inverter modulation index is introduced. The Simplified Space Vector Pulse Width Modulation Technique (SSVPWM) is used in this paper in order to get the best voltage waveform. For the configuration with only one PV source, we introduce in the control loops another algorithm which uses the redundant vector of Space Vector Diagram (SVD) of five levels inverter to stabilise the DC bus capacitor voltages [12]. A real data of solar irradiation and temperature obtained by radiometric station in Ghardaïa city in south Algeria are used to test the performance of proposed controls.

## 2. FIVE LEVELS INVERTER FED BY FOUR PV GENERATORS

In the first case where the five levels inverter is fed by four PV generators (Figure 2), the reference voltage vector amplitude is determined by applying a proportional regulator of inverter modulation index. After that, the simplified space vector pulse width modulation for five levels inverter is used in order to get a good output waveform.

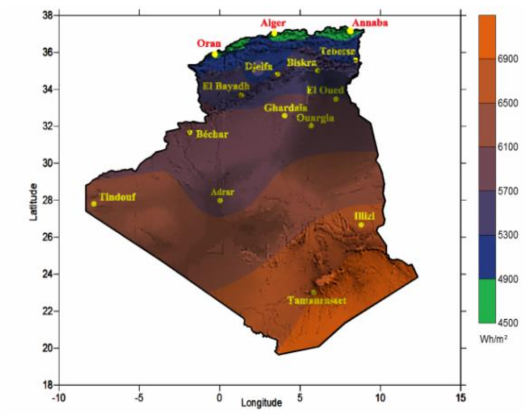


Figure 1. Average annual global solar irradiation received on a horizontal plane

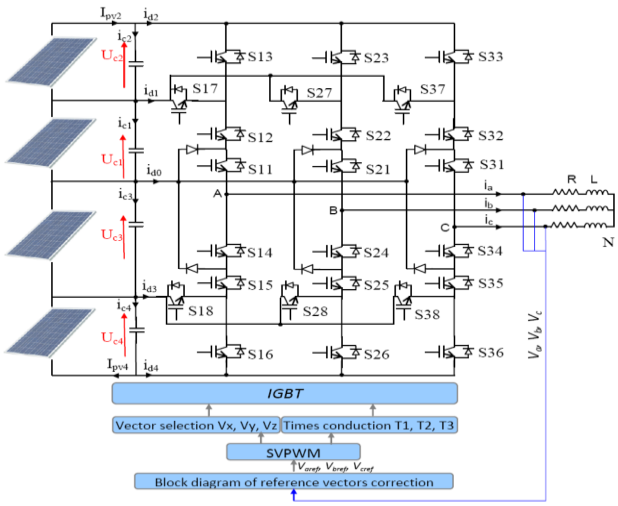


Figure 2. Photovoltaic array-five levels inverter

### 2.1. Reference Voltage Vector Amplitude Correction (RVVAC)

In this part, a proportional regulator of modulation index $r$ of five levels inverter is used. The reference voltage vector of inverter is given by:

$$V^{*}=\begin{pmatrix}V_{aref}\\V_{bref}\\V_{cref}\end{pmatrix}=\begin{pmatrix}r\times V_m\times\sin(\omega t)\\r\times V_m\times\sin(\omega t-2\pi/3)\\r\times V_m\times\sin(\omega t-4\pi/3)\end{pmatrix}=r\times V_m\begin{pmatrix}\sin(\omega t)\\\sin(\omega t-2\pi/3)\\\sin(\omega t-4\pi/3)\end{pmatrix}\tag{1}$$

Where: $v_m=\sqrt{3}/2$ and $0<r<1$

This algorithm consists to correct the reference amplitude voltage vector (modulation index $r$) after each 20ms. The voltage $V_{rms(t)}$ at time ($t$) is compared to its previous $V_{rms(t-1)}$ (time ($t$-1)) and also compared to $V_{rmsref}$ =230Vand based to the errors obtained; the new modulation index $r$ is calculated as presented.

$$\begin{cases} if\ Er_{rms} > 0 \Rightarrow r_{(t+1)} = r_{(t)} - P_{r(t)} \\ if\ Er_{rms} < 0 \Rightarrow r_{(t+1)} = r_{(t)} + P_{r(t)} \\ if\ Er_{rms} = 0 \Rightarrow r_{(t+1)} = r_{(t)} \end{cases} \tag{2}$$

Where: $Er_{rms} = V_{rms(t)} - V_{rmsref}$ and $P_{r(t)} = |Er_{rms}| / (Er_{rms21} \times P_{r(t-1)})$

$Er_{rms}$: error between the root mean square value of output voltages at times *t* and the reference.

$P_{r(t)}$ is the amplitude correction of *r* at time *t*. It is limited by a constant value $P_{r\max}$ .

$V_{rms(t)}$ : root mean square value of output voltage at time *t*

The error between the root mean square values of output voltages at times *t* and (*t-1*) $Er_{rms_{21}}$ is defined:

$$Er_{rms21} = |V_{rms(t)} - V_{rms(t-1)}| \tag{3}$$

The block diagram of the reference vectors vector amplitude correction is presented in Figure 3.

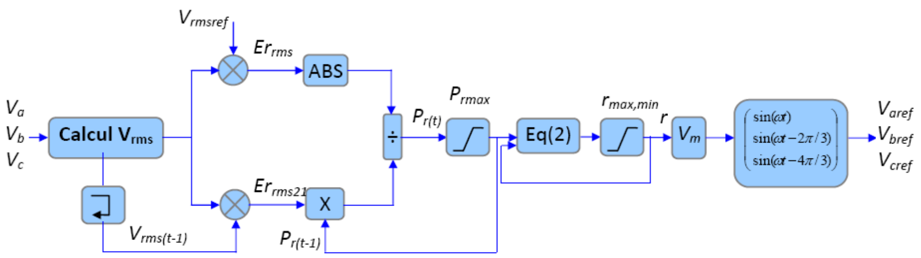


Figure 3. Block diagram of *RVVAC*

### 2.2. Reference Voltage Vector Selection

In this work, we applied the SSVPWM of five levels inverter [13]. This simple and fast method divides the SVD of five levels inverter (Figure 4) into six hexagons. Each hexagon is the SVD of three levels inverter. After that the SVD of three levels is divided to six small hexagons constituting the SVD of two levels inverter as shown in Figure 5.

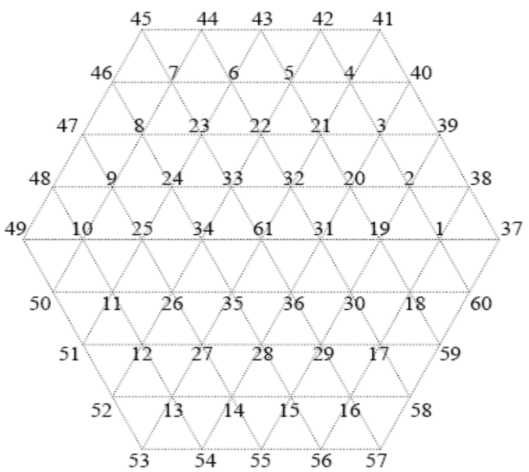


Figure 4. Space vector diagram of a five levels inverter

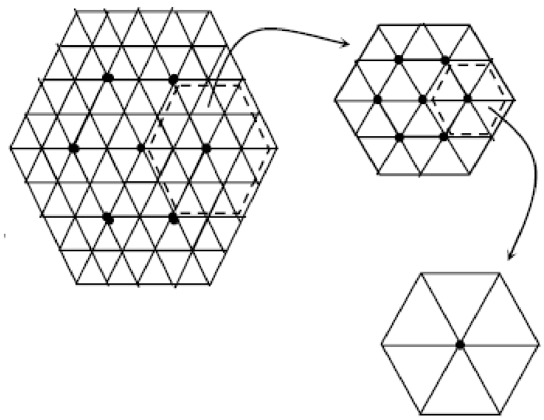

Figure 5. Simplification of a five levels space vector diagram into two levels space vector diagram

## 3. FIVE LEVELS INVERTER FED BY ONE PV GENERATOR

In this case where the five levels inverter is fed by only one PV generator (Figure 6), we must introduce another algorithm (Redundancy Selection (RS)) to balance the DC bus capacitors voltage.

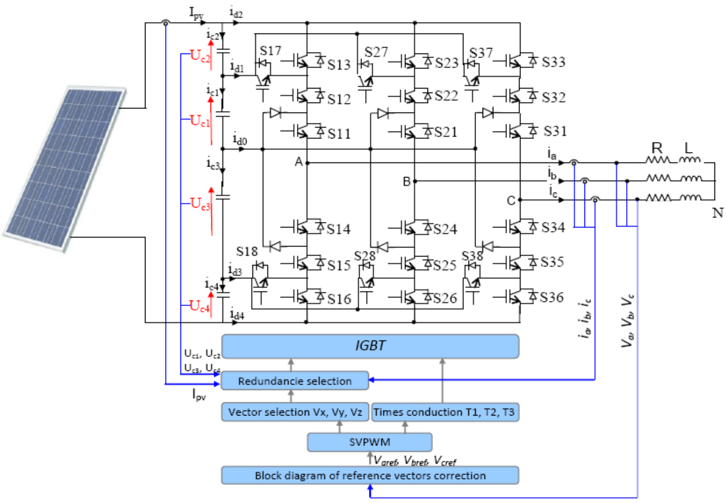


Figure 6. Photovoltaic array-five levels inverter

To choose the redundancy to be used to balance the DC bus, we must know the impact of each one on capacitors voltages. The detailed steps of this algorithm are like follow:

### 3.1. Step

This step consists in definition of the relationship between capacitors current ($i_{c1}$, $i_{c2}$, $i_{c3}$ and $i_{c4}$), photovoltaic array current $I_{pv}$ and load currents $i_a$, $i_b$ and $i_c$ for each vector with redundant states (4).

$$\begin{cases} i_{c1} = I_{pv} - (F_{17} + F_{11}^b) \times i_a - (F_{27} + F_{21}^b) \times i_b - (F_{37} + F_{31}^b) \times i_c \\ i_{c2} = I_{pv} - F_{11}^b \times i_a - F_{21}^b \times i_b - F_{31}^b \times i_c \\ i_{c3} = I_{pv} + (F_{18} + F_{10}^b) \times i_a + (F_{28} + F_{20}^b) \times i_b + (F_{38} + F_{30}^b) \times i_c \\ i_{c4} = I_{pv} + F_{10}^b \times i_a + F_{20}^b \times i_b + F_{30}^b \times i_c \end{cases} \quad (4)$$

$F_{ij}$ and $F_{ij}^b$ : are the connection functions of switches.

Table 1 resume relationships between capacitors, photovoltaic array and load currents for vectors with three redundants state (V19 to V30). The same work is applied to the vectors with two and four redundants state (V1 to V18 and V31 to V36).

### 3.2. Step 2

To reduce the size of control algorithm, the second step consists in constituting vectors groups that have the same disposition in Table 1 the equations *S1* to *S5*. Six groups have been constituted, each one composed by six vectors (Table 2):

Group 1 (G1): *V1, V4, V7, V10, V13, V16*
Group 2 (G2): *V2, V6, V8, V12, V14, V18*
Group 3 (G3): *V3, V5, V9, V11, V15, V17*
Group 4 (G4): *V19, V21, V23, V25, V27, V29*
Group 5 (G5): *V20, V22, V24, V26, V28, V30*
Group 6 (G6)*: V31, V32, V33, V34, V35, V36*

### 3.3. Step 3

This step consists to analyzing the influence of the redundancies of these six groups constituted on capacitors voltage variations. From Table 2 it can remark that vectors of group:

G1 and G4 depend on three equations S1, S2 and S3,
G2 and G3 depend on four equations S1, S2, S3 and S4,

G5 and G6 depend on five equations S1, S2, S3, S4 and S5

Considering the photovoltaic array current Ipv > 0, we can obtain three possibilities Pi of load variation for groups G1 and G4 (5), six possibilities Pi of load variation for groups G2 and G3 and fourteen possibilities Pi of load variation for groups G5 and G6:

$$\begin{cases} P_i = P_1 \; if \;\; S1 > 0,\, S2 < 0 \\ P_i = P_2 \; if \;\; S1 < 0,\, S2 > 0 \\ P_i = P_3 \; if \;\; S1 < 0,\, S2 < 0 \end{cases} \tag{5}$$

By applying these possibilities of load variations for all groups, we obtain the capacitors voltages increasing or decreasing as presented in Table 3 for the first group.

### 3.4. Step 4

In this step, a choice criterion of selected redundancy is defined. With four capacitors in DC bus, we can obtain 24 derivation cases. The proposed algorithm allowed reducing the 24 derivation cases to 6 using only one criterion of redundancy selection. This criterion consists to choose vectors that decrease the two largest capacitors voltages and increase the two others. Table 4 presents the redundancy to be used to cancel the unbalance in capacitors' voltages for groups 1,2 and 3.

## 4. RESULTS AND DISCUSSION

To test the performance of proposed control, a real data of solar irradiation and temperature profiles obtained by a radiometric station installed in Ghardaïa city (*32°26'N 03°46'E*) are used (Figure 7). Figure 8 presents the Global Horizontal Irradiance *GHI* ($W/m^2$), the Diffuse Horizontal Irradiance *DHI* ($W/m^2$), the Direct Normal Irradiance *DNI* ($W/m^2$) and the ambient Temperature $T_a$(°C) of June 23 2013. We note some perturbations between $9^h$ and $15^h$. The *GHI* is more than 850 $W/m^2$ and temperature is between 25°C and 35°C. The PV generator is introduced at $6^h44$ when the *GHI* is greater than 100$W/m^2$ ($T_a$ =24.9°C), and the simulation is stopped at $18^h47$ when the *GHI* is less than 100$W/m^2$ ($T_a$ =33.1°C).

In the first part of simulation, we present the results obtained where the five levels inverter is fed by only one PV generators (Figure 6). At times $t=10^h40$ and $t=15^h30$ the inductor value is varied respectively from $L=0.4H$ to $L=0.45H$ and $L=0.35H$. The inverter output current ia increase after that decrease as shown in Figure 9(a). After application of *RS* algorithm at the start of simulation, DC bus voltages $U_{c1}$,$U_{c2}$,$U_{c3}$ and $U_{c4}$ of five levels inverter (Figure 9(b)) are equal but not all the day. Their difference are caused by the reducing the 24 derivation cases of capacitors voltage to only 6 in the redundancy selection algorithm.

Figure 7. Radiometric devices (Sun tracker)

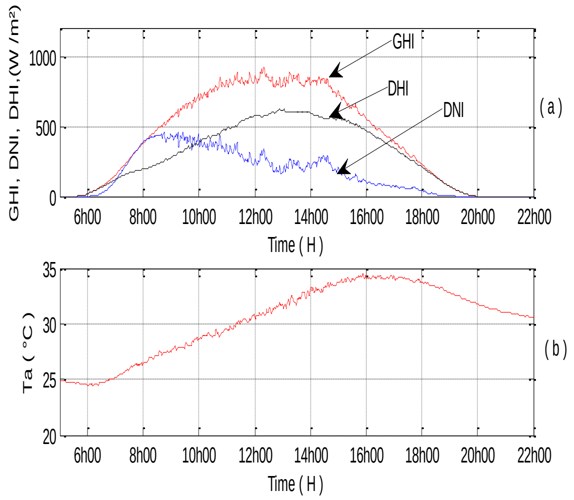


Figure 8(a). Global Horizontal Irradiance (*GHI*), Diffus Horizontal Irradiance (*DHI*), Direct Normal Irradiance (*DNI*), (b)-Ambient Temperature (Ta)

Table 1. Relationships load currents, photovoltaic array current and capacitors current for the vectors with three redundant states

| Vectors | | | $i_{c1}$ | $i_{c2}$ | $i_{c3}$ | $i_{c4}$ | *S1=* | *S2=* | *S3=* | *S4=* | *S5=* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | P2OO | S1 | S1 | S3 | S3 | | | | | |
| *V19* | b | P1N1N1 | S1 | S3 | S2 | S3 | $I_{pv}$-$i_a$ | $I_{pv}$+$i_b$+$i_c$ | $I_{pv}$ | | |
| | c | ON2N2 | S3 | S3 | S2 | S2 | | | | | |
| | a | P2P1O | S1 | S2 | S5 | S5 | | | | | |
| *V20* | b | P1ON1 | S2 | S5 | S3 | S5 | $I_{pv}$-$i_a$-$i_b$ | $I_{pv}$-$i_a$ | $I_{pv}$+$i_c$ | $I_{pv}$+$i_b$+$i_c$ | $I_{pv}$ |
| | c | ON1N2 | S5 | S5 | S4 | S3 | | | | | |
| | a | P2P2O | S1 | S1 | S3 | S3 | | | | | |
| *V21* | b | P1P1N1 | S1 | S3 | S2 | S3 | $I_{pv}$-$i_a$-$i_b$ | $I_{pv}$+$i_c$ | $I_{pv}$ | | |
| | c | OON2 | S3 | S3 | S2 | S2 | | | | | |
| | a | P1P2O | S1 | S2 | S5 | S5 | | | | | |
| *V22* | b | OP1N1 | S2 | S5 | S3 | S5 | $I_{pv}$-$i_a$-$i_b$ | $I_{pv}$-$i_b$ | $I_{pv}$+$i_c$ | $I_{pv}$+$i_a$+$i_c$ | $I_{pv}$ |
| | c | N1ON2 | S5 | S5 | S4 | S3 | | | | | |
| | a | OP2O | S1 | S1 | S3 | S3 | | | | | |
| *V23* | b | N1P1N1 | S1 | S3 | S2 | S3 | $I_{pv}$-$i_b$ | $I_{pv}$+$i_a$+$i_c$ | $I_{pv}$ | | |
| | c | N2ON2 | S3 | S3 | S2 | S2 | | | | | |
| | a | OP2P1 | S1 | S2 | S5 | S5 | | | | | |
| *V24* | b | N1P1O | S2 | S5 | S3 | S5 | $I_{pv}$-$i_b$-$i_c$ | $I_{pv}$-$i_b$ | $I_{pv}$+$i_a$ | $I_{pv}$+$i_a$+$i_c$ | $I_{pv}$ |
| | c | N2ON1 | S5 | S5 | S4 | S3 | | | | | |
| | a | OP2P2 | S1 | S1 | S3 | S3 | | | | | |
| *V25* | b | N1P1P1 | S1 | S3 | S2 | S3 | $I_{pv}$-$i_b$-$i_c$ | $I_{pv}$+ $i_a$ | $I_{pv}$ | | |
| | c | N2OO | S3 | S3 | S2 | S2 | | | | | |
| | a | OP1P2 | S1 | S2 | S5 | S5 | | | | | |
| *V26* | b | N1OP1 | S2 | S5 | S3 | S5 | $I_{pv}$-$i_b$-$i_c$ | $I_{pv}$-$i_c$ | $I_{pv}$+$i_a$ | $I_{pv}$+$i_a$+$i_b$ | $I_{pv}$ |
| | c | N2N1O | S5 | S5 | S4 | S3 | | | | | |
| | a | OOP2 | S1 | S1 | S3 | S3 | | | | | |
| *V27* | b | N1N1P1 | S1 | S3 | S2 | S3 | $I_{pv}$-$i_c$ | $I_{pv}$+$i_a$+$i_b$ | $I_{pv}$ | | |
| | c | N2N2O | S3 | S3 | S2 | S2 | | | | | |
| | a | P1OP2 | S1 | S2 | S5 | S5 | | | | | |
| *V28* | b | ON1P1 | S2 | S5 | S3 | S5 | $I_{pv}$-$i_a$-$i_c$ | $I_{pv}$-$i_c$ | $I_{pv}$+$i_b$ | $I_{pv}$+$i_a$+$i_b$ | $I_{pv}$ |
| | c | N1N2O | S5 | S5 | S4 | S3 | | | | | |
| | a | P2OP2 | S1 | S1 | S3 | S3 | | | | | |
| *V29* | b | P1N1P1 | S1 | S3 | S2 | S3 | $I_{pv}$-$i_a$-$i_c$ | $I_{pv}$+$i_b$ | $I_{pv}$ | | |
| | c | ON2O | S3 | S3 | S2 | S2 | | | | | |
| | a | P2OP1 | S1 | S2 | S5 | S5 | | | | | |
| *V30* | b | P1N1O | S2 | S5 | S3 | S5 | $I_{pv}$-$i_a$-$i_c$ | $I_{pv}$-$i_a$ | $I_{pv}$+$i_b$ | $I_{pv}$+$i_b$+$i_c$ | $I_{pv}$ |
| | c | ON2N1 | S5 | S5 | S4 | S3 | | | | | |

Table 2. Six vectors group

| Groups | | $i_{c1}$ | $i_{c2}$ | $i_{c3}$ | $i_{c4}$ | Groups | | $i_{c1}$ | $i_{c2}$ | $i_{c3}$ | $i_{c4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *G1* | a | S1 | S1 | S2 | S3 | *G5* | a | S1 | S2 | S5 | S5 |
| | b | S1 | S3 | S2 | S2 | | b | S2 | S5 | S3 | S5 |
| *G2* | a | S1 | S1 | S2 | S4 | | c | S5 | S5 | S4 | S3 |
| | b | S1 | S4 | S3 | S2 | *G6* | a | S1 | S2 | S5 | S5 |
| *G3* | a | S1 | S2 | S3 | S4 | | b | S2 | S5 | S5 | S5 |
| | b | S2 | S4 | S3 | S3 | | c | S5 | S5 | S3 | S5 |
| *G4* | a | S1 | S1 | S3 | S3 | | d | S5 | S5 | S4 | S3 |
| | b | S1 | S3 | S2 | S3 | | | | | | |
| | c | S3 | S3 | S2 | S2 | | | | | | |

Table 3. Group 1 redundancies effect on capacitors voltages

| Group | Redundancy | $P_i$ | $U_{c1}$ | $U_{c2}$ | $U_{c3}$ | $U_{c4}$ |
|---|---|---|---|---|---|---|
| *G1* | a | $P_1$ | ↑ | ↑ | ↓ | ↑ |
| | | $P_2$ | ↓ | ↓ | ↑ | ↑ |
| | | $P_3$ | ↓ | ↓ | ↓ | ↑ |
| | b | $P_1$ | ↑ | ↑ | ↓ | ↓ |
| | | $P_2$ | ↓ | ↑ | ↑ | ↑ |
| | | $P_3$ | ↓ | ↑ | ↓ | ↓ |

Table 4. Selected redundancy for groups G1, G2 and G3

| Groups | | *G1* | | | *G2* | | | | | | *G3* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Derivation | $P_i$ | $P_1$ | $P_2$ | $P_3$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ |
| 01 | $U_{c1}$ or $U_{c2}$ < $U_{c3}$ or $U_{c4}$ | b | b | b | b | b | b | b | b | b | b | b | b | b | a | b |
| 02 | $U_{c1}$ or $U_{c3}$ < $U_{c2}$ or $U_{c4}$ | b | a | b | a | a | a | b | b | a | a | b | b | a | a | b |
| 03 | $U_{c1}$ or $U_{c4}$ < $U_{c2}$ or $U_{c3}$ | a | a | a | a | b | a | a | a | b | a | b | b | a | a | a |
| 04 | $U_{c2}$ or $U_{c3}$ < $U_{c1}$ or $U_{c4}$ | b | b | b | b | b | b | b | b | a | b | b | a | b | b | b |
| 05 | $U_{c2}$ or $U_{c4}$ < $U_{c1}$ or $U_{c3}$ | a | b | a | a | b | b | a | a | b | b | a | a | b | b | a |
| 06 | $U_{c3}$ or $U_{c4}$ < $U_{c1}$ or $U_{c2}$ | a | a | a | a | a | a | a | a | a | a | a | a | a | a | a |

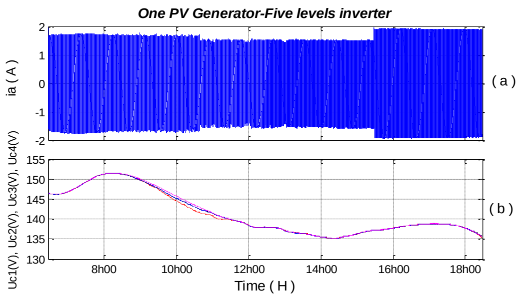


Figure 9. (a). Load current $i_a$, (b). DC bus voltages $U_{c1}$,$U_{c2}$,$U_{c3}$ and $U_{c4}$

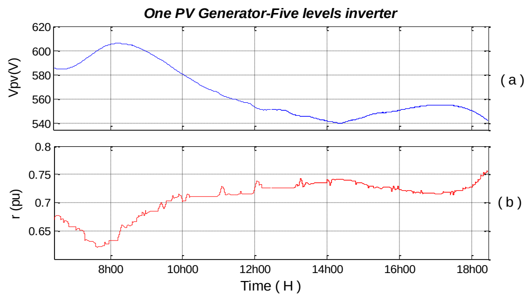


Figure 10. (a)-Photovoltaic array voltage $V_{pv}(V)$, (b)- Modulation index $r$

In this part of simulation, we present the results obtained where the five levels inverter is fed by four PV generators (Figure 2). At times $t=10^h40$ and $t=15^h30$ the inductor value is varied respectively from $L=0.5H$ to $L=0.45H$ and $L=0.35H$. The inverter output current $i_a$ increase after that decrease as shown in Figure 12(a). The DC bus voltages $U_{c1}$,$U_{c2}$,$U_{c3}$ and $U_{c4}$ are not equal as presented in Figure 12(b).

The sum of the photovoltaic generators voltages $U_{c1}+U_{c2}+U_{c3}+U_{c4}$ (Figure 13(a)) present the same variations seen in the previous simulation. Also the modulation index $r$ value (Figure 13(b) increase when the sum of the photovoltaic generators voltages decrease and vice versa. The root mean square output voltage $V_{rms}$ value is stable all the day as presented in Figure 14(a). The output voltage and its spectral analysis are illustrated in Figure 14(b). It is shown that the total harmonic distortion is less than 5% (Figure 14(c)). Then, the PV cascade with separate PV sources is the best solution seeing that we do not need to use another algorithms such as application of redundant states of vectors [12], or introduce a resistive clamping bridge [14] or the use of four DC/DC converters [15] to balance the capacitor voltage DC bus.

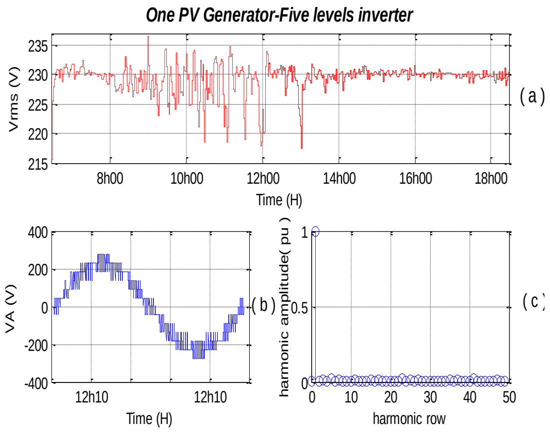


Figure 11 (a) Root mean square voltage $V_{rms}$, (b) Output voltage $V_A$, (c) spectral analysis of $V_A$ THD=5.73%

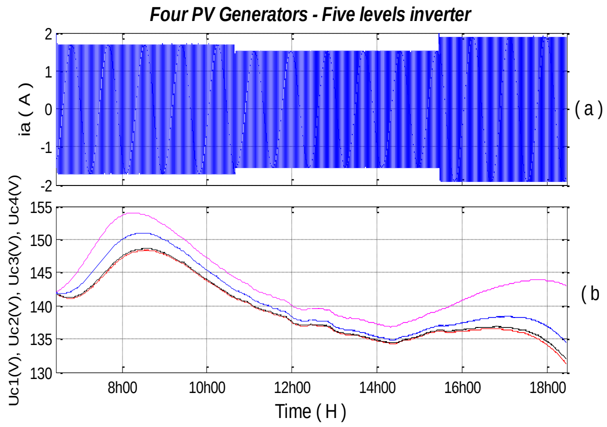


Figure 12 (a). Load current $i_a$ (b) DC bus voltages $U_{c1}$,$U_{c2}$,$U_{c3}$ and $U_{c4}$

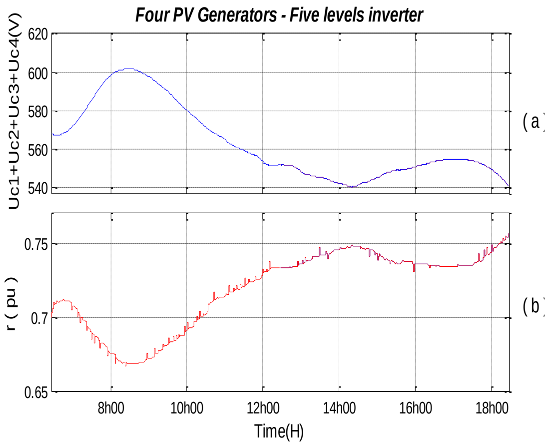


Figure 13 (a) Photovoltaic array voltage $U_{c1}+U_{c2}+U_{c3}+U_{c4}$ (V), (b) Modulation index $r$

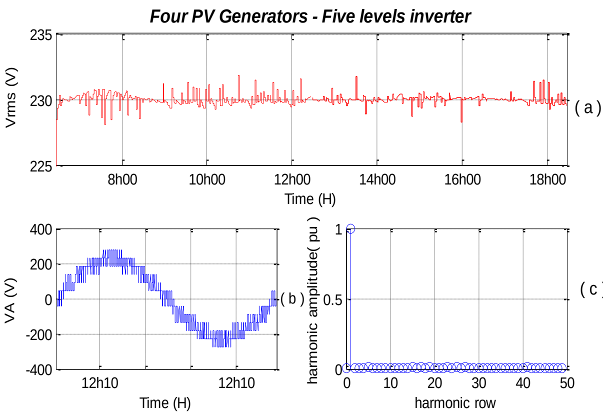


Figure 14 (a) Root mean square voltage $V_{rms}$, (b) Output voltage $V_A$, (c) spectral analysis of $V_A$ THD=4.39%

## 5. CONCLUSION

In this paper, two configurations of photovoltaic generators-three phases five levels NPC voltage source inverter for stand-alone application was studied. The simplified space vector pulse width modulation technique and a proportional regulator of inverter modulation index; used to determine the reference of voltage vector amplitude; are used in the two studied cascades. A solar irradiation and temperature obtained by a radiometric station installed in Ghardaïa city are used to test the performance of proposed control.

The result presents that the DC bus capacitor voltages are not equal in case of inverter fed by four photovoltaic generators. The use of redundant vectors of space vector diagram of five levels inverter allows reducing the difference between the DC bus voltages. But this technique can be applied only for the cascade with one PV generator. The AC output voltages of inverters of these two configurations studied present a good total harmonic distortion with stable root mean square value. Then, the PV cascade with separate PV sources is the best solution seeing that we do not need to use another algorithm and introduce eight current and voltage sensors in practical implementation.

## REFERENCES

[1] M. R. Yaiche *et al.*, "Revised solar maps of Algeria based on sunshine duration," *Energy Conversion and Management*, vol. 82, pp. 114-123, 2014.

[2] K. Gairaa and S. Benkaciali, "Analysis of solar radiation measurements at Ghardaïa area, south Algeria," *Energy Procedia*, vol. 6, pp. 122-129, 2011.
[3] A. Nabae and H. Akagi, "A new neutral-point clamped PWM inverter," *IEEE Trans. Ind. Appl*., vol. IA-17, pp. 518–523, Sep./Oct 1981.
[4] T. Abdelkrim, *et al.*, "DC-Link Capacitor Voltage Balancing using Redundant Vectors for Five-Level Neutral Point Clamped Voltage Source Inverter ," in *14th IEEE International Vacuum Electronics Conference, IVEC'2013*, 21-23 May 2013, Paris, France.
[5] Ravin Nair a/l P.Nagarajan, *et al*., "Enhanced Performance of DTC-DSC of Induction Machine utilizing 3-Level Cascade H-Bridge Multilevel Inverter," *in Proceeding of International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2014)*, pp. 361-367.
[6] C. Gomathi, *et al.,* "Sampled Reference Frame Algorithm Based on Space Vector Pulse Width Modulation for Five Level Cascaded H-Bridge Inverter," *Bulletin of Electrical Engineering and Informatics*, vol. 3, pp. 127-140, 2014.
[7] S. Sanusi, *et al.*, "Implementation of Space Vector Modulator for Cascaded H-Bridge Multilevel Inverters," *International Journal of Power Electronics and Drive System*, vol. 6, pp. 906-918, December 2015.
[8] T. Abdelkrim, *et al.,* "Stability Study of Output Voltages of Single Stage Three Levels Inverter for PV System in South Algeria," *in International Conference on Materials and Energy ICOME'16* La rochelle, France, 17-20 Mai 2016.
[9] Shantanu Chatterjee, "A Multilevel Inverter Based on SVPWM Technique for Photovoltaic Application," *International Journal of Power Electronics and Drive System*, vol. 3, pp. 62-73, March 2013.
[10] A. Ravi, *et al.*, "Modeling and simulation of three phase multilevel inverter for grid connected photovoltaic systems," *Solar Energy*, vol 85, pp. 2811-2818, 2011.
[11] N. Altin, *et al.*, "Three-phase three-level grid interactive inverter with fuzzy logic based maximum power point tracking controller", *Energy Conversion and Management*, vol 69, pp. 19-26, 2013.
[12] A. I. Maswood, *et al.*, "Comparative study of multilevel inverters under unbalanced voltage in a single DC link," *Power Electronics, IET*, vol. 6, pp. 1530-1543, 2013.
[13] T. Abdelkrim, *et al.*, "Study and control of five-level PWM rectifier-five-level NPC active power filter cascade using feedback control and redundant vectors," *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 20, pp. 655-677, 2012.
[14] S. Arezki and M. Boudour, "DC bus voltage balancing of multi-inverter in photovoltaic system", in Proc. *16th International Power Electronics and Motion Control Conference and Exposition*, 2014, pp. 1059-1065.
[15] K. Himour, *et al.,* "Supervision and control of grid connected PV-Storage systems with the five level diode clamped inverter", *Energy Conversion and Management*, vol 77, pp. 98-107, 2014.


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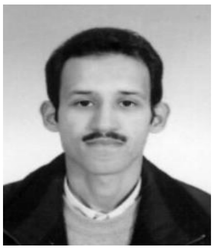

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