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# 15-LEVEL CASCADE MULTILEVEL INVERTER USING A SINGLE DC SOURCE

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## ABSTRACT

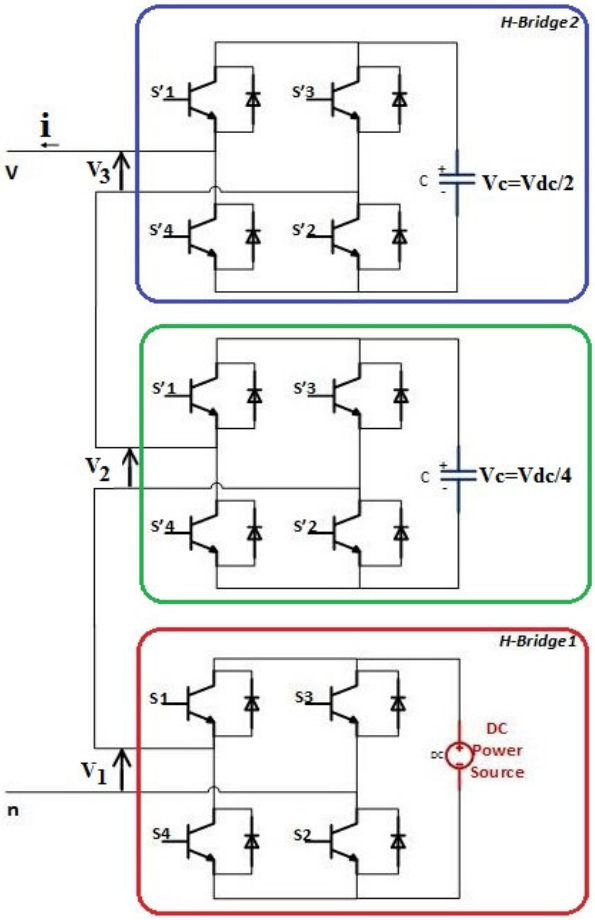
In this paper, a 15-level cascade multilevel inverter using a single Dc source was considered. Switching angles were obtained using a smart technique to remove the selected harmonics. Furthermore, it leads to the simple design of the inverter output filters. The equations have been presented in several sections and simulations performed by PSCAD/EMTDC software.

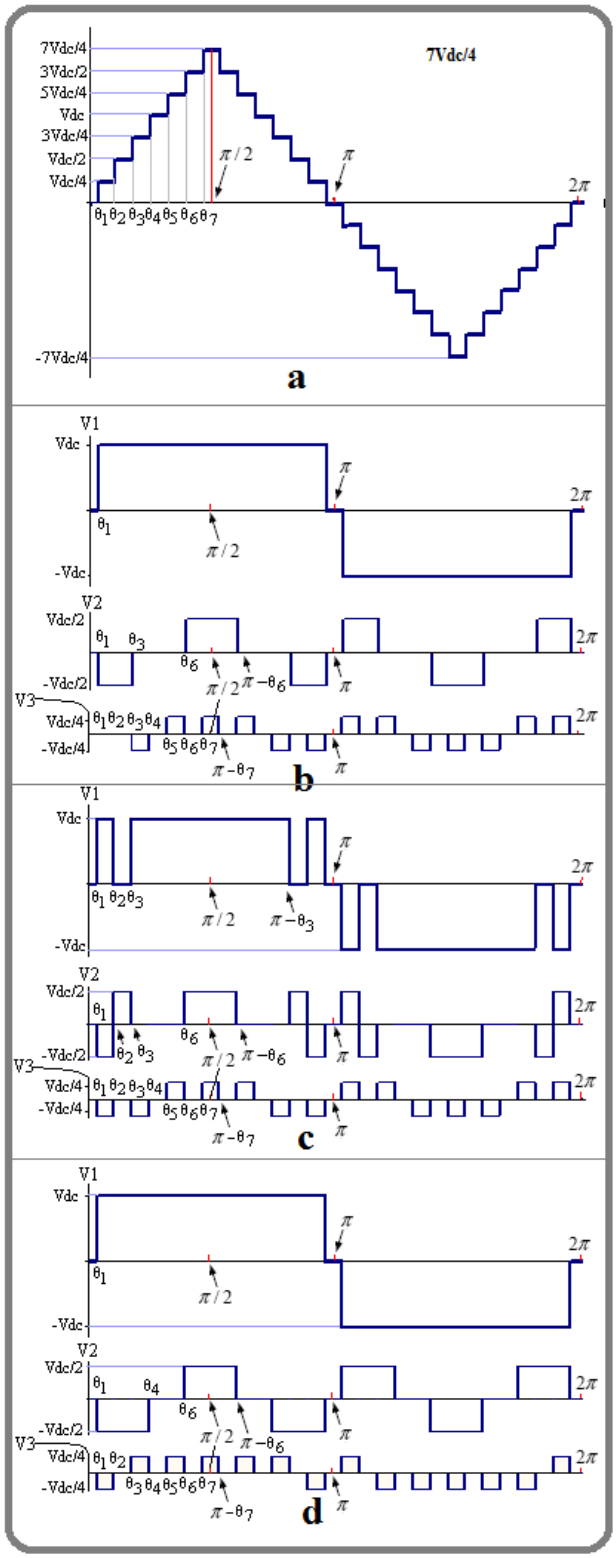
**Keywords:** *Multilevel inverter, Harmonic, Switching, THD*

## INTRODUCTION

There are many applications for multilevel inverters, such as Flexible AC Transmission Systems (FACTS), High Voltage Direct Current (HVDC) transmission, electrical drives and Dispersed Generation (DG) systems. In some applications the converter connects one DC source to the network and some other applications; they can connect separate DC sources to the network [1]. Multilevel inverters of voltage source have a unique structure that allows them to be used with minimal harmonic without high-voltage transformers. Waveform of desired voltage is generated through a combination of several levels of DC-voltage. For this reason, the multilevel inverters can be generating high powers. The number of the output waveform levels is increased by increasing the number of levels of multilevel inverter which leads to the generation of a waveform with less distortion harmonic and the distortion tends to zero as the number of levels increases. There are three important types of multilevel inverters which are used in industrial applications; capacitor clamped multilevel inverter, diode clamped multilevel inverter and cascaded multilevel inverter. In recent years, the multilevel inverters have been studied by a few researchers [2-7]. Among multilevel inverters, the cascade multilevel inverter despite having many advantages, such as less THD, reduction of ratio dv/dt, reduction of voltage pressure on switches etc. Due to the separate DC source, they cannot be connected back to back and this problem was solved by a novel structure [3]. Another point about multilevel inverter is the change of switching modulation which leads to changes in THD value and also undesirable output waveform in some cases. In this paper, a cascade multilevel inverter is presented with only a DC source without transformer by method of selected harmonics elimination. Switching angles have been obtained by an intelligence method for minimum value of THD while in each case a capacitor has been used instead of the DC source. The obtained results confirm that change DC link voltage leads to stabilizing output THD in minimum value and design output filters of inverters in the simplest mode by selecting proper switching angles(with PSO method) to eliminate selected harmonics for minimum value of THD in output voltage.

**Figure 1**
***Structure of cascade 15-level inverter by a DC source***






Bridges in -of each H $_3$and V $_2$V , $_1$Voltages of output V .(a)level inverter -15waveform of output The .2 Fig c and d ,b) ($_3$V+$_2$V+$_1$V=V)different cases to generate same voltage in inverter output

## *VI. STRUCTURE OF 15-LEVEL CASCADE MULTILEVEL INVERTER WITH SINGLE DC SOURCE[1]*

The structure of 15-level inverter, which composed of three HBridges, has been illustrated in Fig.1. Table 1 presents production of these waveforms by the structure of Fig.1.

**TABLE I**
***OUTPUT VOLTAGES OF 15-LEVEL INVERTER***

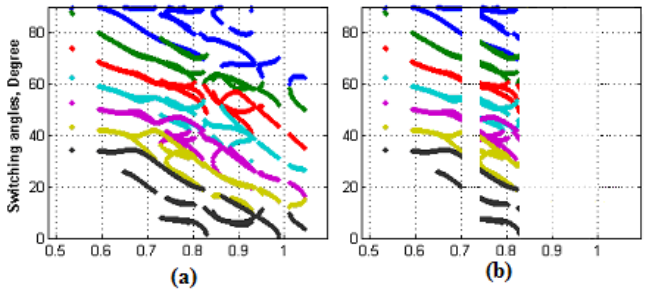
| θ | $_1$V | $_2$V | $_3$V | $_3$V+$_2$V+$_1$V=V |
|---|---|---|---|---|
| $_1$θ≥θ≥0 | 0 | 0 | 0 | 0 |
| $_2$θ≥θ≥$_1$θ | $_{dc}$V | 2/$_{dc}$V- | 4/$_{dc}$V- | 4/$_{dc}$V |
| $_3$θ≥θ≥$_2$θ | $_{dc}$V | 2/$_{dc}$V- | 0 | 2/$_{dc}$V |
| $_3$θ≥θ≥$_2$θ | 0 | 2/$_{dc}$V | 0 | 2/$_{dc}$V |
| $_4$θ≥θ≥$_3$θ | $_{dc}$V | 0 | 4/$_{dc}$V- | 4/$_{dc}$V3 |
| $_4$θ≥θ≥$_3$θ | $_{dc}$V | 2/$_{dc}$V- | 4/$_{dc}$V | 4/$_{dc}$V3 |
| $_5$θ≥θ≥$_4$θ | $_{dc}$V | 0 | 0 | $_{dc}$V |
| $_6$θ≥θ≥$_5$θ | $_{dc}$V | 0 | 4/$_{dc}$V | 4/$_{dc}$V5 |
| $_7$θ≥θ≥$_6$θ | $_{dc}$V | 2/$_{dc}$V | 0 | 2/$_{dc}$V3 |
| 2/π≥θ≥$_7$θ | $_{dc}$V | 2/$_{dc}$V | 4/$_{dc}$V | 4/$_{dc}$V7 |

Fig. 2-b shows generation of waveform of Fig.2-a for θ2≤ θ≤θ3 and θ3≤ θ≤θ4, Fig. 2-c shows generation of waveform of Fig. 2-a for θ2≤ θ≤ θ3 and Fig. 2-d shows generation of waveform of Fig. 2-a for θ3≤ θ≤ θ4. In fact, the output voltage level Vdc/2 can be generated by the two mentioned and alsow a slow the output voltage level Vdc/4 can generated by the two mentioned cases which selected to stabilize DC capacitor voltage. Times of charge and discharge of capacitor has been listed in Table 2. Times of charge and discharge of capacitor has been listed in Table 2.

**TABLE II**.
***Control of voltage level of capacitor $c_1$ in 7-level inverter***

| System state | $_1$V | $_2$V | $_3$V | $_3$V+$_2$V+$_1$V=V |
|---|---|---|---|---|
| 0<i , 2/$_{dc}$V>$_{1c}$v | $_{dc}$V | 2/$_{dc}$V- | 0 | 2/$_{dc}$V |
| 0>i , 2/$_{dc}$V>$_{1c}$v | 0 | 2/$_{dc}$V | 0 | 2/$_{dc}$V |
| 0<i , 2/$_{dc}$V<$_{1c}$v | 0 | 2/$_{dc}$V | 0 | 2/$_{dc}$V |
| 0>i , 2/$_{dc}$V<$_{1c}$v | $_{dc}$V | 2/$_{dc}$V- | 0 | 2/$_{dc}$V |
| 0<i , 2/$_{dc}$V>$_{2c}$v | $_{dc}$V | 0 | 4/$_{dc}$V- | 4/$_{dc}$V3 |
| 0>i , 2/$_{dc}$V>$_{2c}$v | $_{dc}$V | 2/$_{dc}$V- | 4/$_{dc}$V | 4/$_{dc}$V3 |
| 0<i , 2/$_{dc}$V<$_{2c}$v | $_{dc}$V | 2/$_{dc}$V- | 4/$_{dc}$V | 4/$_{dc}$V3 |
| 0>i , 2/$_{dc}$V<$_{2c}$v | $_{dc}$V | 0 | 4/$_{dc}$V- | 4/$_{dc}$V3 |

**Figure 3**
***Limitations of switching angles for 15-level in modulation interval(a)***




he range of switching angles for 15-level inverter in the modulation interval subjects to constrain 3(b).

***VII. CALCULATION OF SWITCHING ANGLES FOR 15-LEVEL MULTILEVEL INVERTER .***

The Fourier expansion of 15-level inverter output waveform (Fig.8-a) for θ1, θ2, θ3, … , θ7 switching angles by assuming a constant output voltage in 15-level inverter of structure of Fig.7 is as follows:

The mathematical relations of the case are:

$$\frac{2}{\pi}\cdot\frac{V_{dc}}{2}\left(\cos(\theta_1)+\cos(\theta_2)+.....+\cos(\theta_7)\right)=V_1$$
$$\left(\cos(5\theta_1)+\cos(5\theta_2)+.....+\cos(5\theta_7)\right)=0$$
$$\left(\cos(7\theta_1)+\cos(7\theta_2)+.....+\cos(7\theta_7)\right)=0$$
M
$$\left(\cos(19\theta_1)+\cos(19\theta_2)+.....+\cos(19\theta_7)\right)=0$$

The equations are seven unknown nonlinear equations for unknown θ1, θ2, θ3, … and θ7. Various techniques have been suggested to solve the equations. In this paper, the switching angles has obtained using the intelligent method. Switching angle by this method has been depicted in Fig.3-a.

## *VIII. SELECTING OPTIMAL SWITCHING ANGLE FOR 7-LEVEL MULTILEVEL INVERTER*

By considering the obtained switching angles, there are no restrictions for balance between charge and discharge of capacitors C1 and C2 because the interval of capacitors charge is slightly longer than interval of capacitor discharge. The restrictions of the intervals lead to restriction of the obtained switching angles. The switching interval is expressed as follow by considering Figs.2:

$$2\left(\theta_3-\theta_1\right)\geq\left[2\left(\theta_6-\theta_5\right)+\left[\left(\pi-\theta_7\right)-\theta_7\right]\right]$$
$$2\left[\left(\theta_2-\theta_1\right)+\left(\theta_4-\theta_3\right)\right]\geq\left[2\left(\theta_6-\theta_5\right)+\left[\left(\pi-\theta_1\right)-\theta_7\right]\right]$$

Based on Fig.8 and Table 3, there is only one case to select desired voltages V1 , V2 and V3 to generate waveform of Fig.2-a in intervals of θ5 to (π-θ5) which by considering positive current in the first half-cycle C1 and C2 discharged. while there are two cases of switching for output voltages of V1 and V2 in interval of θ2 to θ3 an interval of π-θ2 to π-θ3 that by change of this cases, capacitor C1 is charged or discharged. Also there are two cases of switching for output voltages of V2 and V3 in interval of θ3 to θ4 an interval of π-θ3 to π-θ4 that by change of this cases, capacitor C2 is charged or discharged. The obtained switching angles are restricted by applying the mentioned restriction (constrain or Eq. 3). Fig.3-b shows the obtained switching angles for 15-level inverter subjects to constrain 3. Among the obtained switching angles in Fig. 3-b, the angles θ1, θ2 , θ3 , … and θ7 are selected for the minimum value of THD of output voltage.

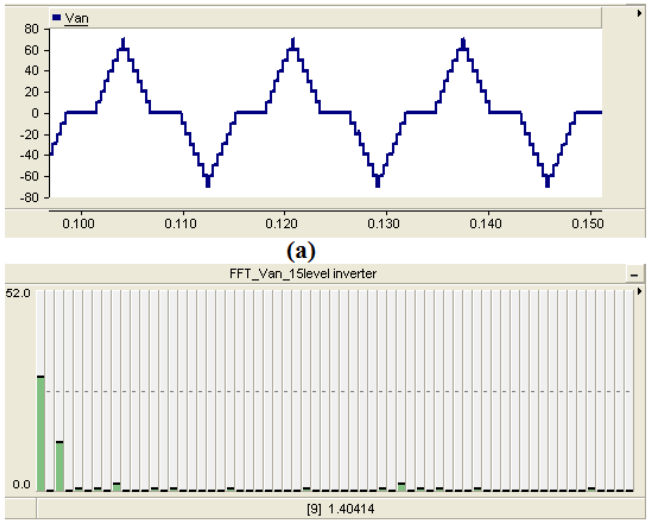
## *IX. SIMULATION RESULTS OF CASCADE MULTILEVEL INVERTER BY A DC SOURCE*

Due to the mentioned description, the switching angles θ1, θ2 , θ3 , … and θ7 for a cascade 15-level inverter using an intelligent method and applying constrain or Eq. 3 for the minimum value of THD are following:

$\theta_1$=38.321,
$\theta_2$=42.3,
$\theta_3$=51.5,
$\theta_4$=59.172,
$\theta_5$=69.21,
$\theta_6$=79.72 and
$\theta_7$=88.17

Waveforms of the phase voltage A and harmonic spectrum of cascade 15-level inverter have been illustrated in Fig.4.

**Figure 4**
***Waveforms of output voltage (a) and harmonic spectrum of phase A of cascade 15-level inverter by a DC source (b)***




Also, Waveforms of the output line voltage and harmonic spectrum of cascade 15-level inverter by a DC source have been presented in Fig.5. With respect to fig.6, amount of THD is 5.01% that by increasing the level of inverter lead to standard value(less than 4%).

**Figure 5**
***The waveform of output voltage (a) and harmonic spectrum of cascade 15-level inverter by a DC source (b)***

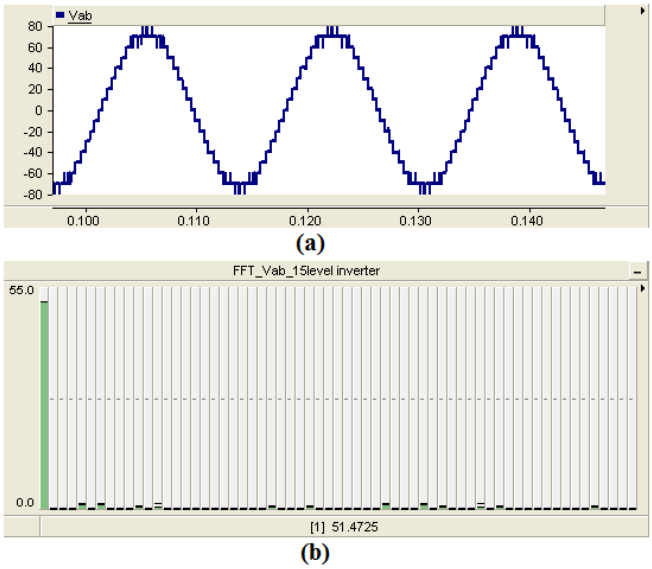
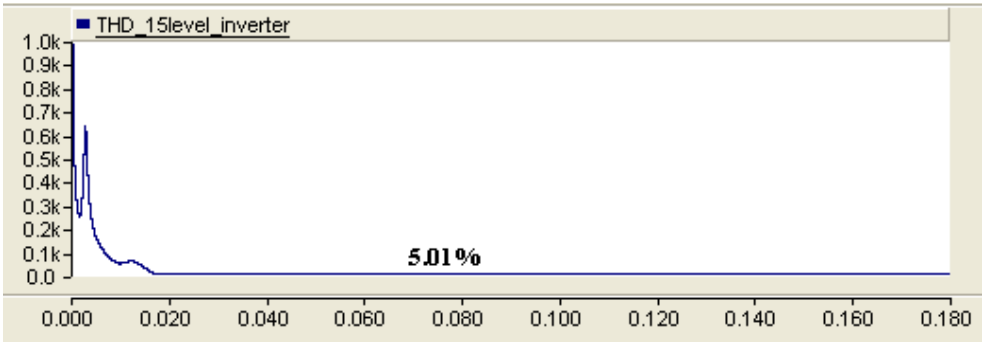


**Figure 6**
***Output line voltage THD of cascade 15-level inverter by a DC source***




## CONCLUSION

This study is an initial step, which needs to be improved by future researches. Thus, authors can consider other variables to expand this study. In the current paper, a 15-level cascade multilevel inverter using a single Dc source was considered. Switching angles were obtained using a smart technique to remove the selected harmonics. Moreover, it leads to the simple design of the inverter output filters. The equations have been presented in several sections and simulations performed by PSCAD/EMTDC software.

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