Abstract—The DC link Neutral Point Voltage balance problem is a permanent attribute in the Neutral Point Clamped multilevel inverters. DC link neutral point voltage can be balanced by keeping the upper and lower dc link capacitor voltages balanced for proper operation of Neutral Point Clamped multilevel inverters. In most respects, the balancing of neutral point voltage is dishonor at very low operating frequencies of the inverter. The earlier proposed methods of neutral point voltage balancing techniques result in an increase of switching losses and increase in cost of the inverter. In this paper, to solve the problem of DC link voltage unbalance, without increasing the switching losses a New Neutral Point Voltage Balancing method using SVPWM Technique is proposed and implemented for five level NPC inverter. This algorithm balances the dc link neutral point voltage without increasing the switching losses of the devices. The proposed method is implemented in SIMULINK/ MATLAB using a list of SIMULINK blocks and MATLAB codes.

Keywords: SVPWM, five level inverter, neutral point voltage, total harmonic distortion.

I. INTRODUCTION

The aim of the work presented in the paper is a neutral point voltage balancing method for three and five level neutral point clamped GTO inverters using space vector pulse width modulation technique and vector balance of induction motor, to balance the neutral point voltage and to reduce the switching losses of devices. This paper describes a neutral point voltage balancing method for neutral point clamped GTO inverters using space vector pulse width modulation technique to balance the neutral point voltage. This includes an algorithm to balance the neutral point voltage without increasing the switching losses. An inverter is an electronic device that converts DC power into AC power at desired output voltage and frequency. Inverters are used in a wide range of applications, from small switching power supplies in computers, to large electric utility applications that transport bulk power.

Let us consider a Three Phase Inverter System with a DC Voltage source $V_{dc}$, series connected capacitors constitute the energy tank for the inverter, providing some nodes to which the multilevel inverter can be connected.

![Fig.1.1 One phase leg of an inverter with (a) Two levels, (b) Three levels, (c) N-levels.](image)

Where each capacitor has the same voltage $V_c$, which is given by

$$V_c = \frac{V_{dc}}{(m-1)}$$

And ‘m’ denotes the number of levels; an ‘m-level’ inverter needs (m-1) capacitors. The term ‘level’ is referred to as the number of nodes to which the inverter can be accessible.

Fig.1.1 shows a schematic diagram of one phase leg of inverters with different numbers of levels, for which the action of the power semiconductors is represented by an ideal switch with several positions. A two-level inverter generates an output voltage with two values (levels) with respect to the negative terminal of the capacitor; Fig.1.1 (a) represents a two level inverter, while the three-level inverter generates three voltages, and so on. By increasing the number of levels in the inverter, the output voltages will have more steps generating a staircase waveform, which has a reduced harmonic distortion.

1.1. PULSE WIDTH MODULATION TECHNIQUES

Types of PWM Techniques:

a. Sinusoidal PWM Technique
b. Hysteresis (Bang-Bang) PWM Technique
c. Space Vector PWM Technique
1.2. SPACE VECTOR PULSE WIDTH MODULATION TECHNIQUE

SVM techniques have several advantages that are offering better DC bus utilization, lower torque ripple, lower Total Harmonic Distortion (THD) in the AC motor current, lower switching losses, and easier to implement in the digital systems. At each cycle period, a preview technique is used to obtain the voltage space vector required to exactly compensate the flux and torque errors.

- Space Vector PWM (SVM) is a more sophisticated technique for generating a fundamental sine wave that provides a higher voltage to the motor and lower total harmonic distortion.
- Any three phase balanced vectors can be represented using a single vector called space vector.

1.3. CONCEPT OF SPACE VECTOR

The concept of space vector is derived from the rotating field of AC machine which is used for modulating the inverter output voltage. In this modulation technique the three phase quantities can be transformed to their equivalent two-phase quantities either in synchronously rotating frame (or) stationary frame. From this two-phase component the reference vector magnitude can be found and used for modulating the inverter output. The process of obtaining the rotating space vector is explained in the following section, considering the stationary reference frame.

II. NEUTRAL POINT BALANCING ANALYSIS

Two capacitors, $C_p$ and $C_N$, are connected in series to obtain the mid-point that provides the zero voltage at the output or the neutral point of the three-level inverter. The neutral point voltage will deviate from its implicit zero level if a current flows from the inverter bridge into the capacitor mid-point. Maintaining the voltage balance between the capacitors is important and influences the balance strategy. The mid-point of dc bus capacitors is connected to the inverter bridge circuit through clamp diodes as shown in Fig.2.1. The flow of current through this neutral point causes voltage imbalance between the upper and lower capacitors, $C_p$ and $C_N$.

III. EFFICIENT ALGORITHM FOR BALANCING NEUTRAL POINT VOLTAGE

The below algorithmic steps are followed for producing new modified line to line reference voltages $(e_*, *)$.

Step-1: Read input data, i.e. original reference voltages $V_{s0}^*$, $V_{bo}^*$, $V_{co}^*$.
Step-2: Set minimum voltage reference $\Delta e = 0.8$ and $Y = 0$.
Step-3: Calculate absolute values of $V_{s0}^*$, $V_{bo}^*$, $V_{co}^*$, i.e. $|e_0|$, $|e_b|$, $|e_c|$.
Step-4: If $|e_0| \geq |e_b|$ and $|e_0| \geq |e_c|$ and $|e_b| \geq |e_c|$, then Set output $Y = 1$ and go to step-10. The new modified line to line reference voltages are

\[
\begin{align*}
e_0^* &= - \text{signum}(e_0) \times \Delta e \\
e_b^* &= - \text{signum}(e_b) \times \Delta e - (e_0 - e_b) \\
e_c^* &= - \text{signum}(e_c) \times \Delta e - (e_0 - e_c)
\end{align*}
\]

Else go to Step-5.
Step-5: If $|e_0| \geq |e_b|$ and $|e_0| \geq |e_c|$ and $|e_b| \geq |e_c|$, then Set output $Y = 2$ and go to step-10. The new modified line to line reference voltages are

\[
\begin{align*}
e_0^* &= - \text{signum}(e_0) \times \Delta e \\
e_b^* &= - \text{signum}(e_b) \times \Delta e - (e_0 - e_b) \\
e_c^* &= - \text{signum}(e_c) \times \Delta e - (e_0 - e_c)
\end{align*}
\]

Else go to Step-6.
Step-6: If $|e_0| \geq |e_b|$ and $|e_0| \geq |e_c|$ and $|e_b| \geq |e_c|$, then Set output $Y = 3$ and go to step-10. The new modified line to line reference voltages are

\[
\begin{align*}
e_0^* &= - \text{signum}(e_0) \times \Delta e - (e_b - e_0) \\
e_b^* &= - \text{signum}(e_b) \times \Delta e \\
e_c^* &= - \text{signum}(e_c) \times \Delta e - (e_b - e_c)
\end{align*}
\]

Else go to Step-7.
Step-7: If $|e_0| \geq |e_b|$ and $|e_0| \geq |e_c|$ and $|e_b| \geq |e_c|$, then Set output $Y = 4$ and go to step-10. The new modified line to line reference voltages are

\[
\begin{align*}
e_0^* &= - \text{signum}(e_0) \times \Delta e - (e_c - e_0) \\
e_b^* &= - \text{signum}(e_b) \times \Delta e \\
e_c^* &= - \text{signum}(e_c) \times \Delta e - (e_c - e_b)
\end{align*}
\]

Else go to Step-8.
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Step-8: If \( |e_u| \geq |e_d| \) and \( |e_u| \geq |e_o| \) and \( |e_u| \geq |e_v| \), then Set output \( Y = 5 \) and go to step-10. The new modified line to line reference voltages are
\[
e_u^* = \text{signum}(e_u) \times \Delta \alpha - (e_u - e_u) \\
e_d^* = \text{signum}(e_d) \times \Delta \alpha - (e_d - e_d) \\
e_o^* = \text{signum}(e_o) \times \Delta \alpha
\]
Else go to Step-9.

Step-9: Set \( Y = 6 \) and go to step-10. The new modified line to line reference voltages are
\[
e_u^* = \text{signum}(e_u) \times \Delta \alpha - (e_u - e_u) \\
e_d^* = \text{signum}(e_d) \times \Delta \alpha - (e_d - e_d) \\
e_o^* = \text{signum}(e_o) \times \Delta \alpha
\]

Step-10: Stop.

The above algorithm reduces the neutral point voltage imbalance, and avoids the minimum ON-time GTO pulses without increasing the switching losses of the GTO devices. At low frequency operation, even if the magnitudes of the three phase voltage references are all above the critical value \( \Delta \alpha \), the time switching pattern is used. This results in a significant reduction of the fluctuations of the neutral point voltage, \( V_o \).

**IV. IMPLEMENTATION OF SVPWM TECHNIQUE BY CONSIDERING NEW MODIFIED L-L REFERENCE VOLTAGES - FIVE LEVEL INVERTER**

The new modified line to line reference voltages \( (e_u^*, e_d^*, e_o^*) \) are given to the SVPWM block for generating switching pulses to GTO’s.

![Fig.4.1 Space Vector Representation of Five level inverter.](image)

**4.1 SECTOR IDENTIFICATION**

The magnitude of reference voltage vector \( (V_{ref}) \) is calculated by using the below formulae as follows.
\[
V_{ref} = \sqrt{(V\alpha)^2 + (V\beta)^2}
\]
Where, the \( V\alpha \) and \( V\beta \) are calculated by considering the new modified line to line reference voltages.
\[
V\alpha = \frac{2V_a - V_b - V_c}{3} \\
V\beta = \frac{V_b - V_c}{\sqrt{3}}
\]

Modulation index \( (M.I) \) is calculated as
\[
M.I = \frac{V_{ref}}{V_{dc}}
\]
Sector is identified by considering the angle \( \alpha \) as follows.
\[
\text{Sector} (n) = \left\{ \text{fix} \left( \frac{\alpha}{60} \right) \right\} + 1
\]
Here the ‘fix’ function rounds the element present in the brackets towards zero.

If the angle \( \alpha \) is in the range of \( 0^\circ \leq \alpha < 60^\circ \) (let \( \alpha = 30^\circ \)), then the sector \( (n) \) is identified as
\[
\text{Sector}, \quad n = \left\lceil \text{fix}(30/60) \right\rceil + 1 = \left\lceil \text{fix}(0.5) \right\rceil + 1 = [0 + 1] = 1
\]
and
\[
\text{If the angle } \alpha \text{ is in the range of } 60^\circ \leq \alpha < 120^\circ \text{ (let } \alpha = 90^\circ \text{), then the sector } (n) \text{ is identified as}
\]
\[
\text{Sector}, \quad n = \left\lceil \text{fix}(90/60) \right\rceil + 1 = \left\lceil \text{fix}(1.5) \right\rceil + 1 = [1 + 1] = 2
\]
and
\[
\text{If the angle } \alpha \text{ is in the range of } 120^\circ \leq \alpha < 180^\circ \text{ (let } \alpha = 150^\circ \text{), then the sector } (n) \text{ is identified as}
\]
\[
\text{Sector}, \quad n = \left\lceil \text{fix}(150/60) \right\rceil + 1 = \left\lceil \text{fix}(2.5) \right\rceil + 1 = [2 + 1] = 3
\]
and
\[
\text{If the angle } \alpha \text{ is in the range of } 180^\circ \leq \alpha < 240^\circ \text{ (let } \alpha = 200^\circ \text{), then the sector } (n) \text{ is identified as}
\]
\[
\text{Sector}, \quad n = \left\lceil \text{fix}(200/60) \right\rceil + 1 = \left\lceil \text{fix}(3.33) \right\rceil + 1 = [3 + 1] = 4
\]
and
\[
\text{If the angle } \alpha \text{ is in the range of } 240^\circ \leq \alpha < 300^\circ \text{ (let } \alpha = 240^\circ \text{), then the sector } (n) \text{ is identified as}
\]
\[
\text{Sector}, \quad n = \left\lceil \text{fix}(240/60) \right\rceil + 1 = \left\lceil \text{fix}(4) \right\rceil + 1 = [4 + 1] = 5
\]
and
\[
\text{If the angle } \alpha \text{ is in the range of } 300^\circ \leq \alpha < 360^\circ \text{ (let } \alpha = 300^\circ \text{), then the sector } (n) \text{ is identified as}
\]
\[
\text{Sector}, \quad n = \left\lceil \text{fix}(300/60) \right\rceil + 1 = \left\lceil \text{fix}(5) \right\rceil + 1 = [5 + 1] = 6.
\]

The below table shows the sector identification of five level inverter.

<table>
<thead>
<tr>
<th>Range of Angle</th>
<th>Selected Sector Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° ≤ α &lt; 60°</td>
<td>1</td>
</tr>
<tr>
<td>60° ≤ α &lt; 120°</td>
<td>2</td>
</tr>
<tr>
<td>120° ≤ α &lt; 180°</td>
<td>3</td>
</tr>
<tr>
<td>180° ≤ α &lt; 240°</td>
<td>4</td>
</tr>
<tr>
<td>240° ≤ α &lt; 300°</td>
<td>5</td>
</tr>
<tr>
<td>300° ≤ α &lt; 360°</td>
<td>6</td>
</tr>
</tbody>
</table>
4.2 ANGLE CALCULATION

Angle of the reference voltage vector for particular sector is calculated as follows.

If the selected sector number is \( n = 1 \) and the angle \( (\alpha) \) is in the range of \( 0^\circ \leq \alpha < 60^\circ \), then the corresponding angle for sector-1 is calculated by using mod-function.

Here the ‘mod’ function is used to find the modulus after division. i.e. remainder after division.

If the selected sector number is \( n = 2 \) and the angle \( (\alpha) \) is in the range of \( 60^\circ \leq \alpha < 120^\circ \), then the angle is modified as \( \alpha' = (\alpha - 60^\circ) \) and the corresponding angle for sector-2 is calculated by using mod-function.

If the selected sector number is \( n = 3 \) and the angle \( (\alpha) \) is in the range of \( 120^\circ \leq \alpha < 180^\circ \), then the angle is modified as \( \alpha' = (\alpha - 120^\circ) \) and the corresponding angle for sector-3 is calculated by using mod-function.

If the selected sector number is \( n = 4 \) and the angle \( (\alpha) \) is in the range of \( 180^\circ \leq \alpha < 240^\circ \), then the angle is modified as \( \alpha' = (\alpha - 180^\circ) \) and the corresponding angle for sector-4 is calculated by using mod-function.

If the selected sector number is \( n = 5 \) and the angle \( (\alpha) \) is in the range of \( 240^\circ \leq \alpha < 300^\circ \), then the angle is modified as \( \alpha' = (\alpha - 240^\circ) \) and the corresponding angle for sector-5 is calculated by using mod-function.

If the selected sector number is \( n = 6 \) and the angle \( (\alpha) \) is in the range of \( 300^\circ \leq \alpha < 360^\circ \), then the angle is modified as \( \alpha' = (\alpha - 300^\circ) \) and the corresponding angle for sector-6 is calculated by using mod-function.

4.3 VECTOR LENGTHS CALCULATION

The formulae used for the calculation of vector lengths are as follows.

\[
m_1 = m \times \left\{ \cos \theta - \frac{\sin \theta}{\sqrt{3}} \right\}
\]

\[
m_2 = 2 \times m \times \left\{ \frac{\sin \theta}{\sqrt{3}} \right\}
\]

4.4 DETERMINING THE REGION IN THE SECTOR

According to the above calculated vector lengths the corresponding Region is selected as follows. Consider the sector-1 diagram with sixteen regions shown in Fig.4.2.

![Fig.4.2 Sector-1 diagram with sixteen regions](image-url)

If the condition \([ 0 < m_1 < 0.25 ] \) and \([ 0 < m_2 < 0.25 ] \) and \([ (m_1+m_2) < 0.25 ] \) is satisfied then the region-1 is selected.

If the condition \([ 0.25 < m_1 < 0.5 ] \) and \([ 0 < m_2 < 0.25 ] \) and \([ 0.25 < (m_1+m_2) < 0.5 ] \) is satisfied then the region-2 is selected.

If the condition \([ 0 < m_1 < 0.25 ] \) and \([ 0 < m_2 < 0.25 ] \) and \([ (m_1+m_2) > 0.25 ] \) is satisfied then the region-3 is selected.

If the condition \([ 0 < m_1 < 0.25 ] \) and \([ 0.25 < m_2 < 0.5 ] \) and \([ 0.25 < (m_1+m_2) < 0.5 ] \) is satisfied then the region-4 is selected.

If the condition \([ 0.5 < m_1 < 0.75 ] \) and \([ 0 < m_2 < 0.25 ] \) and \([ 0.5 < (m_1+m_2) < 0.75 ] \) is satisfied then the region-5 is selected.

If the condition \([ 0.25 < m_1 < 0.5 ] \) and \([ 0.25 < m_2 < 0.5 ] \) and \([ (m_1+m_2) > 0.5 ] \) is satisfied then the region-6 is selected.

If the condition \([ 0.25 < m_1 < 0.5 ] \) and \([ 0.25 < m_2 < 0.5 ] \) and \([ (m_1+m_2) < 0.75 ] \) is satisfied then the region-7 is selected.

If the condition \([ 0.5 < m_1 < 0.75 ] \) and \([ 0 < m_2 < 0.25 ] \) and \([ (m_1+m_2) > 0.5 ] \) is satisfied then the region-8 is selected.

If the condition \([ 0 < m_1 < 0.25 ] \) and \([ 0.5 < m_2 < 0.75 ] \) and \([ (m_1+m_2) < 0.75 ] \) is satisfied then the region-9 is selected.
If the condition [ 0.75 < m₁ < 1 ] and [ m₂ < 0.25 ] and [ (m₁+m₂) < 1 ] is satisfied then the region-10 is selected.

If the condition [ 0.5 < m₁ < 0.75 ] and [ m₂ < 0.25 ] and [ (m₁+m₂) > 0.75 ] is satisfied then the region-11 is selected.

If the condition [ 0.5 < m₁ < 0.75 ] and [ m₂ > 0.25 ] and [ (m₁+m₂) < 1 ] is satisfied then the region-12 is selected.

If the condition [ 0.25 < m₁ < 0.5 ] and [ 0.25 < m₂ < 0.5 ] and [ (m₁+m₂) < 1 ] is satisfied then the region-13 is selected.

If the condition [ 0.25 < m₁ < 0.5 ] and [ 0.5 < m₂ < 0.75 ] and [ (m₁+m₂) > 0.75 ] is satisfied then the region-14 is selected.

If the condition [ m₁ < 0.25 ] and [ 0.5 < m₂ < 0.75 ] and [ (m₁+m₂) > 0.75 ] is satisfied then the region-15 is selected.

If the condition [ m₁ < 0.25 ] and [ 0.75 < m₂ < 1 ] and [ (m₁+m₂) < 1 ] is satisfied then the region-16 is selected.

4.5 CALCULATING THE SWITCHING TIMES Tₐ, T₋, T₃

The duration of voltage vector for particular region is calculated and these times are compared with a time base signal to produce the switching pulses.

4.6 FINDING THE SWITCHING STATES

By considering the switching transition of only one device at any time, the switching orders given below are obtained for each region located in sector-1 if all switching states in each region are used. The switching signals for sector-1 are shown in the below table.

<table>
<thead>
<tr>
<th>Region</th>
<th>ON Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3-0-0, 4-0-0, 4-1-0, 4-1-1</td>
</tr>
<tr>
<td>11</td>
<td>3-0-0, 3-1-0, 4-1-0, 4-2-1</td>
</tr>
<tr>
<td>12</td>
<td>3-1-0, 4-1-0, 4-2-0, 4-2-1</td>
</tr>
<tr>
<td>13</td>
<td>3-1-0, 3-2-0, 4-2-0, 4-2-1</td>
</tr>
<tr>
<td>14</td>
<td>3-2-0, 4-2-0, 4-3-0, 4-3-1</td>
</tr>
<tr>
<td>15</td>
<td>3-2-0, 3-3-0, 4-3-0, 4-3-1</td>
</tr>
<tr>
<td>16</td>
<td>3-3-0, 4-3-0, 4-4-0, 4-4-1</td>
</tr>
</tbody>
</table>

V. FIVE LEVEL INVERTER RESULTS

5.1. DC LINK CAPACITOR VOLTAGES (V₁ₚ AND V₁ₙ)

![Fig.5.1 Upper and Lower DC Link Capacitor Voltages (V₁ₚ and V₁ₙ)](image)

5.2. DC LINK NEUTRAL POINT VOLTAGE (Vₙ)

![Fig.5.2 Neutral Point Voltage (Vₙ)](image)

5.3. MODIFIED PHASE REFERENCE VOLTAGES (Eₚ *, Eᵥ *, Eₜ *)

![Fig.5.3 Modified Phase Reference Voltages (Eₚ *, Eᵥ *, Eₜ *)](image)
5.4. FIVE LEVEL INVERTER OUTPUT L-L VOLTAGES

![Figure 5.4 Five Level Inverter Output L-L Voltages]

5.5. FIVE LEVEL INVERTER VOLTAGE THD

![Figure 5.5 Five Level Inverter Voltage THD]

5.6. FIVE LEVEL INVERTER CURRENT THD

![Figure 5.6 Five Level Inverter Current THD]

VI. CONCLUSION

In this paper an effective algorithm suitable for reducing the imbalanced voltage of the neutral point voltage for five level inverter is proposed and applied for five level NPC inverter without increasing switching losses. The total harmonic distortion of output current for five level inverter is 0.48%.

REFERENCES