Space Vector Modulation for Two-Level Unidirectional PWM Rectifiers
Ivo Barbi, Senior Member, IEEE, and Flabio Alberto Bardemaker Batista

Abstract—This paper presents the concepts for application of space vector modulation to two-level unidirectional pulsewidth modulation (PWM) rectifiers, and a methodology for the use of this modulation is proposed and applied in three different groups of rectifiers. For each group of rectifiers, the converter switching stages are analyzed to determine switch control signals for space vector modulation. One switching sequence is proposed for all rectifiers in order to minimize the number of switch commutations and reduce the switching losses. Duty cycle functions are determined, and the desired switching sequences are performed by a simple PWM, without the need to determine the present sector of the vector. For this purpose, it is necessary to impose the desired current sectors from input voltage references only. In order to validate the proposed modulation techniques, simulation and experimental results are presented for a 20-kW prototype.

Index Terms—Power factor correction (PFC), space-vector modulation, three-phase ac-dc converters, unidirectional rectifiers.

I. INTRODUCTION

A LARGE number of topologies of unidirectional pulsewidth modulation (PWM) rectifiers are available with power factor correction [1]–[9]. In cases where bidirectional power flow is not necessary, these converters offer some advantages, including a decrease in the number of power switches, natural protection for dc bus short circuits, and less processing of energy for the active switches [7]–[9].

Various methods to implement space vector modulation in unidirectional PWM rectifiers have been proposed, especially for multilevel topologies [10]–[17]. When the output voltage is lower than the rated voltage of commercial switches, two-level topologies [1]–[6] become attractive, because they do not need to control middle-point voltage, thus reducing the number of sensors and/or controllers [16], [17].

In this study, a simple methodology to apply space vector modulation to two-level unidirectional PWM rectifiers, in order to minimize the number of switch commutations as well as reduce converter losses, is proposed. Section II presents some unidirectional PWM two-level rectifiers, and in Section III, the basic steps required to apply space vector modulation to these converters, with simulation verification, are described.

The proposed application methodology for this modulation technique is based on subsector definition, rectifier operation stage analysis, and duty cycle determination.

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Therefore, it is not necessary to identify the present vector sector, but simple to impose the appropriate current sector in phase with line voltages [1].

In Section IV, the experimental results are presented, and in Section V, the analysis results and conclusions are discussed.

II. TWO-LEVEL UNIDIRECTIONAL PWM RECTIFIERS

The three-phase three-switch two-level Y-connected unidirectional PWM rectifier [1], [2], shown in Fig. 1, has unity power factor and output voltage regulation. This rectifier uses six diodes and one inner controlled switch per arm. A structure similar to rectifier Y_1 is presented in Fig. 2. In this converter (rectifier ∆_1), the bidirectional switches are connected in ∆ [3].

Two unidirectional rectifiers are presented in [4] with the bidirectional switches outside the arms of the converter. The
Fig. 3. Unidirectional PWM rectifier Y_2.

Fig. 4. Unidirectional PWM rectifier Δ_2.

Fig. 5. Unidirectional PWM rectifier Bridge_1.

Fig. 6. Unidirectional PWM rectifier Bridge_2.

Fig. 7. Definition of current sectors.

The rectifier Bridge_2, shown in Fig. 6, has the same number of semiconductors as rectifiers Y_2 and Δ_2, with the bidirectional switches in a bridge arrangement [6].

These unidirectional rectifiers may be grouped according to the connection of switches as Y-connected rectifiers, Δ-connected rectifiers, or bridge-connected rectifiers.

Each converter has different characteristics, such as the number of semiconductors, the voltage and current stress of the semiconductors, efficiency, loss distribution, and others.

In this study, the application of space vector modulation to these topologies is studied. General aspects of the modulation applied to unidirectional rectifiers as the subsector definition, the vector sequence, and duty cycle functions are presented, and specific characteristic for each group are determined.

III. SPACE VECTOR METHODOLOGY

The space vector modulation is applied to rectifier Y_1 in [1]. In this section, the definitions used for the rectifier Y_1 are adopted for all rectifiers presented.

These topologies have six symmetrical operation intervals [2], where six current sectors are defined in one line period: A+, B−, C+, A−, B+, and C−, as shown in Fig. 7. Each sector has an interval of 60°, and it is defined by the current that has the greatest value and its respective signal.
TABLE I
AVAILABLE VECTORS

<table>
<thead>
<tr>
<th>Vector</th>
<th>Point A</th>
<th>Point B</th>
<th>Point C</th>
<th>VA_B</th>
<th>VB_C</th>
<th>VCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_0</td>
<td>A = B = C</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>V_1 (0 0 0)</td>
<td>P</td>
<td>N</td>
<td>N</td>
<td>+V_0</td>
<td>0</td>
<td>-V_0</td>
</tr>
<tr>
<td>V_2 (1 0 0)</td>
<td>P</td>
<td>P</td>
<td>N</td>
<td>0</td>
<td>+V_0</td>
<td>-V_0</td>
</tr>
<tr>
<td>V_3 (0 1 0)</td>
<td>N</td>
<td>P</td>
<td>N</td>
<td>-V_0</td>
<td>+V_0</td>
<td>0</td>
</tr>
<tr>
<td>V_4 (0 1 1)</td>
<td>N</td>
<td>N</td>
<td>P</td>
<td>-V_0</td>
<td>0</td>
<td>+V_0</td>
</tr>
<tr>
<td>V_5 (1 0 1)</td>
<td>P</td>
<td>N</td>
<td>P</td>
<td>+V_0</td>
<td>-V_0</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 8. Relation between input voltages v_F(t) and rectifier fundamental voltage component v_R(t).

From the analysis of the rectifier topologies, seven available vectors are defined, as shown in Table I. Nonnull vectors are represented by the potential of points A, B, and C, and the null vector represents the situation where the three points are connected.

In this notation, used for unidirectional converters, the representation of the available vectors does not agree with the switching states, because the potentials of points A, B, and C are dependent on the input currents’ direction.

For unidirectional rectifiers, the definition of the sectors is a little different from the traditional one [18]. In this case, implementation of the available vectors considers phase current direction. Supposing the currents to be in phase with the respective voltages, each phase presents an equivalent circuit, with the relation between input voltages v_F(t) and the rectifier fundamental voltage component v_R(t) shown in Fig. 8.

Subsectors are defined from the intersection of vector sectors and current sectors, as shown in Fig. 9.

Therefore, space vector representation is carried out in one diagram divided into these subsectors, as shown in Fig. 10, where each current sector is divided into two subsectors and has four available vectors.

For all groups of rectifiers, a specific sector analysis will be described for sector 1, and this can be extended to each of the other sectors considering the adaptation of the direction of input currents [1]. In sector 1, the subsectors SS1A and SS1C are considered. In subsector SS1A, the highest current is in phase A, and this current is positive and vectors \(-\vec{V}_0\), \(-\vec{V}_1\), and \(-\vec{V}_2\) are used.

However, in subsector SS1C, the highest current is in phase C. This current is negative and the vectors used are the same as in the previous case: \(\vec{V}_0\), \(\vec{V}_1\), and \(\vec{V}_2\).

Table II shows the proposed vector sequences in sectors 1 and 2 for the different groups of rectifiers. These sequences are the same for all rectifiers, and they are dependent on the input currents’ direction.

In one sector, to update the sequence from one subsector to another, the position of the nonnull vectors needs to be changed.
The same methodology used to apply the space vector modulation technique in [1] was extended to other three-phase two-level unidirectional PWM rectifiers.

This methodology is summarized as:
1) identification of current sectors and vector sectors, and definition of subsectors;
2) analysis of topological stages of the converter and verification of available vectors in each subsector;
3) definition of most appropriate logic for the available command signals and vector sequence;
4) determination of intervals for application of vectors and calculation of duty cycle functions in subsectors;
5) implementation of command signals from the PWM.

The switching stages of rectifier Y_2 are analyzed to apply the space vector modulation to this group of rectifiers. In subsector SS1A, the space vector $\vec{V}_1$ is performed in the operation stage of Fig. 11(a) and space vector $\vec{V}_2$ is performed in the operation stage of Fig. 11(b).

In subsector SS1C, the space vector $\vec{V}_1$ is performed in the operation stage of Fig. 12(a) and space vector $\vec{V}_2$ is performed in the operation stage of Fig. 12(b).

In both sectors, in order to implement the null vector, the three switches need to be turned on, and the points A, B, and C are connected to the point M.

The logic used to determine the command signals considers that the switches in the arm, which processes the highest current, are turned on in the respective current sector interval. The proposed control signals for implementing these vectors are those shown in Table III.

The main objective of the logic behind the distribution of the command signals is the minimization of the number of switch commutations and reduction of the switching losses of the converter.

However, the selected switching pattern was chosen so that in the three phases, the level of the control signal is the same (ON) at the beginning and end of the switching period.

For subsector SS1A, the proposed vector sequence is $\vec{V}_0 \vec{V}_1 \vec{V}_2 \vec{V}_0$, resulting in the drive signals in Fig. 13(a). Therefore, the intervals for the commands of the switches are

\begin{align*}
T_{A1,2} &= T_S \\
T_{B1,2} &= T_0 + T_2 \\
T_{C1,2} &= T_0.
\end{align*}

(1)

Using the projections of the vectors on the axes $\alpha$ and $\beta$ [1] for the respective sectors, the three-phase duty cycles are determined as a function of the $D_\alpha$ and $D_\beta$ duty cycles

\begin{align*}
D_{A1,2} &= 1 \\
D_{B1,2} &= 1 - \frac{\sqrt{3}}{2} D_\alpha + \frac{1}{\sqrt{2}} D_\beta \\
D_{C1,2} &= 1 - \frac{\sqrt{3}}{2} D_\alpha - \frac{1}{\sqrt{2}} D_\beta.
\end{align*}

(2)

For subsector SS1C, the proposed vector sequence is $\vec{V}_0 \vec{V}_1 \vec{V}_2 \vec{V}_1 \vec{V}_0$, resulting in the drive signals of Fig. 13(b). In this case, the intervals for the commands of switches and the three-phase duty cycles are

\begin{align*}
T_{A1,2} &= T_0 \\
T_{B1,2} &= T_0 + T_1 \\
T_{C1,2} &= T_S
\end{align*}

(3)
Fig. 14. Duty cycle for switches $S_{A1}$ and $S_{A2}$ in rectifier $Y_2$.

Fig. 15. Operation stages for rectifier $\Delta_1$ in subsector SS1A. (a) Vector $\overrightarrow{V_1}$. (b) Vector $\overrightarrow{V_2}$.

\[
D_{A1,2} = 1 - \sqrt{3/2}D_\alpha - \frac{1}{\sqrt{2}}D_\beta
\]
\[
D_{B1,2} = 1 - \sqrt{2}D_\beta
\]
\[
D_{C1,2} = 1.
\] (4)

Extending this analysis to the other sectors, the duty cycle functions for each switch are defined as shown in Fig 14. In this scenario, the duty cycle for switch $S_A$ is presented for $D_d = 0.359$ and $D_q = 0.076$. Observe that when using the same methodology to a rectifier in the same group (rectifier $Y_1$ [1]), the same duty cycle function is found.

In the analysis of duty cycle equations, one can verify that the expressions for neighboring subsectors are equal in the same current sector. Therefore, it is not necessary to identify the sectors of vectors, but only the desired current sectors need to be imposed from the input voltages.

The switch control signals to implement the desired vectors are performed by a simple PWM, through the comparison of duty cycle functions with a triangular waveform.

B. Space Vector Modulation Applied to $\Delta$-Connected Two-Level Rectifiers

For this group of rectifiers, the switching stages of rectifier $\Delta_1$ are analyzed to apply space vector modulation.

In subsector SS1A, the space vector $\overrightarrow{V_1}$ is performed in the operation stage of Fig. 15(a) and space vector $\overrightarrow{V_2}$ is performed in the operation stage of Fig. 15(b).

Therefore, in subsector SS1C, the space vector $\overrightarrow{V_1}$ is performed in the operation stage of Fig. 16(a) and space vector $\overrightarrow{V_2}$ is performed in the operation stage of Fig. 16(b).

In both sectors, in order to implement the null vector, two of the three switches need to be turned on.

The logic used to determine the command signals considers that the switch in the arm, which processes the highest current, is turned on in the respective current sector interval.

In this sector interval, one of the other two switches is turned off. The proposed control signals for implementing these vectors are those shown in Table IV.

The selected switching pattern was chosen such that in the three phases, the level of the control signal is the same (OFF) at the beginning and end of the switching period.

For subsector SS1A, the proposed vector sequence is $\overrightarrow{V_1} \overrightarrow{V_2} \overrightarrow{V_0} \overrightarrow{V_2} \overrightarrow{V_1}$, resulting in the drive signals in Fig. 17(a). Therefore, the intervals for the commands of the switches are

\[
T_A = T_0 + T_2
\]
\[
T_B = 0
\]
\[
T_C = T_0.
\] (5)
The three-phase duty cycles are determined as a function of the $D_\alpha$ and $D_\beta$ duty cycles

$$
D_A = 1 - \sqrt{\frac{3}{2}} D_\alpha + \frac{1}{\sqrt{2}} D_\beta 
$$

$$
D_B = 0 
$$

$$
D_C = 1 - \sqrt{\frac{3}{2}} D_\alpha - \frac{1}{\sqrt{2}} D_\beta . 
$$

(6)

For subsector SS1C, the proposed vector sequence is $\overrightarrow{V_1} \overrightarrow{V_2} \overrightarrow{V_0} \overrightarrow{V_2} \overrightarrow{V_1}$, resulting in the drive signals in Fig. 17(b).

In this case, the intervals for the commands of the switches and the three-phase duty cycles are

$$
T_A = 0 
$$

$$
T_B = T_0 + T_1 
$$

$$
T_C = T_0 
$$

(7)

$$
D_A = 0 
$$

$$
D_B = 1 - \sqrt{2} D_\beta 
$$

$$
D_C = 1 - \sqrt{\frac{3}{2}} D_\alpha - \frac{1}{\sqrt{2}} D_\beta . 
$$

(8)

Extending this analysis to the other sectors, the duty cycle functions for each switch are defined, as shown in Fig. 18, for the same values of Fig. 14.

Also, for this rectifier, with the analysis of duty cycle equations, it is not necessary to identify the sectors of vectors, but only the desired current sectors be imposed from the input voltages.

C. Space Vector Modulation Applied to Bridge-Connected Two-Level Rectifiers

To this group of rectifiers, the switching stages of rectifier Bridge_1 are analyzed to apply the space vector modulation.

In subsector SS1A, the space vector $\overrightarrow{V_1}$ is performed in the operation stage of Fig. 19(a) and space vector $\overrightarrow{V_2}$ is performed in the operation stage of Fig. 19(b).

![Fig. 19. Operation stages for rectifier Bridge_1 in subsector SS1A. (a) Vector $\overrightarrow{V_1}$. (b) Vector $\overrightarrow{V_2}$.
](image)

![Fig. 20. Operation stages for rectifier Bridge_1 in subsector SS1C. (a) Vector $\overrightarrow{V_1}$. (b) Vector $\overrightarrow{V_2}$.
](image)

Table V

<table>
<thead>
<tr>
<th>Control Signals for Subsectors SS1A and SS1C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SUB-SECTOR SS1A</strong></td>
</tr>
<tr>
<td>$V_1 (1 0 0)$</td>
</tr>
<tr>
<td>$V_2 (1 1 0)$</td>
</tr>
<tr>
<td>$V_0 (0 0 0)$</td>
</tr>
</tbody>
</table>

Therefore, in subsector SS1C, the space vector $\overrightarrow{V_1}$ is performed in the operation stage of Fig. 20(a) and space vector $\overrightarrow{V_2}$ is performed in the operation stage of Fig. 20(b).

The logic used to determine the command signals considers that the switches in the arm, which processes the highest current, are turned off in the respective current sector interval. In order to implement the null vector, two switches need to be turned on, and for nonnull vectors, just one switch is turned on.

The proposed control signals for implementing these vectors are shown in Table V. However, the selected switching pattern was chosen such that in the three phases, the level of the control signal is the same (OFF) at the beginning and end of the switching period.

For subsector SS1A, the proposed vector sequence is $\overrightarrow{V_1} \overrightarrow{V_2} \overrightarrow{V_0} \overrightarrow{V_2} \overrightarrow{V_1}$, resulting in the drive signals in Fig. 21(a). Therefore, the intervals for the commands of the switches are

$$
T_{A1} = T_{A2} = T_{B2} = T_{C2} = 0 
$$

$$
T_{B1} = T_0 + T_2 
$$

$$
T_{C1} = T_0 
$$

(9)
Fig. 21. Drive signals for rectifier Bridge_1. (a) Subsector SS1A. (b) Subsector SS1C.

Fig. 22. Duty cycle function for switch $S_{A1}$ in rectifier Bridge_1.

$$D_{A1} = D_{B1} = D_{B2} = D_{C1} = 0$$

$$D_{B1} = 1 - \sqrt{3/2}D_\alpha + \frac{1}{\sqrt{2}}D_\beta$$

$$D_{C1} = 1 - \sqrt{3/2}D_\alpha - \frac{1}{\sqrt{2}}D_\beta.$$  \hspace{1cm} (10)

For subsector SS1C, the proposed vector sequence is $\overrightarrow{V_2} \overrightarrow{V_1} \overrightarrow{V_0} \overrightarrow{V_1} \overrightarrow{V_2}$, resulting in the drive signals in Fig. 21(b).

In this case, the intervals for the commands of the switches and the three-phase duty cycles are

$$T_{A2} = T_0$$

$$T_{B2} = T_0 + T_1$$

$$T_{C2} = T_{A1} = T_{B1} = T_{C1} = 0$$  \hspace{1cm} (11)

$$D_{A2} = 1 - \sqrt{3/2}D_\alpha - \frac{1}{\sqrt{2}}D_\beta$$

$$D_{B2} = 1 - \sqrt{2}D_\beta$$

$$D_{C2} = D_{A1} = D_{B1} = D_{C1} = 0.$$  \hspace{1cm} (12)

Extending this analysis to the other sectors, the duty cycle functions for each switch are defined, as shown in Fig. 22, for the same values as in Fig. 14.

As in the other rectifiers, from the analysis of the duty cycle equations, it is not necessary to identify the sectors of vectors, but only the desired current sectors be imposed from the input voltages.

D. Simulation Results

Simulations are realized to verify the proposed modulation for all rectifiers. The power parameters used in the simulations and the experimental verification are shown in Table VI.

The input line currents and the duty cycle for one switch are given in Figs. 23–25 for one rectifier of each group (Y-connected, $\Delta$-connected, and bridge-connected).

In these simulations, duty cycle functions are consistent with the theoretical ones, and input line currents have a sinusoidal format.

To evaluate the semiconductors arrangements, performance indexes are defined as presented in (13)–(15) [7]. Simulation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_p$</td>
<td>Peak line voltage</td>
<td>311 V</td>
</tr>
<tr>
<td>$V_{rms}$</td>
<td>RMS input voltage</td>
<td>220 V</td>
</tr>
<tr>
<td>$V_i$</td>
<td>Output voltage</td>
<td>700 V</td>
</tr>
<tr>
<td>$f$</td>
<td>Line frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>$P_r$</td>
<td>Output power</td>
<td>20 kW</td>
</tr>
<tr>
<td>$L_1, L_2, L_3$</td>
<td>Rectifier input inductors</td>
<td>2.4 mH</td>
</tr>
<tr>
<td>$C_r$</td>
<td>Output capacitor</td>
<td>4400 $\mu$F</td>
</tr>
<tr>
<td>$f_s$</td>
<td>Switching frequency</td>
<td>10 kHz</td>
</tr>
</tbody>
</table>
TABLE VII
RECTIFIER COMPARISON

<table>
<thead>
<tr>
<th>Rectifier</th>
<th>$S$</th>
<th>$\mu_S$</th>
<th>$p_S$</th>
<th>$s_P$</th>
<th>$D_{LF}$</th>
<th>$D_{HF}$</th>
<th>$\mu_D$</th>
<th>$p_D$</th>
<th>$P_O$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_1$</td>
<td>3</td>
<td>0.205</td>
<td>1.013</td>
<td>1.013</td>
<td>6</td>
<td>12</td>
<td>0.034</td>
<td>6.073</td>
<td></td>
</tr>
<tr>
<td>$Y_2$</td>
<td>6</td>
<td>0.102</td>
<td>1.013</td>
<td>1.013</td>
<td>0</td>
<td>12</td>
<td>0.051</td>
<td>3.042</td>
<td></td>
</tr>
<tr>
<td>$\Delta_1$</td>
<td>3</td>
<td>0.247</td>
<td>0.507</td>
<td>0.507</td>
<td>0</td>
<td>18</td>
<td>0.047</td>
<td>4.967</td>
<td></td>
</tr>
<tr>
<td>$\Delta_2$</td>
<td>6</td>
<td>0.123</td>
<td>0.487</td>
<td>0.487</td>
<td>0</td>
<td>12</td>
<td>0.056</td>
<td>2.546</td>
<td></td>
</tr>
<tr>
<td>Bridge 1</td>
<td>6</td>
<td>0.123</td>
<td>0.487</td>
<td>0.487</td>
<td>0</td>
<td>7</td>
<td>0.087</td>
<td>3.630</td>
<td></td>
</tr>
<tr>
<td>Bridge 2</td>
<td>6</td>
<td>0.123</td>
<td>0.487</td>
<td>0.487</td>
<td>0</td>
<td>12</td>
<td>0.051</td>
<td>2.587</td>
<td></td>
</tr>
</tbody>
</table>

results show the rectifier performance indexes in Table VII

$$
\begin{align*}
\mu_S &= \frac{P_O}{\sum_n V_{S_{\text{MAX}}} I_{S_{\text{MAX}}}} \\
\mu_D &= \frac{P_O}{\sum_n V_{D_{\text{MAX}}} I_{D_{\text{MAX}}}} \\
p_S &= \frac{\sum_n I_{S_{\text{MED}}}}{I_O} \\
p_D &= \frac{\sum_n I_{D_{\text{MED}}}}{I_O} \\
s_P &= \frac{\sum_n V_{S_{\text{MAX}}} I_{S_{\text{MED}}}}{P_O}
\end{align*}
$$

where $S$ is the number of active switches, $D_{LF}$ is the number of low-frequency diodes, $D_{HF}$ is the number of high-frequency diodes, $\mu_S$ and $\mu_D$ characterize transistor and diode utilization, respectively, $p_S$ and $p_D$ characterize transistor and diode conduction loses, respectively, and $s_P$ characterizes transistor switching loses.

IV. EXPERIMENTAL RESULTS

The laboratory setup for a 20-kW PWM rectifier is shown in [1]; this prototype allows the performance of rectifiers $Y_1$ and $\Delta_1$. The selected components of the converter, the control strategy, and an example of the design procedure are presented in [1] and [2].

A. Experimental Results for PWM Rectifier $Y_1$

Duty cycles for three switches, with a format similar to the theoretical and simulation duty cycles, are shown in Fig. 26. In analogical measurements, 5 V correspond to a duty cycle of 100%.

The input currents in the unidirectional PWM rectifier are given in Fig. 27, where it can be observed that they present a low current distortion (THD$_{40}$ = 3.16%).

The input current in phase A and the voltage reference for phase A are presented simultaneously in Fig. 28. In this case, the system has a high power factor (0.998).

The measured total harmonic distortion (THD) of the input voltage is 2.83%, and the rectifier efficiency is greater than 95% when operating at above one half of the nominal load.

B. Experimental Results for PWM Rectifier $\Delta_1$

In Fig. 29, the duty cycles for three switches with a format similar to the theoretical and simulation duty cycles are shown. The input currents in rectifier $\Delta_1$ are given in Fig. 30, where it can be observed that they present a low current distortion (THD$_{40}$ = 2.18%).
The input current in phase A and the voltage reference for phase A are presented simultaneously in Fig. 31. The system has a high power factor (0.996), and in this case, the measured THD of the input voltage is 3.08%.

The rectifier efficiency is greater than 96% when operating at above one half of the nominal load.

V. CONCLUSION

A simple methodology to apply the space vector modulation technique was proposed and extended to three different groups of three-phase two-level unidirectional PWM rectifiers. The same steps are used to apply the space vector modulation to all rectifiers.

The proposed vector sequences are the same for all rectifiers because they have the same points of connection at the input (A, B, and C) and output (P and N). Therefore, it is necessary to verify the characteristics of the semiconductor arrangements to determine the duty cycle functions.

Rectifiers in the same group use the same duty cycle functions as verified in simulation and experimental results. These steps may be used as the starting point for the analysis of new topologies or different semiconductor arrangements.

With this methodology, it is not necessary to determine the sectors of vectors, but only the desired current sectors be imposed from the input voltage references. The proposed modulation reduces the number of switch commutations and improves the rectifier efficiency.

The simulation and experimental results validated the proposed modulation, and the unidirectional rectifiers offer regulated output voltage, high efficiency, high power factor, and low input current THD.

In Y-connected rectifiers, the number of switches turned on to perform the desired vectors is greater than in the other rectifiers. ∆-Connected rectifiers and bridge-connected rectifiers allow the possibility to maintain one switch open for an interval of 60°. Therefore, conduction loses and switching losses are reduced in these topologies.

REFERENCES


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