Space Vector Modulation for PWM Rectifiers

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Abstract— this paper presents the concepts for application of space vector modulation to two-level unidirectional pulse width 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 results are presented.

Keywords — Space Vector Modulation, Power Factor Correction, three phase ac-dc converters, unidirectional rectifiers.

I. INTRODUCTION

Large number of topologies of unidirectional pulse width modulation (PWM) rectifiers is available with power factor correction [1]-[7]. 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].

Various methods to implement space vector modulation in unidirectional PWM rectifiers have been proposed, especially for multilevel topologies. 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.

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. The proposed application methodology for this modulation technique is

based on subsector definition, rectifier operation stage analysis, and duty cycle determination.

I. TWO-LEVEL UNIDIRECTIONAL PWM RECTIFIERS

The three-phase three-switch two-level Y-connected unidirectional PWM rectifier [1] shown in Fig. 1 is presented with the bidirectional switches outside the arms of the converter.

Fig.2. shows the Δ-connected unidirectional PWM rectifier. In this converter the switches are connected in Δ. In Fig. 3, the Rectifier Bridge is presented. This structure is derived from the bidirectional rectifier with the additional dc rail diode.

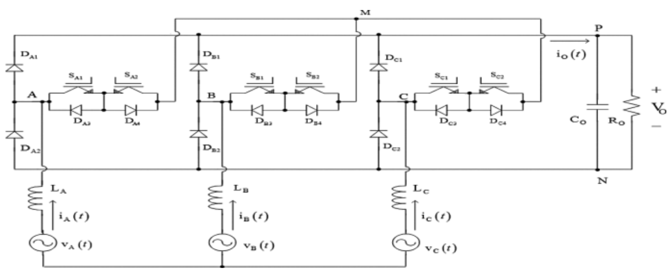

Fig.1 Unidirectional PWM rectifier Y

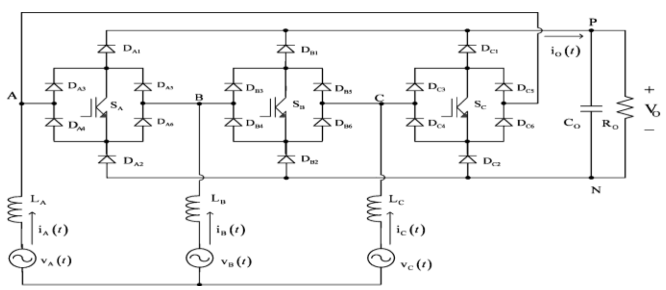

Fig.2 Unidirectional PWM rectifier Δ

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.

II. SPACE VECTOR METHODOLOGY

Space Vector modulation (SVM) technique was originally developed as a vector approach to pulse-width modulation (PWM). It is a more sophisticated technique for generating sine wave that provides a higher voltage with lower total harmonic distortion. It confines space vectors to be applied according to the region where the output voltage vector is located.

Its principles are:

Treat the sinusoidal voltage as a constant amplitude vector rotating at constant frequency.

This PWM technique approximates the reference voltage V_{ref} by a combination of the eight switching patterns (V_0 to V_7).

Coordinate Transformation (abc reference frame to the stationary d-q frame): A three-phase voltage vector is transformed into a vector in the stationary d-q coordinate frame which represents the spatial vector sum of the three-phase voltage.

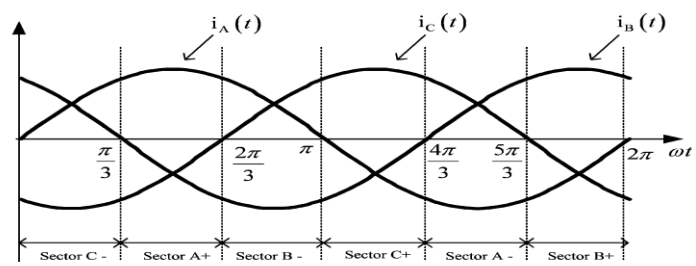

Fig.3 Definition of current sectors

The space vector modulation is applied to rectifier Y. These topologies have six symmetrical operation intervals, where six current sectors are defined in one line period: A+, B−, C+, A−, B+, and C−, as shown in Fig.4.

From the analysis of the rectifier topologies, seven available vectors are defined, as shown in Table I.

Vector	Point A	Point B	Point C	V_{AB}	V_{BC}	V_{CA}
$\vec{V}_0$ (0 0 0)	A = B = C			0	0	0
$\vec{V}_1$ (1 0 0)	P	N	N	$+V_O$	0	$-V_O$
$\vec{V}_2$ (1 1 0)	P	P	N	0	$+V_O$	$-V_O$
$\vec{V}_3$ (0 1 0)	N	P	N	$-V_O$	$+V_O$	0
$\vec{V}_4$ (0 1 1)	N	P	P	$-V_O$	0	$+V_O$
$\vec{V}_5$ (0 0 1)	N	N	P	0	$-V_O$	$+V_O$
$\vec{V}_6$ (1 0 1)	P	N	P	$+V_O$	$-V_O$	0

TABLE I- AVAILABLE VECTORS

Subsectors are defined from the intersection of vector sectors and current sectors, as shown in Fig.5

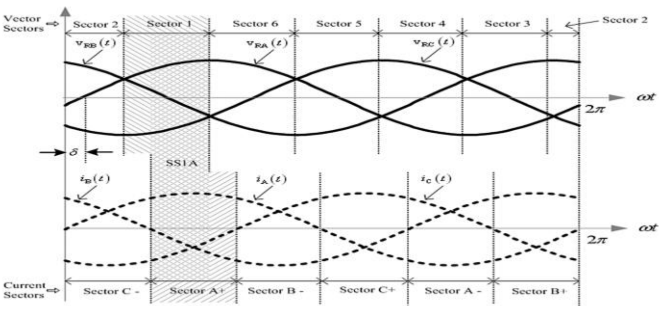

Fig.4 Definition of subsectors

Therefore, space vector representation is carried out in one diagram divided into these subsectors, as shown in Fig.6.

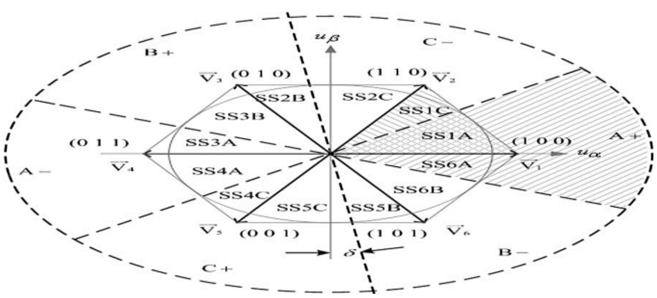

Fig.5 Space vector representation with

For all groups of rectifiers, a specific sector analysis will be described for sector 1 [1].

Table II shows the proposed vector sequences in sectors 1 and 2 for the different groups of rectifiers.

Sub-Sector	Y - Connected Rectifiers	Δ - Connected Rectifiers	Bridge - Connected Rectifiers	Signal of I
SS1A	$\vec{V_0}\vec{V_2}\vec{V_1}\vec{V_2}\vec{V_0}$	$\vec{V_1}\vec{V_2}\vec{V_0}\vec{V_2}\vec{V_1}$	$\vec{V_1}\vec{V_2}\vec{V_0}\vec{V_2}\vec{V_1}$	+
SS1C	$\vec{V_0}\vec{V_1}\vec{V_2}\vec{V_1}\vec{V_0}$	$\vec{V_2}\vec{V_1}\vec{V_0}\vec{V_1}\vec{V_2}$	$\vec{V_2}\vec{V_1}\vec{V_0}\vec{V_1}\vec{V_2}$	−
SS2C	$\vec{V_0}\vec{V_3}\vec{V_2}\vec{V_3}\vec{V_0}$	$\vec{V_2}\vec{V_3}\vec{V_0}\vec{V_3}\vec{V_2}$	$\vec{V_2}\vec{V_3}\vec{V_0}\vec{V_3}\vec{V_2}$	−
SS2B	$\vec{V_0}\vec{V_2}\vec{V_3}\vec{V_2}\vec{V_0}$	$\vec{V_3}\vec{V_2}\vec{V_0}\vec{V_2}\vec{V_3}$	$\vec{V_3}\vec{V_2}\vec{V_0}\vec{V_2}\vec{V_3}$	+

TABLE II- VECTOR SEQUENCES

In one sector, to update the sequence from one subsector to another, the position of the non-null vectors needs to be changed.

III.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.

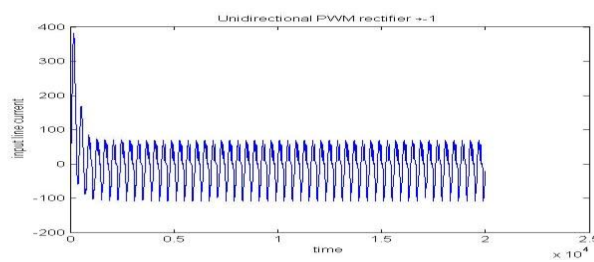

Fig.6 Input current waveform for unidirectional PWM rectifier Y

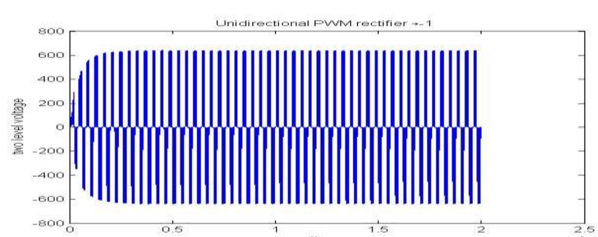

Fig.7 Input current waveform for unidirectional PWM rectifier Δ

Variable	Description	Value
V_p	Peak line voltage	311 V
V_{in}	RMS input voltage	220 V
V_o	Output voltage	700 V
f_r	Line frequency	60 Hz
P_o	Output power	20 kW
L_1,L_2,L_3	Rectifier input inductors	2.4 mH
C_o	Output capacitor	4400 µF
f_s	Switching frequency	10k Hz

TABLE II-SPECIFICATIONS USED IN SIMULATIONS

III. 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 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. Δ-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.

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