Power Quality Analysis of Six Phase Indirect Matrix Converter Based on Multi Phase Generator

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Abstract

Nowadays, multiphase machine drives are considered in many applications, especially for medium and highpower applications. This work focuses on the topology of the six to three phase (hexaphase) indirect matrix converter (IMC). The matrix converter (MC) is designed based on twelve bidirectional switches for the rectifier stage and six single switches for the inverter stage. It is interfaced to a high-performance, fault-tolerant multiphase permanent magnet synchronous generator (PMSG) on one side and to the grid on the other side. In the literature, the most common MCs are of the three-phase type and papers on multiple input converters (N>3) are not common. This work deals with all possible configurations of SVM that can be deduced in a hexaphase MC to determine the modulation indexes and then to assess the VTR (Voltage Transfer Ratio). Simulations are performed on a pure inductive load and THD analysis are performed on the input currents of the MC to show the impact of the studied configurations on the system,

System description

In this project, the system under study is a 6Φ-3Φ hexaphase matrix converter as shown in Fig. 1 applied to an IMC connected to the grid. All the rectifier and inverter stages are controlled using the indirect SVM modulation technique.

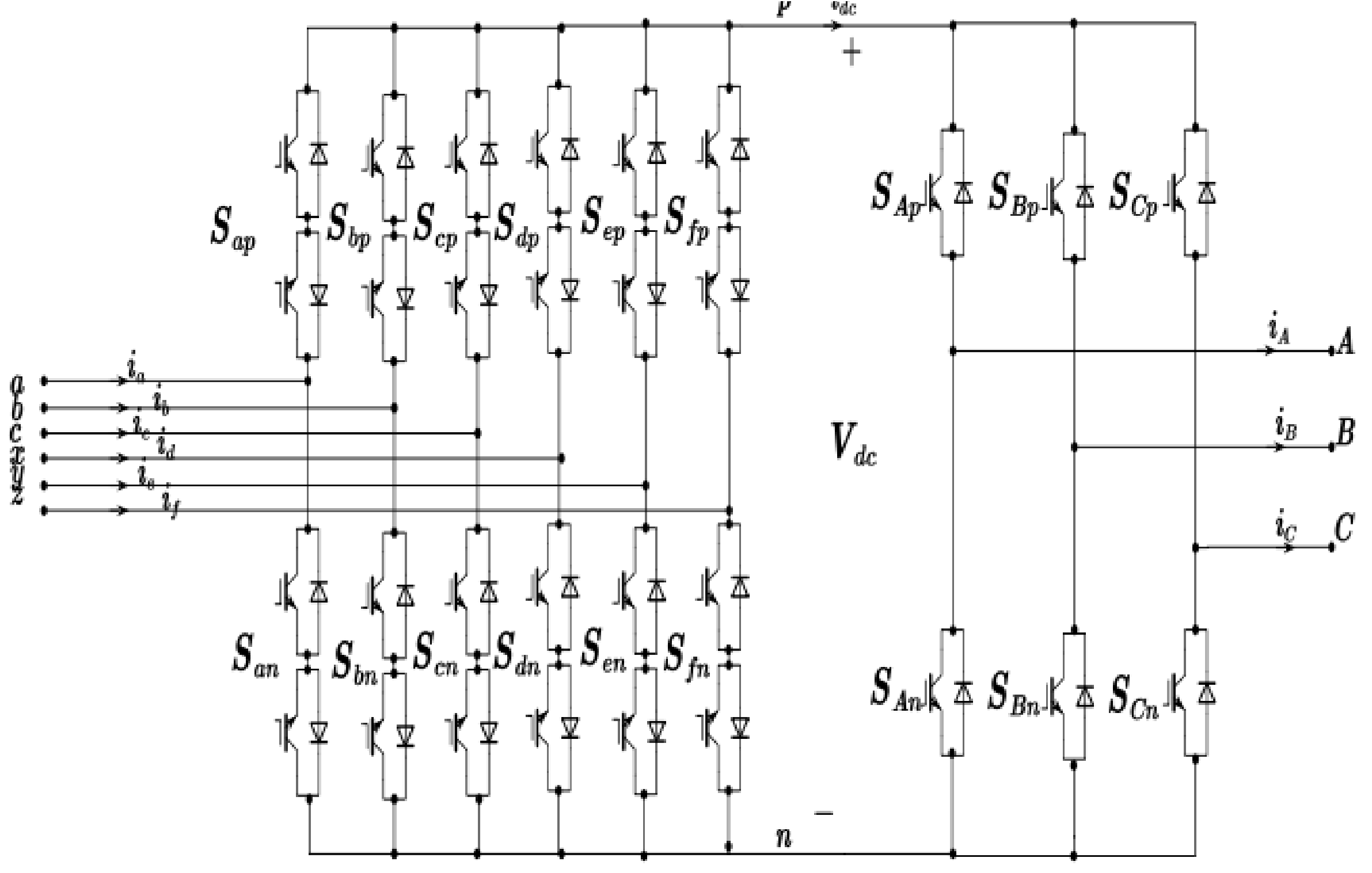


Fig.1 :Complete configuration of the hexaphase IMC

The input voltage and current vectors are given by the following expressions:

$$\begin{cases} V_{in}=\left(\frac{1}{3}\right)\left(V_a+V_b e^{j\frac{2\pi}{3}}+V_c e^{j\frac{4\pi}{3}}+V_x e^{j\frac{\pi}{6}}+V_y e^{j\frac{5\pi}{6}}+V_z e^{j\frac{3\pi}{2}}\right) \\ I_{in}=\left(\frac{1}{3}\right)\left(I_a+I_b e^{j\frac{2\pi}{3}}+I_c e^{j\frac{4\pi}{3}}+I_x e^{j\frac{\pi}{6}}+I_y e^{j\frac{5\pi}{6}}+I_z e^{j\frac{3\pi}{2}}\right) \end{cases}$$

The analytical expressions for the output voltage and current vectors are of the following form:

$$\begin{cases} V_{out}=\left(\frac{2}{3}\right)\left(V_A+V_B e^{j\frac{2\pi}{3}}+V_C e^{j\frac{4\pi}{3}}\right) \\ I_{out}=\left(\frac{2}{3}\right)\left(I_A+I_B e^{j\frac{2\pi}{3}}+I_C e^{j\frac{4\pi}{3}}\right) \end{cases}$$

VTR of all configurations studied

Table III. Summary of configurations studied

Configuration	m_c	m_v	VTR (q_{max})
$3\emptyset-3\emptyset$	$\frac{I_{ref}}{I_d}$	$\sqrt{3}\frac{V_{ref}}{V_d}$	**86.6%**
$6\emptyset-3\emptyset$ (Scheme1) Do_vectors	$3.464\frac{I_{ref}}{I_d}$		**50%**
$6\emptyset-3\emptyset$ (Scheme2) Sx_vectors	$1.793\frac{I_{ref}}{I_d}$		**96.6%**
$6\emptyset-3\emptyset$ (Scheme3) Tw_vectors	$m_c=2.196\frac{I_{ref}}{I_d}$		**78.9%**
	$m'_c=2.45\frac{I_{ref}}{I_d}$		
	$m''_c=1.793\frac{I_{ref}}{I_d}$		

Methodology

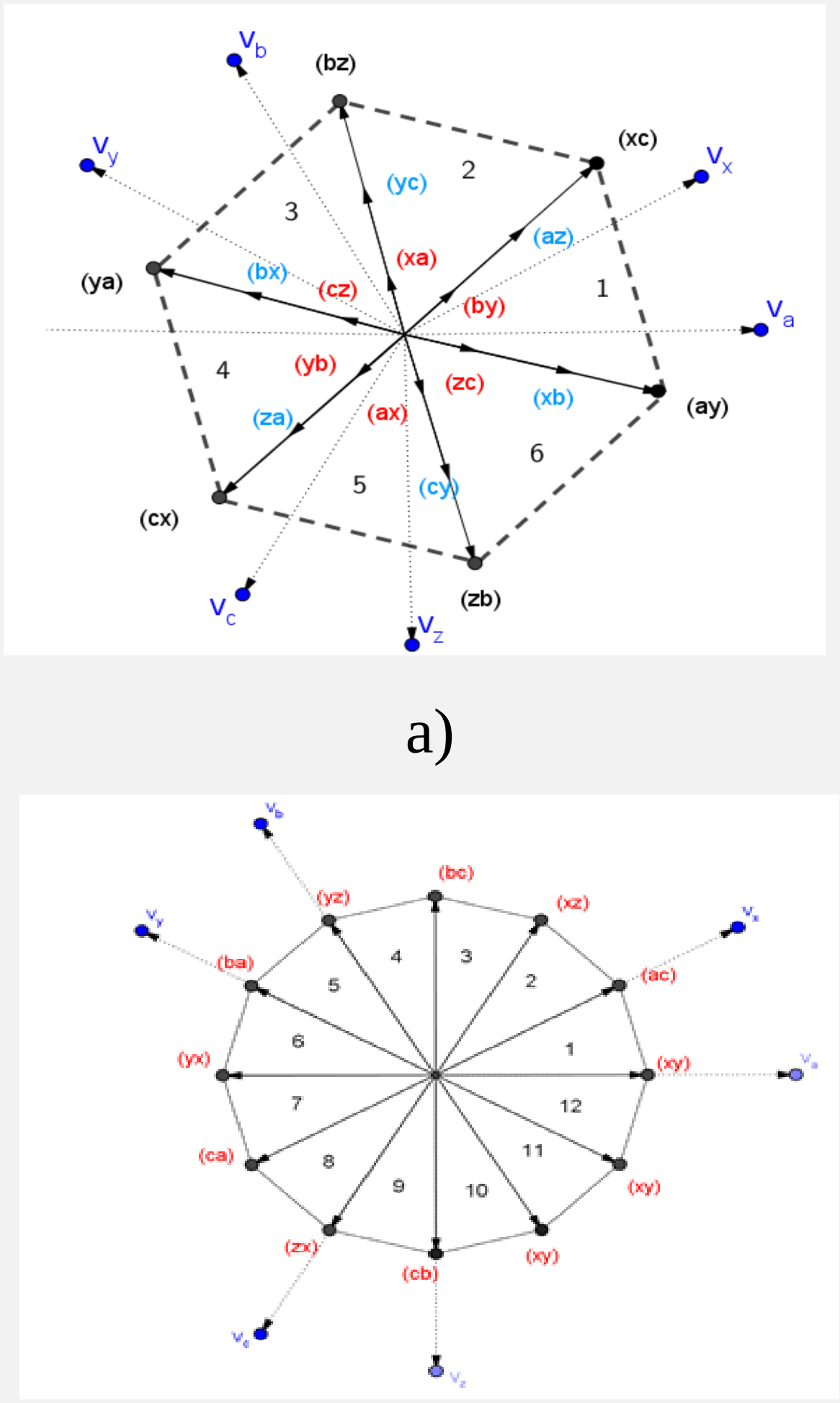
A. Active vectors and vector plane for both stage

Rectifier Stage

The rectifier stage is supplied by a voltage source. By considering the interconnection laws of the energy sources, the input phases must not be short-circuited. Then, the number of available combinations of interconnections of phases is thirty-six (6^2), thirty active vectors and six null vectors as figured in Table I. The complex plane is defined by Fig. 2a and Fig. 2b.

Table I. Table of rectifier stage switch combinations

	a	b	c	x	y	z
a		ab	ac	ax	ay	az
b	ba		bc	bx	by	bz
c	ca	cb		cx	cy	cz
x	xa	xb	xc		xy	xz
y	ya	yb	yc	yx		yz
z	za	zb	zc	zx	zy	



a)

b)

Fig.2: VSR complex plane of active vectors: a) Hexagon b) Dodecagone

Inverter Stage

The inverter stage is connected to an inductive load. By considering the interconnection laws of the energy sources, the output phases must not be open circuit. Then, the number of possible combinations of interconnections of phases is eight (2^3) with six active vectors and two zero vectors as shown in Table II. The complex plane is defined by the hexagon below (Fig. 3).

Table II. Table of inverter stage switch combinations

A	B	C	|Module|	Angle (rad)
0	0	0	0	-
0	0	1	(2/3)V_{DC}	$-2\pi/3$
0	1	0	(2/3)V_{DC}	$2\pi / 3$
0	1	1	(2/3)V_{DC}	π
1	0	0	(2/3)V_{DC}	0
1	0	1	(2/3)V_{DC}	$-\pi / 3$
1	1	0	(2/3)V_{DC}	$\pi / 3$
1	1	1	0	-

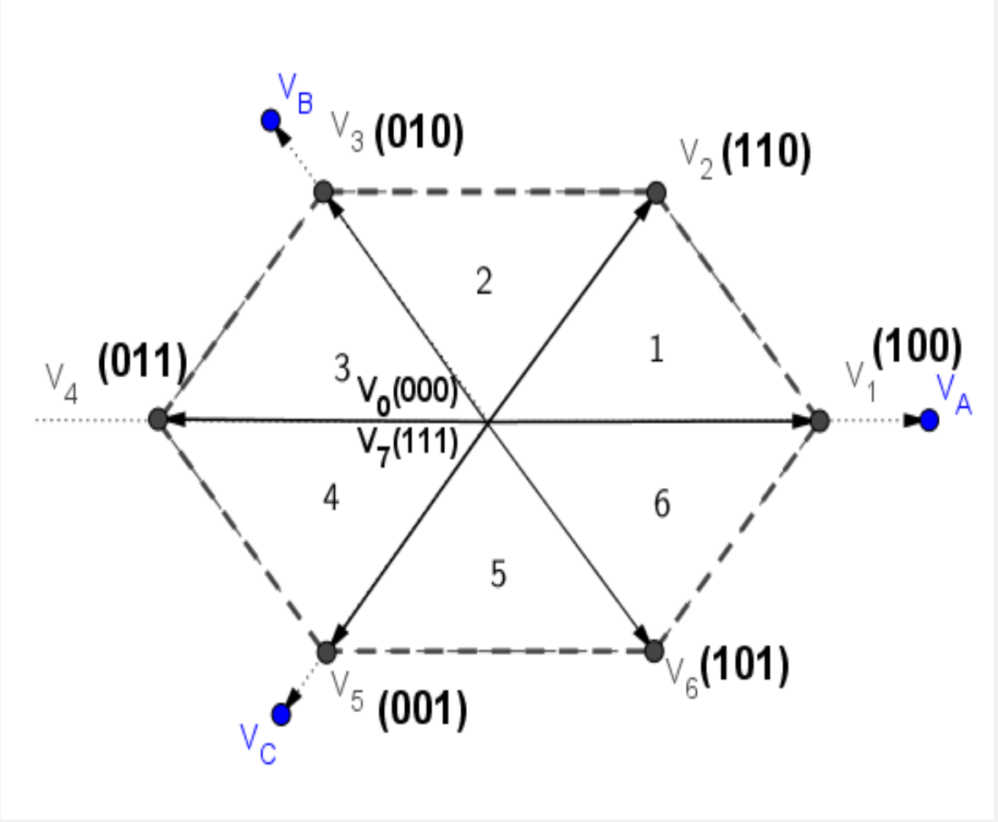


Fig.3: Complex plan (Hexagon) of the inverter stage (VSI)

B. Possibles configurations with the complex plans

With the two VSR complex plans, three configurations are defined for the development of the SVM control.

Do_vectors (Scheme1): Use of the 12 active vectors of the Dodecagon (VSR) for the control with the magnitude of |D|=0.5774Vdc.

The hexagon with 18 active vectors leads to 3 main groups of active vector amplitudes which are:

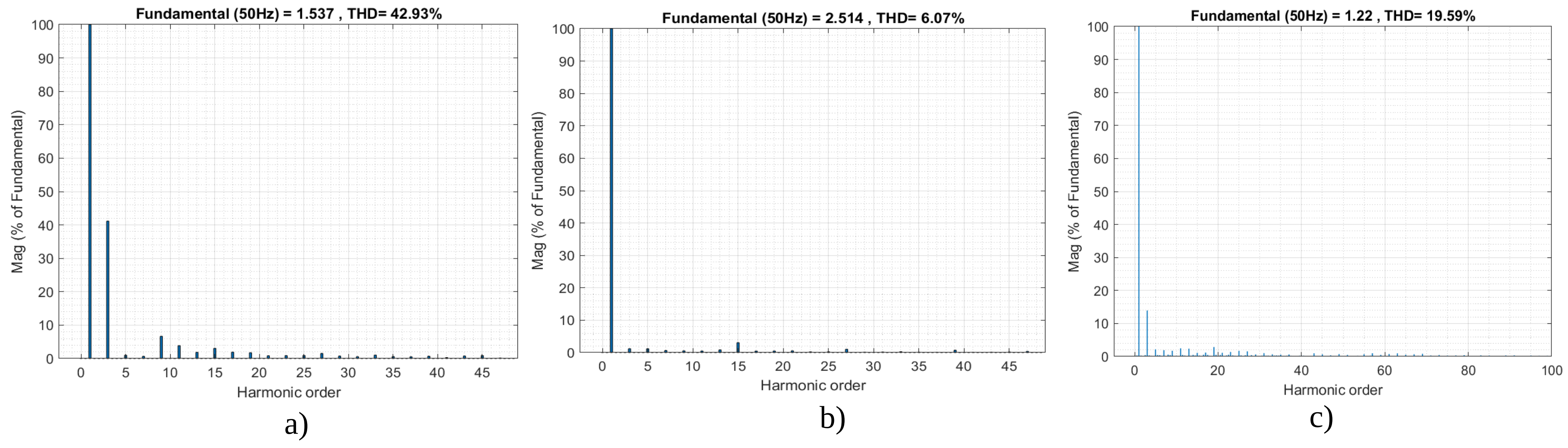
Large: |L|=0.6440Vdc, Medium: |M|=0.4714Vdc and Small: |S|=0.1725Vdc.

Sx_vectors (Scheme2): Use of the six large active vectors

Tw_vectors (Scheme3): Use of the six large and six medium actives vectors

The VTR of these configurations are summarize in Table III.

Results



a) b) c)

Fig.4 : Input's current THDs: a) 3Ø-3Ø system; b) 6Ø-3Ø with the scheme2; c) 6Ø-3Ø with the scheme3.

Conclusion

The purpose of this work is to study all possible configuration schemes and to determine the maximum associated voltage transfer ratio (VTR). Table III summarizes all the possible configurations VTR. The highest VTR (96.6%) comes with the hexaphase system which is higher than the three-phase VTR (86.6%), and the minimum being 50%. The Sx_vectors configuration (96.6% VTR) has a higher THD due to the presence of rank 3 harmonics. It can be observed that the higher the number of active vectors used (Tw_vectors configuration), the lower the THD. The reason is because the rank 3 harmonics are lower with less switching losses.

In closed loop the number of vectors used has no impact on the control and consequently the THD is lower.