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Non-Zero Space Vector Modulation Scheme for Indirect Matrix Converter

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Abstract: Matrix converters are frequency converters which do not contain a direct current link circuit with passive components, unlike conventional frequency converters. Thus, matrix converters may provide a solution for applications where large passive components are not allowed or a purely semiconductor-based solution provides an economically more efficient result than conventional frequency converters. The matrix converter (MC) is an alternative ac-ac power converter by connecting directly input to output phases through bidirectional switches and without using any dc-link or energy storing element, therefore is called an all-silicon converter. Two topologies of matrix converter are established such as direct topology and the indirect topology. This paper is devoting to presents the topology of the indirect sparse matrix converter (ISMC). The article is focused on Non-Zero Space Vector Modulation (NZSVM) modelling applied to very sparse matrix converter (VSMC). Matrix Converter is modulated using the Non-Zero Space Vector Modulation (NZSVM) model. The model is flexible about changing the modulation technique, the load or removing the input filter, becoming an effective simulation tool in the first stage of a real implementation.

Key words: Indirect Matrix Converter · Non-Zero Space Vector Modulation · Total Harmonic Distortion

INTRODUCTION

The Indirect Matrix Converter (IMC) is a modern direct converter of AC/AC electrical power without dc-link capacitor. It consists of a matrix of bi-directional switches arranged such that any input phase can be connected to any output phase at any point in time. It ensures bidirectional power flow between the network and the receiver load with a control of the output voltage amplitude and frequency [1-8]. So, matrix converter provides an adjustable input power factor and high quality sine waveform through to a matrix structure of bidirectional power switches in current and voltage, in each output phase is really to each input phase. Matrix converter has a die remarkable interest since appeared in 1976 especially during the last decade. View the advantage of IMC compared to conventional converters such as cyclo-converter, dimmer and conventional converter. Indirect Matrix converter has an advantages of

- A wide range of operating frequency to the output voltage
- A variable ratio between the output and input voltage can be maximized at possible
- The decouple controlling of output voltage amplitude and frequency
- A reduced total harmonic distortion also for the input and output currents
- Input and output current and voltage sine wives with an adjustable phase shift, so the ability to operate at unity power factor for any load
- Operation in all four quadrants
- The absence of a large capacitor for filtering and energy storage, bulky, heavy and susceptible to failure, which reduces the cost and design of the converter
- Operation at high temperature
- Gain reliability.

All these advantages facilitate the integration of this new converter topology in several areas of industrial applications such as aerospace industries that have a great interest in this converter, industries marine propulsion, the electric drive variable speed machines,

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Corresponding Author: R. Natarajan, Department of EEE, Annamalai University, Annamalai Nagar - 608002, Tamil Nadu, India embedded systems and renewable energy field based wind and fuel cells [9-11]. In this paper a very sparse indirect matrix converter is developed and results are obtained for R and RL output load. Simulation results are discussed and the performance of the very sparse indirect matrix converter topology is therefore evaluated.

Indirect Matrix Converter: The indirect matrix converter (IMC) has received considerable attention as it provides a good alternative to double-sided PWM voltage source rectifier-inverter having advantage of being a two stage converter with six bidirectional switches and six unidirectional switches for three phase to three phase conversion and inherent bidirectional power flow, sinusoidal input/output waveforms with modulate switching frequency, the possibility of compact design due to the absence of dc-link reactive components and controllable input power factor independent of output load current. The main disadvantages of matrix converter are the inherent restriction of the voltage transfer ratio (0.866), more complex control and protection strategy.

The direct AC-DC-AC matrix converter topology has a trouble less structure and it includes several attractive features; but the complexity of its conventional PWM control strategy and the commutation problem prevent it from being used in industry. An alternative approach to overcome these failures is proposed [12-14]. It is a two stage converter topology known as an indirect matrix converter. This topology is similar to the conventional inverter -based converter topology without any reactive DC-link energy storage components for the intermediate imaginary DC -link bus. A block diagram of the indirect matrix converter topology is shown in Fig. 1.

All the desired features of the direct matrix converter topology, such as sinusoidal input current and sinusoidal output voltage, four -quadrant operation, unity power factor, elimination of DC-storage elements are achieved by this indirect matrix converter topology. In addition, this topology simplifies the complexity of the conventional PWM control strategy and overcome the commutation problems of the previous topology.

Very Sparse Matrix Converter: The Characteristics of Very Sparse Matrix Converter topology includes 12 Transistors and 30 Diodes. There is no limitation in functionality compared with the Direct Matrix Converter and Sparse Matrix Converter. When compared to the Sparse Matrix Converter it uses reduced number of transistors but increases the conduction losses due to more number of diodes in the conduction paths. Fig. 2 shows the circuit diagram of Very Sparse Matrix Converter.

Pulse Width Modulation: PWM strategies are applied to generate acceptable input and output waveforms. Different switching strategies yield distinctive performances which may be applied in industry. Several switching modulations are available for matrix converters. In this paper, space vector modulation (SVM) is chosen to satisfy the objectives of the design. It is very critical to analyze each of these features in order to match industry demand. SVM switching pattern brings higher dynamic performance and variable modulation index ma to the converter. The space vector theory is used for the explicit presentation of matrix converter modulation. In addition, some space vector modulation methods are compared from the point of view of the power losses and the output common-mode voltages produced. The space vector approach is used to analyze the migration of supply voltage distortion to output and its reflection back to the supply side. Three computationally simple methods for mitigation of the distortion migration are also compared. These new analytical results are confirmed by simulations and measurements: the distortion migration can be mitigated but not removed totally and the mitigation also increases the complexity of control and decreases supply current quality.

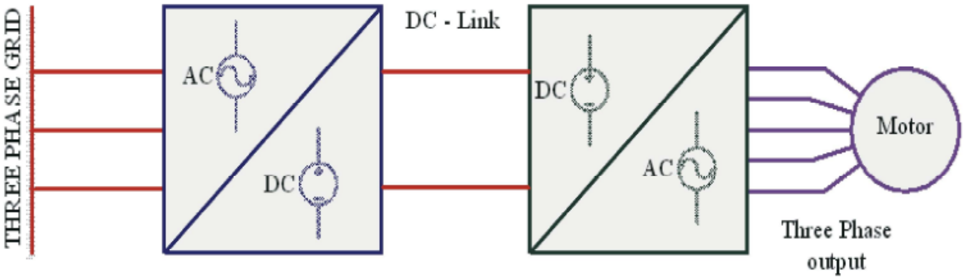


Fig. 1: Indirect matrix converter topology block diagram feeding to an AC –Load

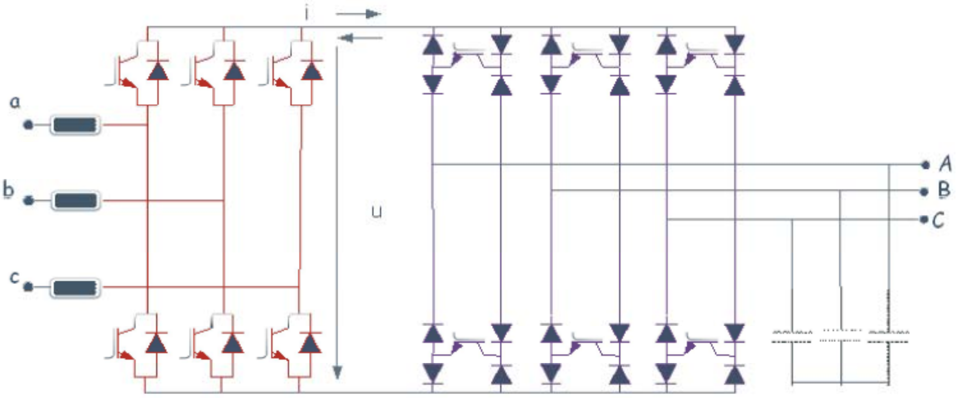


Fig. 2: Very Sparse Matrix Converter

Space Vector Modulation (SVM): Space Vector Modulation (SVM) is one of the vector approaches to PWM technique for three phase inverters. It is the most advanced technique to generate AC signal which produce a high voltage to the motor load with lower total harmonic distortion. In this Space Vector PWM (SVPWM) method the reference signal is sampled regularly. After sampling each signal the non-zero active switching vectors are adjacent to the reference vector. For variable frequency drive application this is the best technique to implement and provides better results. This is an advanced; computation intensive PWM method. Every switching state can be represented as a vector in the converters α-β space vector plane.

Non-Zero Space Vector Modulation (NZSVM): The modulation method applied in [15-21] is a conventional Space Vector Modulation (CSVM), which is based on the optimization rules presented in [22]. In the conventional Space Vector Modulation, the switching patterns are arranged to minimize the number of commutations. As a result, only one switching is performed for every duty cycle change.

In addition to switching losses and distortion, the modulation method also affects the common-mode voltage of output as discussed in [16, 23, 24]. The common mode voltage is the average value of the instantaneous output phase voltages and it is seen between the load neutral point and the ground.

In [23], an improved space vector modulation (ISVM) method based on the conventional Space Vector Modulation is introduced. The operation is the same as with the conventional Space Vector Modulation when the angle θ_i is below $\pi/6$. When the angle θ_i is greater than $\pi/6$, the zero state is divided into States 1 and 9 and the principle of single switching per vector change is retained.

In addition to common-mode voltage minimization, the improved Space Vector Modulation also decreases switching losses compared with the conventional Space Vector Modulation because the average voltage involved in the switching's at the edges of the zero duty cycle is minimized. The other possibility to limit the common-mode voltage to the maximum voltage during the active states is to use the active states only [24]. The method is called the non-zero space vector modulation method (NZSVM) and its principle is described in Tables 1 and 2 in the row 'NZSVM'. Just like the improved Space Vector Modulation, the non-zero space vector modulation method (NZSVM) is also based on the conventional Space Vector Modulation. The zero duty cycle is now divided into three parts: $d_0/2$, $d_0/4$ and $d_0/4$. As presented in Tables 1 and 2, the active state taken during both $d_0/4$ cycles produces opposite voltage compared to the voltage produced by the state during $d_0/2$ in State 6. Thus, these voltages compensate each other and the total effect is zero when the whole modulation period is considered.

At the same time, the rule is that there is again only one switching allowed for every normal state transition. The main drawback of the NZSVM is the greater number of switching's compared to the conventional Space Vector Modulation and the ISVM. Thus, it is also more sensitive to the limitation of duty cycle duration in the case of the division of the zero state, as presented above. The division of the zero states into two or three parts as suggested e.g. in [25], generates non-minimized common-mode voltages: the use of all three zero vectors in a modulation period evidently leads to the maximum common-mode voltage of $\hat{u}_i$, i.e. ±326 V.

Table 1: Duty cycle patterns of the modulation methods considered

Method	Sum of Sectors	State 1	State 2	State 3	State 4	State 5	State 6
CSVM	Even	$d_{\gamma\kappa}/2$	$d_{\gamma\lambda}/2$	$d_{\delta\lambda}/2$	$d_{\delta\kappa}/2$	d_0	$d_{\delta\kappa}/2$
	Odd	$d_{\gamma\lambda}/2$	$d_{\gamma\kappa}/2$	$d_{\delta\kappa}/2$	$d_{\delta\lambda}/2$	d_0	$d_{\delta\lambda}/2$
NZSVM	Even	$d_0/4$	$d_{\gamma\kappa}/2$	$d_{\gamma\lambda}/2$	$d_{\delta\kappa}/2$	$d_{\delta\kappa}/2$	$d_0/2$
	odd	$d_0/4$	$d_{\gamma\lambda}/2$	$d_{\gamma\kappa}/2$	$d_{\delta\kappa}/2$	$d_{\delta\lambda}/2$	$d_0/2$

Table 2: Examples of supply phases connected to output phases with the modulation methods

Voltage Sector	Current Sector	State 1	State 2	State 3	State 4	State 5	State 6
		ABC	ABC	ABC	ABC	ABC	ABC
I	1	cbb	abb	aab	aac	acc	bcc
	2	aab	aac	acc	bcc	bbc	bba
	3	acc	bcc	bbc	bba	aba	aca
	4	bbc	bba	aba	aca	cca	ccb
	5	aba	aca	cca	ccb	bcb	bab
	6	cca	ccb	bcb	bab	baa	caa
II	1	bcb	abb	baa	aac	cac	bcc
	2	aab	cac	acc	cbc	bbc	abb
	3	cac	bcc	cbb	abb	aab	aca
	4	bbc	abb	aba	aca	cca	bcc
	5	aab	aca	acc	bcc	bbc	bab
	6	cca	bcc	bcb	bba	baa	aca
III	1	bcb	bab	baa	caa	cac	cbc
	2	baa	cac	cac	cbc	cbb	abb
	3	cac	cbc	cbb	bab	aab	aac
	4	cbb	abb	aab	aca	acc	bcc
	5	aab	aac	acc	cbc	bbc	bba
	6	acc	bcc	bbc	bba	aba	aca
IV	1	bbc	bab	aba	caa	cca	cbc
	2	baa	cca	cac	ccb	cbb	bab
	3	cca	cbc	bcb	bab	baa	aac
	4	cbb	bab	aab	aac	acc	cbc
	5	baa	aac	cac	cbc	cbb	bba
	6	acc	cbc	bbc	abb	aba	aac
V	1	bbc	bba	aba	aca	cca	ccb
	2	aba	cca	cca	ccb	bcb	bab
	3	cca	ccb	bcb	bba	baa	caa
	4	bcb	bab	baa	aac	cac	cbc
	5	baa	cac	cac	ccb	cbb	abb
	6	cac	cbc	cbb	abb	aab	aac
VI	1	cbb	bba	aab	aca	acc	ccb
	2	aba	acc	cca	bcc	bcb	bba
	3	acc	ccb	bbc	bba	aba	caa
	4	bcb	bba	baa	caa	cac	ccb
	5	aba	cac	cca	ccb	bcb	abb
	6	cac	ccb	cbb	bab	aab	caa

RESULTS

Performance evaluation of Very Sparse Matrix converter (VSMC) with different Load Conditions (R and RL) using non-zero Space Vector Modulation (NZSVM) is carried out using MATLAB/Simulink. Switching pulses for the proposed converter is generated using non-zero Space Vector Modulation (NZSVM). The structure of very sparse matrix converter (VSMC) are assigned to be having the parameters of MI=0.8, fs=50 Hz, fc=6 kHz on source side end and for load side end having MI = 0.8 frequency =150 Hz and fc=2 kHz. Figs.3-8 shows the simulated response of the very sparse matrix converters using non-zero Space Vector Modulation (NZSVM) and space vector modulation (SVM).

Figs. 3 and 4 show the voltage and current of source and load for very sparse matrix converter using NZSVM with R load and Fig. 5 show the voltage and current

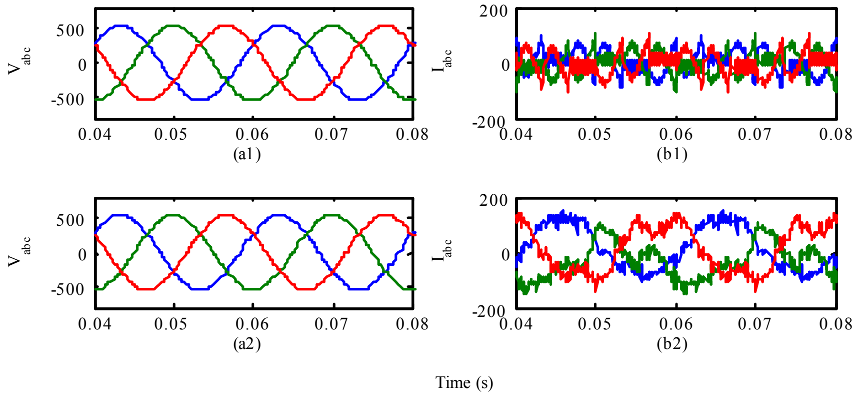


Fig. 3: Input Voltage and Current response of very sparse matrix converter with R Load
(a1) CSVM- Voltage (a2) NZSVM- Voltage (b1) CSVM- Current (b2)NZSVM- Current

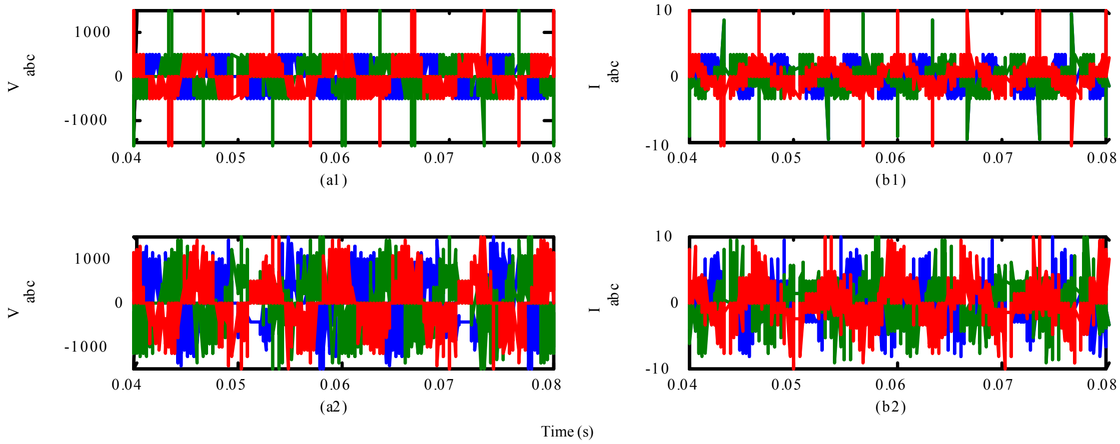


Fig. 4: Output Voltage and Current response of very sparse matrix converter with R Load
(a1) CSVM- Voltage (a2) NZSVM- Voltage (b1) CSVM- Current (b2)NZSVM- Current

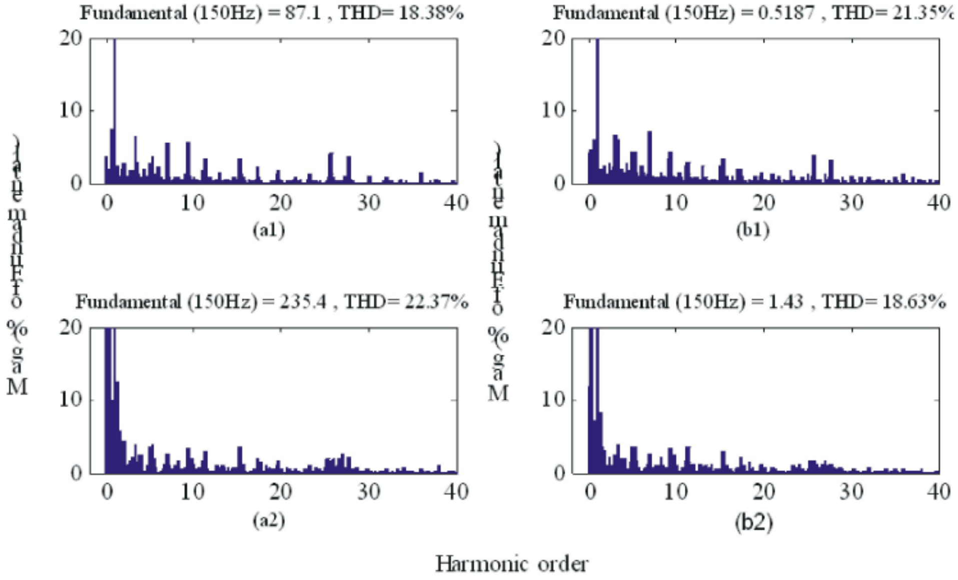


Fig. 5: Output Voltage and Current harmonic response of very sparse matrix converter with R Load
(a1) CSVM- Voltage (a2) NZSVM- Voltage (b1) CSVM- Current (b2) NZSVM- Current

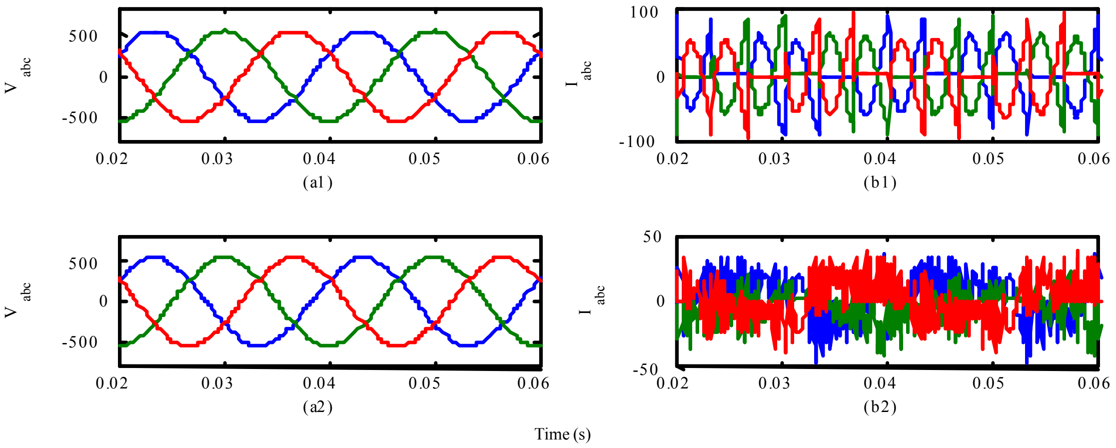


Fig. 6: Input Voltage and Current response of very sparse matrix converter with RL Load (a1) CSVM- Voltage (a2) NZSVM- Voltage (b1) CSVM- Current (b2)NZSVM- Current

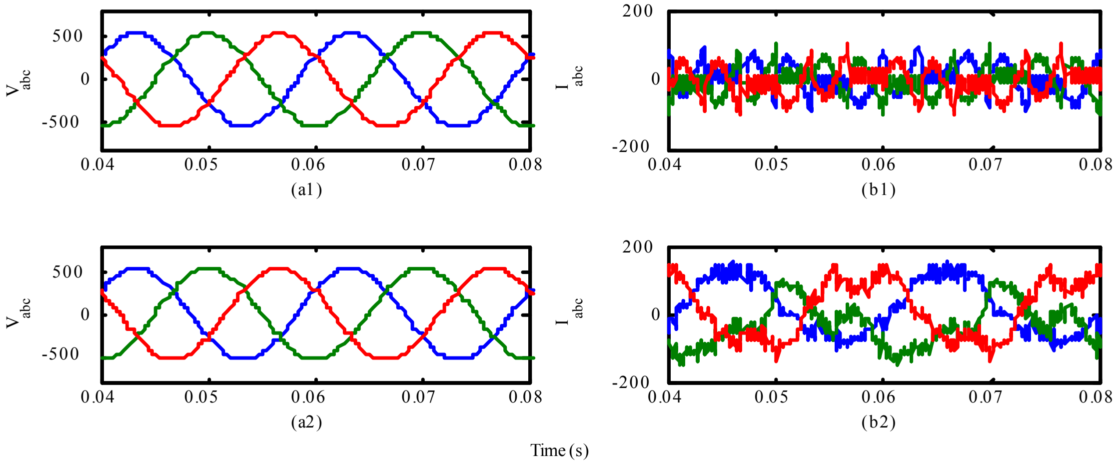
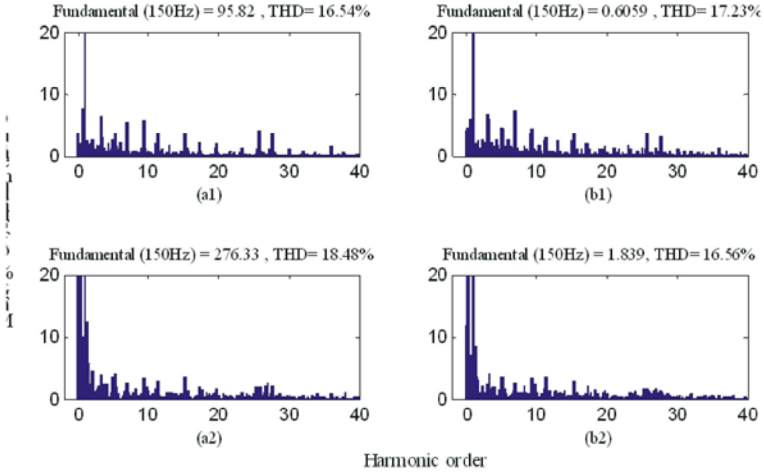


Fig. 7: Output Voltage and Current response of very sparse matrix converter with RL Load (a1) CSVM- Voltage (a2) NZSVM- Voltage (b1) CSVM- Current (b2)NZSVM- Current


Fundamental (150Hz) = 95.82 , THD= 16.54%

Fundamental (150Hz) = 0.6059 , THD= 17.23%

Fundamental (150Hz) = 276.33 , THD= 18.48%

Fundamental (150Hz) = 1.839, THD= 16.56%

Fig. 8: Output Voltage and Current harmonic response of very sparse matrix converter with RL Load (a1) CSVM- Voltage (a2) NZSVM- Voltage (b1) CSVM- Current (b2) NZSVM- Current

harmonic analysis of the very sparse matrix converter using NZSVM with R load. From the results Total Harmonic Distortion (THD in %) is considered to evaluate the performance of Very Sparse Matrix converter for different loads, which is calculated using FFT analysis. Figs. 6 and 7 show the voltage and current of source and load for very sparse matrix converter using NZSVM with RL load and Fig. 8 show the voltage and current harmonic analysis of the very sparse matrix converter using NZSVM with RL load. From the results it is observed that the voltage profile of very sparse matrix converter increased by 276 V using non-zero space vector modulation. The conventional space vector modulation strategy produces less THD of 16.54 compared with NZSVM, but output voltage is very low.

CONCLUSION

This paper has presented the indirect matrix converter and its control using the non-zero space vector modulation method. The harmonic analysis of very sparse matrix converter using SVM and NZSVM with different load conditions has been evaluated. From the analysis the proposed very sparse matrix converter performed superior in non-zero space vector modulation (NZSVM) for both R and RL load conditions. The model is presented step-by-step and in a very clear way following the NZSVM algorithm and enabling an easy future implementation using a real time workshop for DSP programming. Modularity is another advantage in this model; the modulation algorithm can be directly changed for another one, enabling fast modulation comparisons.

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