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Comparison of Modulation Techniques for Cascaded and Reverse Voltage Multilevel Inverter Topologies

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Abstract **- Multilevel inverters have been widely used for high-power, high-voltage applications. Among the existing multilevel inverter topologies Cascaded inverter topology has many advantages over Neutral point clamped and Flying capacitor inverters, but it requires isolated DC sources which is a main drawback of this topology. A new topology with a reversing-voltage component requires fewer numbers of components, switches and carrier signals when compared to other existing topologies. In this paper, the voltage control strategy (Fundamental switching and Sinusoidal Pulse Width Modulation (SPWM)) of the conventional cascaded inverter topology is compared with the new reverse voltage topology. Simulation using MATLAB - Simulink has been carried out for single phase seven level cascaded inverter and RV inverter for both open and closed loop conditions. Results have been compared and validated for the same.**

Index terms-- **Cascaded inverter, Reverse Voltage inverter, PI controller, Level generation, Polarity generation.**

I. INTRODUCTION

Multilevel power conversion has been extensively researched in the past few years for high power applications [1], [2]. Many topologies have been introduced for utility and drive applications. The two level inverters require high switching frequency with various PWM strategies to get quality output which leads to high switching losses. To overcome these problems multi level inverters (MLIs) are introduced. It uses higher number of semiconductor switches to perform the power conversion in small voltage steps. The advantages of MLIs are improvement in Staircase waveform quality, reduction in Common-mode (CM)
Voltage, less input current distortion [3]. MLI are extensively being used in drives, PV systems, HEV systems, automotive applications [4-8].The various topologies of MLI are Cascade inverter, Neutral-point clamped (NPC) inverter, and Flying capacitor inverter. As the level increases, NPC require many clamping diodes, control of real power flow becomes difficult [13]. In Flying capacitor inverter as the level increases, number of storage capacitors also increases hence becomes bulky and costly; the switching losses are also more [14]. The cascaded multilevel inverter has more advantages than other two topologies [9], [10], since it does not require any balancing capacitors and diodes. Cascaded inverter needs separate DC sources for each H-Bridge, hence there is no voltage balancing problem, but isolated DC sources are not readily available, this could be main drawback of this topology [15][16]. Cascaded topology requires more switches. These disadvantages are overcome by a new topology known as Reversing Voltage Component [10]. In this method it is not necessary to utilise all the switches for generating bi-polar levels and separates the output voltage into two parts [10][12]. RV requires less number of switches and components, needs only half of the conventional carriers for SPWM controller [12][17], the complexity of control is also minimized when compared with other topologies.

In this paper Fundamental frequency switching and SPWM switching of both Cascaded and RV MLI topologies are being compared here. The paper tries to prove that RV is better than Cascaded multilevel inverter in terms of their control strategies.

II. CASCADED H-BRIDGE (CHB) AND REVERSE VOLTAGE (RV) MLI TOPOLOGIES

A. Cascaded H-Bridge Inverter Topology

The concept of this inverter is based on connecting H-bridge inverters in series to get a sinusoidal voltage output. The output voltage is the sum of the voltage that is generated by each cell. The number of output voltage levels are $2n+1$, where n is the number of cells. The switching angles can be chosen in such a way that the total harmonic distortion

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is minimized. It needs less number of components comparative to the Diode clamped or the flying capacitor [16], so the price and the weight of the inverter is les. The fig.2 shows an *n* level cascaded H-bridge multilevel inverter. An *n* level cascaded H-bridge multilevel inverter needs 2(*n*-1) switching devices where *n* is the number of the output voltage level.

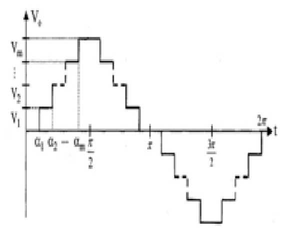

Fig 1. Output wave form of MLI

B. Reverse Voltage Topology.

In conventional multilevel inverters, the power semiconductor switches are combined to produce a high-frequency waveform in positive and negative polarities. However, there is no need to utilize all the switches for generating bipolar levels. This idea has been put into practice by the new topology. This topology is a hybrid multilevel topology which separates the output voltage into two parts. One part is named level generation part and is responsible for level generating in positive polarity. This part requires high-frequency switches to generate the required levels. The switches in this part should have high-switching-frequency capability. The other part is called polarity generation part and is responsible for generating the polarity of the output voltage, which is the low-frequency part operating at line frequency.

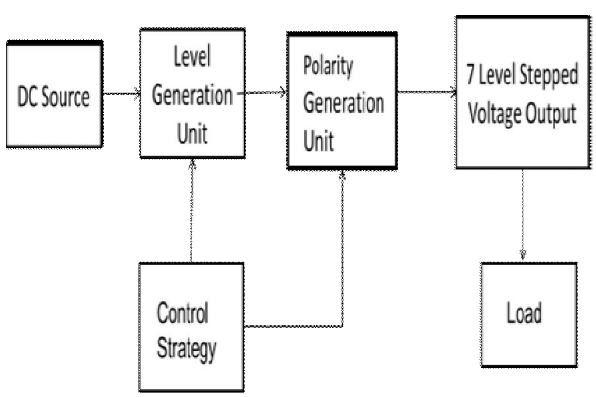

Fig 2. General block diagram of 1 Φ 7 level RV

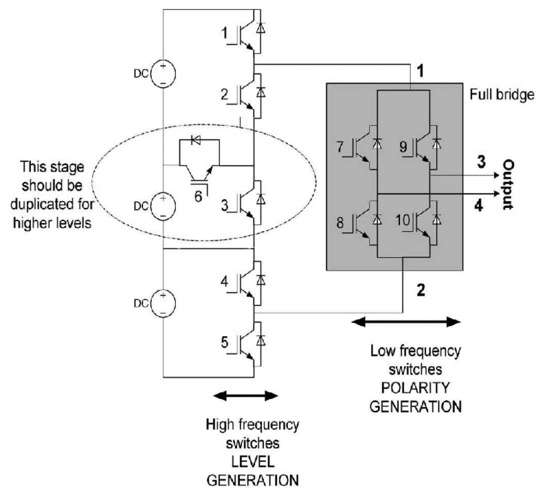

Fig.3 Schematic diagram of 1Φ 7 level RV

This topology easily extends to higher voltage levels by duplicating the middle stage as shown in Fig.3 Therefore; this topology is modular and can be easily increased to higher voltage levels by adding the middle stage in Fig.3. This requires fewer components in comparison to conventional inverters. It just requires half of the conventional carriers for SPWM controller. SPWM for seven-level conventional converters consists of six carriers, but here, three carriers are sufficient. The reason is that, according to Fig.3 , the multilevel converter works only in positive polarity and does not generate negative polarities. In comparison with a cascade topology, it requires just one-third of isolated power supplies used in a cascade-type inverter.

C. Modes Of Operation

As seen from Table I, there are six possible switching patterns to control the inverter. In order to avoid unwanted voltage levels during switching cycles, the switching modes should be selected so that the switching transitions become minimal during each mode transfer, hence it will reduce switching power dissipation. The sequence of switches (2-3-4), (2-3-5), (2-6-5), and (1-5) are chosen for levels 0 up to 3, respectively. The output voltage level is the sum of voltage sources, which are included in the current path that is shown in the following fig.4

TABLE I
SWITCHING MODES FOR GENERATING 7 LEVEL RV INVERTER

Level	0	Vdc	2Vdc	3Vdc
Mode				
1	2,3,4	2,3,5	1,4	1,5
2		2,4,6	2,6,5	

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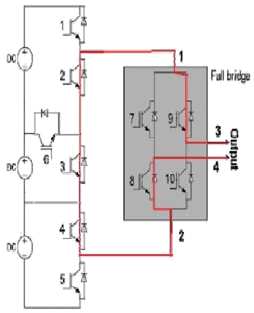
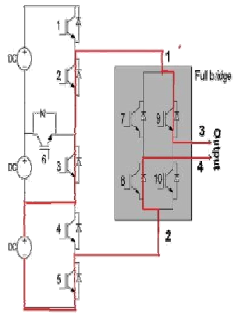
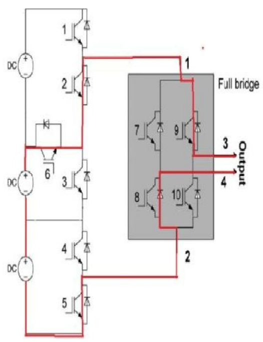


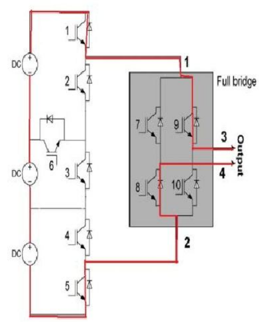
Level 1 = 0Vdc



Level 2 = 1Vdc



Level 3 = 2Vdc



Level 4 = 3Vdc

Fig 4 Levels of 1Φ 7 level RV

D. *Number Of Components*

The reliability of a system is indirectly proportional to the number of its components. As the number of high-frequency switches is increased, the reliability of the converter is decreased. From Table I it is cleared that RV requires very less number of switches than other topologies.

TABLE II
Number of components for three Phase Inverter

Inverter type	NPC	Flying capacitor	Cascade	RV
Main switches	6(N-1)	6(N-1)	6(N-1)	3((N-1)+4)
main diodes	6(N-1)	6(N-1)	6(N-1)	3((N-1)+4)
Clamping diodes	3(N-1)(N-2)	0	0	0
DC bus capacitors/ Isolated supplies	(N-1)	(N-1)	3(N-1)/2	(N-1)/2
Flying capacitors	0	$\frac{3}{2}$(N-1)(N-2)	0	0
Total numbers	(N-1)(3N+7)	$\frac{1}{2}$(N-1)(3N+20)	$\frac{27}{2}$(N-1)	(13N+35)/2

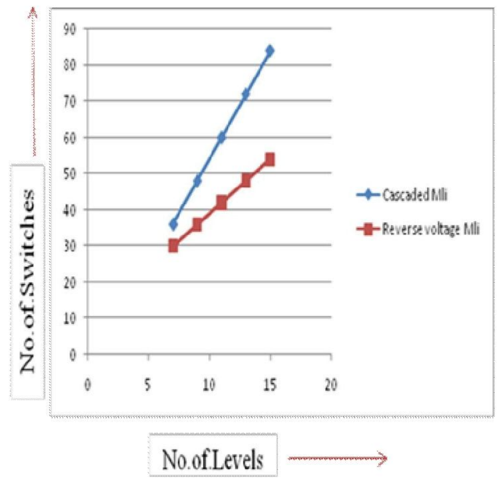


Fig: 5 Number of switches required for three phase Inverter.

III. CONTROL STRATEGIES

A. *Fundamental Frequency*

PWM method and SVM technique will cause extra losses due to high switching frequencies. For this reason, low-switching frequency control methods, such as selective harmonic elimination method, fundamental frequency switching method or active harmonic elimination method, can be used for the HCMLI control.

B. *Sinusoidal Pulse Width Modulation*

It is desired that the ac output voltage V_O = Van follow a given waveform (e.g., sinusoidal) on a continuous basis by properly switching the power valves. The carrier-based PWM technique fulfils such a requirement as it defines the on and off states of the switches of one leg of a VSI by comparing a modulating signal V_A (desired ac output voltage) and a triangular waveform V_C (carrier signal). In practice, when $V_A > V_C$ the switch S+ is on and the switch S- is off; similarly, when $V_A < V_C$ the switch S+ is off and the switch S- is on.

A special case is when the modulating signal V_A is a sinusoidal at frequency F_C and amplitude V^A and the triangular signal V_C is at frequency F_C and amplitude V^C. This is the sinusoidal PWM (SPWM) scheme. In this case, the modulation index ma (also known as the amplitude-modulation ratio) is defined as $m_a = V_C/V_A$ and the normalized carrier frequency m_f (also known as the frequency-modulation ratio) is $m_f = F_C/F_A$.

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TABLE III

CASCADED MLI VS REVERSE VOLTAGE MLI FOR VARIOUS MODULATION INDEX (M.I) WITH R LOAD.

M.I	□1	□2	□3	TOPOLOGY	V1	V3	V5	V7	V9	V11	V13	V15	%THD
0.76	12.85	35.12	60.85	CHB	313.5	22.09	0.01	0.02	10.75	9.37	8.08	26.81	14.8
				RV	313.5	22.08	0.01	0.03	10.75	9.37	8.08	26.81	14.8
0.77	12.28	33.61	60	CHB	313.5	22.08	0.01	0.03	12.43	9.72	2.24	25.74	14.8
				RV	313.5	22.09	0.01	0.02	12.42	9.72	2.24	25.74	14.0
0.81	11.68	26.89	56.03	CHB	334.1	0.11	0	0.01	23.56	5.30	11.54	7.11	12.52
				RV	317.6	17.76	0.01	0.02	23.56	5.30	11.54	7.11	12.52
0.82	12.18	24.86	54.89	CHB	338.3	4.8	0.01	0.01	26.79	13.46	9.14	2.33	12.88
				RV	338.3	4.8	0.01	0.01	26.78	13.45	9.15	2.33	12.88

%THD Comparison between CHB & RV

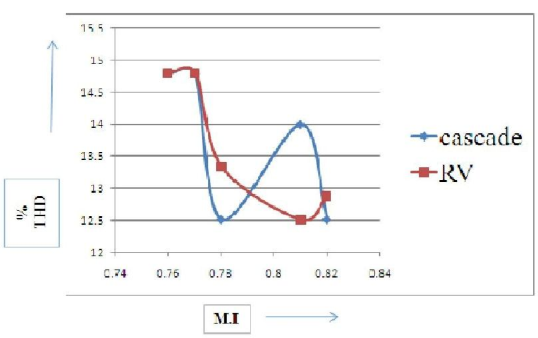

Fig.6 Graph for M.I (VS) %THD with R load

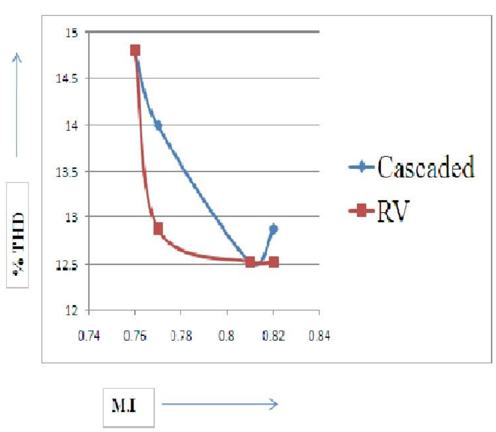

Fig.7 Graph for CHB and RV with RL load

TABLE IV

SPWM COMPARISON FOR OPEN LOOP CHB AND RV WITH RL LOAD.

Topology	Peak(RMS)	%THD
Cascaded	331.5(234.4)	40.60
RV	323.3(228.6)	12.09

Table III & VI shows the values of both Cascaded and RV inverter's %THD for different modulation indexes for both R and RL load respectively. It is cleared that RV has less %THD than Cascaded inverter, which is shown with the help of the above graphs.

Table IV&V shows the comparison in terms of SPWM for both topologies with R and RL load respectively; here also RV has very less %THD than Cascaded inverter.

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TABLE V

RESULTS FOR CLOSED LOOP SPWM RV WITH R&RL LOAD

Load	V_1	V_3	V_5	V_7	V_9	V_{11}	V_{13}	V_{15}	%THD
R	211.3(149.4)	35.36	18.47	10.96	7.21	4.3	2.50	1.59	52.27
RL	211.3 (149.4)	35.15	18.44	11.46	7.09	4.14	2.68	1.44	55.15

TABLE VI
COMPARISON BETWEEN SINGLE PHASE SEVEN LEVEL CHB AND RV WITH RL LOAD

M.I	θ_1	θ_2	θ_3	TOPOLOGY	V_1	V_3	V_5	V_7	V_9	V_{11}	V_{13}	V_{15}	%THD
0.76	12.85	35.12	60.85	CHB	313.5	22.08	0	0.02	10.75	9.37	8.08	26.81	14.80
				RV	313.5	22.09	0.02	0.03	10.74	9.38	8.11	26.81	14.81
0.77	12.28	33.61	60	CHB	317.6	17.77	0.02	0.01	12.93	9.72	2.24	25.74	14.00
				RV	338.2	4.80	0.01	0.02	26.78	13.44	9.15	2.34	12.88
0.81	11.68	26.89	56.03	CHB	334.1	0.11	0	0.01	23.56	5.29	11.54	7.11	12.52
				RV	334.1	0.12	0.01	0.01	23.56	5.29	11.54	7.11	12.52
0.82	12.18	24.86	54.89	CHB	338.2	4.81	0.01	0	26.98	13.45	9.15	2.34	12.88
				RV	334.1	0.11	0.01	0.02	23.56	5.29	11.54	7.12	12.52

IV. SIMULATION AND RESULTS

From the above two tabulations it is cleared that Reverse voltage topology has less %THD when compared to Cascaded inverter, especially for M.I 0.77 for R load, M.I 0.77 & 0.82 for RL load . As already it has been proved that RV requires less number of components, switches, and carrier signals hence automatically the cost, Control complexities will be reduced. Here in this paper the control strategies are compared and from the obtained results it has been proved that RV is better than Cascaded inverter for both fundamental switching technique and SPWM technique.

V. CONCLUSION

Multilevel inverters have been utilized in many industrial applications like UPS, HVDC, FACTS, EV, PV systems and Industrial drive applications. Instead of using Cascaded inverter topology, RV is better for all these applications, since it has less control complexities; cost is also less and gives less % THD. Hence RV is preferred than Cascaded inverter.

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