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Multilevel Inverters: Literature Survey–Topologies and Comparison between different topologies.

[1]Aditya C. Zarekar [2] Dr. Anjali Deshpande [3]Geetha Narayanan
[1] Reading ME EXTC, VIT, Wadala, Mumbai,
[2]Professor And Head Of Electronics Department, Vidyalankar Institute of Technology, Wadala, Mumbai University, Maharashtra, India,
[3]Associate Professor, Electronics Department, Vidyalankar Institute of Technology, Wadala, Mumbai University, Maharashtra, India

Abstract: **Multilevel inverters are in favor of academia as well as industry in the recent decade for high-power and high-voltage applications, due to their ability to synthesize higher voltages with a limited maximum device rating, producing of smaller common-mode voltage (CM), less electromagnetic compatibility (EMC) problems and attain higher voltage with a l imited maximum device rating with the added advantages of low switching stress and lower total harmonic distortion (THD), hence reducing the size and bulk of the passive filters. This paper presents a review on most important topologies like diode-clamped inverter (neutral-point clamped), capacitor-clamped inverter (flying capacitor), and cascaded inverter with separate DC sources and All existing methods are compared in detail with proposal for the best methods available. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references in the fie ld of topologies and modulation strategies of multilevel inverter.**

***Keywords*— Multilevel inverter, Neutral point clamped, Flying capacitor, Cascaded H-bridge, Variable switching frequency, Total harmonic distortion.**

I. INTRODUCTION

Recently, multilevel inverters have become more attractive to researchers and industrial companies due to fast developing of high power devices, and related control techniques. Currently, they are commercialized in standard and customized products that power a wide range of applications, such as compressors, pumps, fans, grinding mills, rolling mills, conveyors, crushers, blast furnace blowers, gas turbine starters, mixers, mine hoists, reactive power compensation, marine propulsion, high-voltage direct-current (HVDC) transmission, hydropumped storage, wind energy conversion. The concept of multilevel inverters (MLI) has been introduced since mid-1970. The term multilevel originated with the three level inverter. The most common multilevel converter topologies are the neutral-point clamped converter (NPC), flying capacitor converter (FC) and Cascaded H-Bridge (CHB). Advantage of multi-level inverter is mainly related with the traditional two-level voltage inverter, it produces step output voltage, high power quality, lower harmonic value, enhanced electromagnetic compatibility and lower switching losses. Output voltage is produced by adding or subtracting several distinct DC voltages to/from others.

II. MULTILEVEL INVERTER TOPOLOGIES

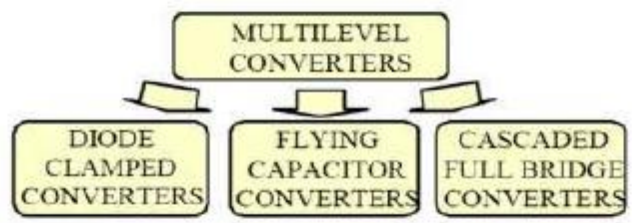

Fig.1: Multilevel inverter topologies

1. Diode Clamped multilevel inverter

One of the traditionally accepted and widely used topology for various industrial and power sector applications is neutral point converter which was proposed by Nabae, Takahashi and Akagi in 1981. The main concept of this inverter is to use diodes to limit the power devices voltage stress. The voltage over each capacitor and each switch is V_{dc}. An n level inverter needs (n-1) capacitors, 2(n-1) switching devices and (n-1) (n- 2) diodes. A three-level diode clamped inverter consists of two pairs of switches and two diodes. Each switch pairs works in complimentary mode and the diodes used to provide access to mid-point voltage. In a three-level inverter each of the three phases of the inverter shares a common dc bus, which has been subdivided by two capacitors into three levels. The DC bus voltage is split into three voltage levels by using two series connections of DC capacitors, C1 and C2. The voltage stress across each switching device is limited to *Vdc* through the clamping diodes Dc1 and Dc2.

5-level diode clamped multilevel inverter:

A three-phase 5-level diode-clamped inverter is shown in fig.2. Each of the three phases of the inverter shares a common dc bus, which has been subdivided by four capacitors into five levels. The voltage stress across each switching device is limited to Vdc through the clamping diodes. In a 5-level diode clamped multilevel: n=5. Number of capacitors= $(n-1) = 4$, Number of switches = $2(n-1) = 8$, Number of diodes= $(n-1)(n-2) = 12$.

The waveform output of five level multilevel inverter is shown in fig.3. Each phase has four complementary switch pairs such that turning on one of the switches of the pair require that the other complementary switch be turned off. The complementary switch pairs for one phase leg are (S1, S5), (S2, S6), (S3, S7), (S4, S 8).

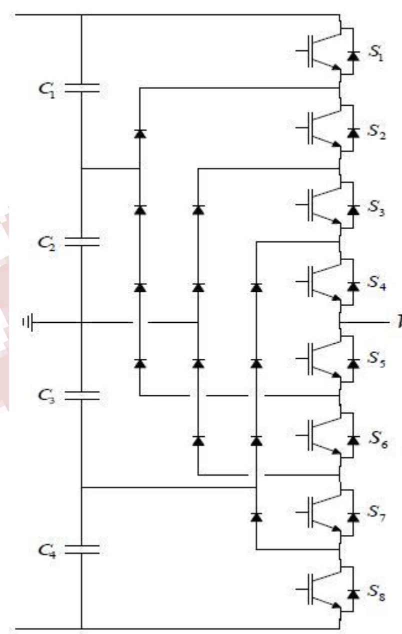

Fig.2: One phase of a diode clamped inverter

V_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
$V_{dc}/2$	1	1	1	1	0	0	0	0
$V_{dc}/4$	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	0
$-V_{dc}/4$	0	0	0	1	1	1	1	0
$-V_{dc}/2$	0	0	0	0	1	1	1	1

Table 1: The switching states of Diode clamped multilevel inverter.

Fig.3: Waveform of a five level multilevel inverter

Disadvantages: 1) Real power flow is difficult for a single inverter because the intermediate dc levels will tend to overcharge or discharge without precise monitoring and control. 2) The number of clamping diodes required is quadratically related to the number of levels, which can be cumbersome for units with a high number of levels.

III. FLYING CAPACITOR MULTILEVEL INVERTER

Meynard and Foch introduced a flying- capacitor-based inverter in 1992. The structure of this inverter is similar to that of the diode-clamped inverter except that instead of using clamping diodes, the inverter uses capacitors in their place. The circuit topology of the flying capacitor multilevel inverter is shown in Fig.4. The voltage increment between two adjacent capacitor legs gives the size of the voltage steps in the output waveform. In addition to the $(m-1)$ dc link capacitors, the *m*-level flying-capacitor multilevel inverter will require $(m-1) \times (m-2)/2$ auxiliary capacitors per phase. Advantages: 1) Phase redundancies are available for balancing the voltage levels of the capacitors.

V_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
$V_{dc}/2$	1	1	1	1	0	0	0	0
$V_{dc}/4$	1	1	1	0	1	0	0	0
0	1	1	0	0	1	1	0	0
$-V_{dc}/4$	1	0	0	0	1	1	1	0
$-V_{dc}/2$	0	0	0	0	1	1	1	1

Table 2: The switching states of capacitor clamped multilevel inverter.

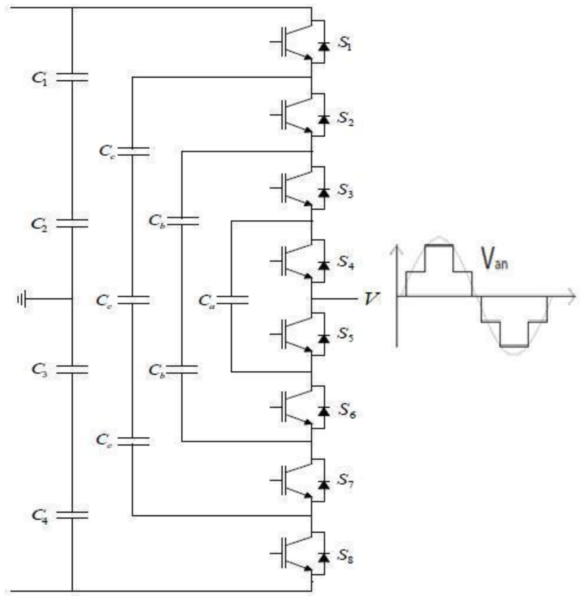

Fig.4. One phase of a 5-level Flying capacitor multilevel inverter

2) Real and reactive power flow can be controlled. 3) The large number of capacitors enables the inverter to ride through short duration outages and deep voltage sags.
Disadvantages: 1) Control is complicated to track the voltage levels for all of the capacitors. Also, recharging all of the capacitors to the same voltage level is complex. 2) Switching utilization and efficiency are poor for real power transmission. 3) The large numbers of capacitors are both more expensive and bulky than clamping diodes in multilevel diode-clamped converters. Packaging is also more difficult in inverters with a high number of levels.

IV. CASCADED MULTILEVEL INVERTER

The concept of series H-bridge inverter was first proposed by R. H. Baker and L. H. Banister in 1975. In order to overcome the drawbacks of NPC and FC topologies such as extra clamping diodes and capacitors, Marchesoni.M. have proposed Cascaded H-Bridge Inverter. 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. One of the advantages of this type of multilevel inverter is that it needs less number of components comparative to the Diode clamped or the flying capacitor, so the price and the weight of the inverter is less than that of the two former types.

Fig.5.shows five level cascaded H-bridge multilevel inverter. An m level cascaded H-bridge multilevel inverter needs $2(m- 1)$ switching devices where m is the number of the output voltage level. The phase voltage $van = vH1 + vH2 + vH3$.

Advantages: 1)Less number of components is needed for getting same number of voltage level. 2) No need of extra diodes and capacitors. 3) Because of same structure it allows the scalable, modularized circuit layout and packaging.

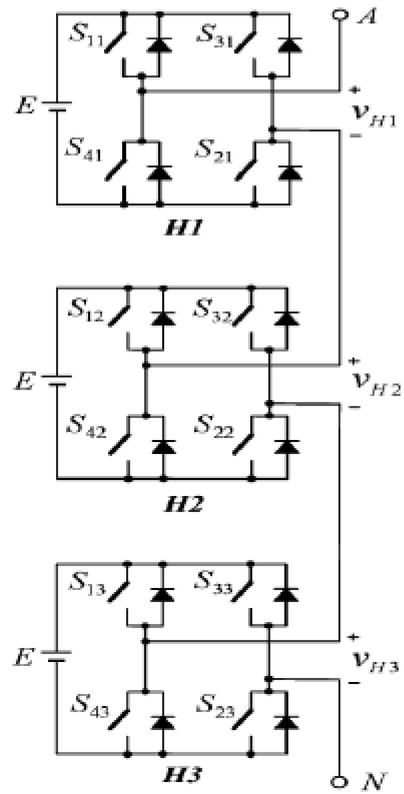

Fig.5. Seven level cascaded H-bridge multilevel inverter.

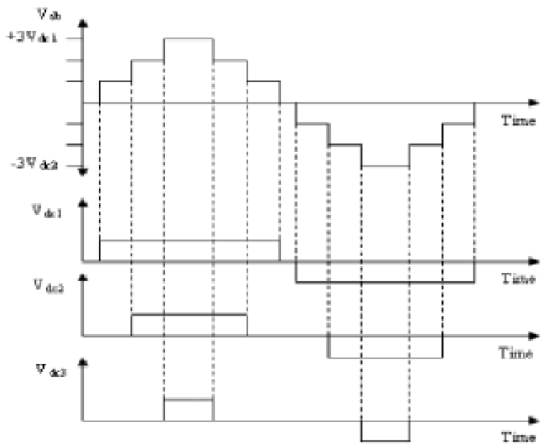

Fig.6. Output phase voltage waveform of an 7-level cascade inverter with 3-separate dc sources.

Disadvantages: Separate DC sources are required for the real power conversion.

V_0	S_{11}	S_{21}	S_{31}	S_{41}	S_{12}	S_{22}	S_{32}	S_{42}	S_{13}	S_{23}	S_{33}	S_{43}
0	0	1	0	1	0	1	0	1	0	1	0	1
V_{DC}	1	1	0	0	0	1	0	1	0	1	0	1
$2V_{DC}$	1	1	0	0	1	1	0	0	0	1	0	1
$3V_{DC}$	1	1	0	0	1	1	0	0	1	1	0	0
$-V_{DC}$	0	1	0	1	0	1	0	1	1	1	0	0
$-2V_{DC}$	0	1	0	1	0	0	1	1	0	0	1	1
$-3V_{DC}$	0	0	1	1	0	0	1	1	0	0	1	1

Table 3: The switching states of cascaded H-bridge multilevel inverter

V. COMPARISON OF MULTILEVEL INVERTERS

All three converters have the potential for application in high voltage applications. The diode clamped converter is most suitable for the back to back intertie system operating as a unified power flow controller, other two are also applicable for the same but they would require more switching per cycle. All devices are assumed to have same voltage ratings but not necessarily same current ratings. The cascaded inverter uses full bridge in each level as compare to the half bridge versions in other two types. The cascaded inverter requires the least number of components and has the potential for utility interface applications because of its capabilities for applying modulation and soft switching techniques.

Elements	DCMLI (5-level)	FCMLI (5-level)	CMLI (5-level)
Main switching devices	8	8	8
Clamping diodes	12	0	0
Balancing capacitor	0	12	0
DC bus capacitor	4	4	2
Main diodes	8	8	8

Table 4: Comparison of components required for various topologies.

VI. CONCLUSION

Multilevel inverters are suitable for high voltages and high current application and also have higher efficiency because the devices can be switched at a lower frequency. We hereby conclude that multilevel inverters is a very promising technology in the power industry. In this paper, the advantages and disadvantages of multilevel Inverters are mentioned and a detailed description of different multilevel inverter topologies is presented. Cascaded multilevel inverter requires minimum number of components when compared will other types (it is shown in Table.4). So it produces an increased stepped output with less number of semiconductor switches. Authors intentions are to provide the brief idea about the major topologies of multilevel inverter. Thus after this study we found that cascaded inverter is the better when we compare the reliability, modulation scheme and switching techniques with other topologies.

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REFERENCES

[1] Rokan Ali Ahmed,S.Mekhilef and Hew Wooi Ping, ―New Multilevel Inverter Topology With Reduced Number of Switches‖, Proc. IEEE conf Rec. 978-1-4244-6890-4, 2010, pp.1862-1867.

[2] Panagiotis Panagis, Fotis Stergiopoulos, Pantelis Marabeas and Stefanos Manias, „Comparison of state of the

art multilevel inverters‟, in IEEE Conf. Rec.: 978-1-4244-1668-4/08, 2008, pp.4296-4301.

[3] Alian chen,Chenghuizhang,Haoma and Yan deng ―A novel multilevel inverter topology with no clamping diodes and flying capacitors‖ in IEEE.Rec:978-1-4244-1766-7, 2008, pp.3184-3187.

[4] J.Rodriguez, J.S.Lai and F.Z.Peng, „Multilevel inverters: A survey of topologies, controls and applications‟, IEEE Trans. Ind. Electron., vol.49, no.4, pp.724-738, 2002.

[5] T. V. V. S Lakshmi , Noby George, S. Umashankar and D.P. Kothari, ―Cascaded seven level inverter with reduced number of switches using level shifting PWM technique,‖ IEEE conf. Rec:978-1-4673-6030-2, pp.676-680, 2013.

[6] Javad Ebrahimi, Ebrahim Babaei, Ebrahim Babaei, ―A new multilevel converter topology with reduced number of power electronic components‖, IEEE Transactions on industrial electronics, vol. 59, no. 2, 2012, pp.655-667.

[7] P. Roshankumar, P. P. Rajeevan, K.Mathew, K. Gopakumar, Jose I. Leon, Leopoldo G. Franquelo, ―A Five-Level Inverter Topology with Single-DC Supply by Cascading a Flying Capacitor Inverter and an H-Bridge‖, IEEE Transactions on Power Electronics, vol. 27, no. 8, 2012, pp.3505-3515.

[8] Jacob James Nedumgatt, D.Vijayakumar, A. Kirubakaran, S. Umashankar, ― A Multilevel Inverter with Reduced Number of Switches,‖ IEEE conf. Rec:978 -1-4673-1515-9,2012.

[9] Zahra Bayat, Ebrahim Babaei, ―A New Cascaded Multilevel Inverter with Reduced Number of Switches‖, Proc. IEEE conf Rec, ISBN: 978-1-4673-0113, 2012, PP.416-421.

[10] F.Z. Peng And J.S Lai, ―Multilevel cascade voltage source inverter with separate DC sources‟, U.S Patent 5642275 June 1997.

[11] B.S Suh, G. Sinha,M. Manjrekar, ―Multilevel power conversion-An overview of topologies and modulation strategies‖, in proc. of International conference on Optimization of Electrical and Electronic Equipments, May 1998, Vol.2, pp.AD11-AD-24

[12] Fang Zhengpeng, Jih Sheng Lai, ―A multilevel voltage source inverter with separate DC source for static var generation‖, IEEE Trans. On Industry Applications, Vol.32 No.5, pp1130-1137, 1996.

[13] R. Teodorescu, F. Beaabjerg, J. K. Pedersen, E. Cengelci, S. Sulistijo, B. Woo, and P. Enjeti, ―Multilevel converters ― A survey,‖ in Proc. European Power Electronics Conf. (EPE'99) , Lausanne, Switzerland, 1999, CD-ROM.

[14] F.Z.Peng, J. W. Mckeever, D.J. Adams, ―Cascade multilevel inverters for utility applications‖, IECON97, 23rd International Conference on Industrial Electronics, Control and Instrumentation, vol.2, pp437-442, 1997.

[15] K.A. Corzine, M.W. Wielebski, ―Control of cascaded multilevel inverters‖, IEEE Trans. on power Electronics, vol.19, no.3 May 2004, pp.732-738.

[16] T.A. Meynardand H.Foch ―Imbricated cells multilevel voltage source inverters for high voltage Applications‖, European power electronics Journal, vol.3 pp.99-106, June 1993.

[17] J.S. Manguelle, A. Rufer,M. Veenstra, ―A generalized design principle of a uniform step asymmetrical multilevel converter for high power conversion‖, in proc. of European Conference on Power Electronics and Applications, Aug 2001

[18] B.P. McGrant and D.G.Holmes, ―Multicarrier PWM strategies for multilevel inverters‖, IEEE Trans. on Industrial Electron. Vol.49 Aug.2002, pp. 858-867

[19] A.M. Massoud, S,J. Finney,B.W Williams, ―Control techniques for multilevel voltage source inverter‖, IEEE 34th Power Electron. Specialists Conference 2003, vol.1, pp.171-176.

[20] D.G Holmes and B.P McGrath, ―Opportunities for harmonic cancellation with carrier-based PWM for two-level and multilevel Cascaded Inverters‖, IEEE Trans. on Industry Applications, vol.37, No 2 pp 574-582, 2001.

[21] A.K. Gupta, A.M. Khambadkone, K.M. Tan, ―A two – level inverter based SVPWM algorithm for a multilevel inverter‖, in Proc. Annu. Conf. IEEE Ind.Electron. Soc.(IECON), Nov.2004, Vol.2,pp1823-1828.

[22] Peftitsis D, Tolstoy G, Antonopoulos A, Rabkowski J, Lim, Jang-Kwon, Bakowski M, Ängquist L, Nee, H-P."High-Power Modular Multilevel Converters With SiC JFETs". IEEE Transactions on Power Electronics. 2012;27(1): 28, 36.
[23] Ferreira JA. "The Multilevel Modular DC Converter". IEEE Transactions on Power Electronics. 2013; 28(10):4460, 4465.

[24] Khan FH, Tolbert LM. "A Multilevel Modular Capacitor-Clamped DC–DC Converter". IEEE Transactions on Industry Applications. 2007; 43(6): 1628, 1638.

[25] Baruschka L, Mertens A. "Comparison of Cascaded H-Bridge and Modular Multilevel Converters for BESS application". *Energy Conversion Congress and Exposition (ECCE), 2011 IEEE*. 2011: 909, 916.

[26] Ilves K, Antonopoulos A, Norrga S, Nee HP. "A new modulation method for the modular multilevel converter allowing fundamental switching frequency". Power Electronics and ECCE Asia (ICPE & ECCE), 2011 IEEE 8th International Conference on. 2011: 991, 998.

[27] Chun Gao, Jianguo Jiang, Xingwu Yang, Liang Xie, Kai Cao. "A novel topology and control strategy of modular multilevel converter (MMC)". 2011 International Conference on Electrical and Control Engineering (ICECE). 2011: 967, 971.

[28] Lucheng Hong, Qirong Jiang, Liang Wang, Wei Du. "A new topology and control strategy for centralized ridethrough capability of wind farm". IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society. 2012: 3516, 3520.