Analysis of 5-level H-bridge Inverter Topologies for Medium Voltage Drive

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This paper describes several topologies of 5-Level Cascaded H-Bridge (5L-CHB) inverter for medium voltage drive and compares the switching and conduction loss distribution of power semiconductors of each topology. CHB multilevel inverters are widely used to achieve medium voltage operation and low harmonic distortion, simultaneously. Each power cell requires the isolated DC voltage source which is fed from the multi-winding input transformer. 5L-CHB topologies can make output voltage of power cells doubled compared with the conventional H-bridge topology with the same number cells. Therefore, it can reduce the number of secondary windings of the input transformer. This paper presents four 5-level H-bridge topologies, namely, Symmetric NPC, Symmetric T-Type, Hybrid NPC and Hybrid T-Type. The semiconductor loss distribution of these topologies is compared in the same operation conditions in terms of output voltage, output power, and switching frequency.

Keywords Medium voltage, Inverter, Cascaded H-Bridge, Topology, Loss distribution.

I. Introduction

VVVF (Variable Voltage Variable Frequency) inverters have been widely used in several industrial applications since thyristor was invented in 1960s. Especially, the development of MV (Medium Voltage) drives started in the mid-1980s when 4500-V gate-turn-off (GTO) thyristor became commercially available [1]. MV drives cover power ratings from 0.4MW to 30MW and voltage ratings from 2.3k to 13.8k. However, most of the installed MV drives are in the 1 to 4 MW range with voltage ratings from 3.3 kV to 6.6 kV [2]. Market research has shown that around 85% of the medium voltage applications are fans, pumps, compressors and conveyors [3]. And, the market grows by 15% annually

Lately, attention to the high-efficiency equipment due to the rising energy cost makes demand for MV drive increasing. Only 3% of the MV motors have been controlled by adjustable-speed drive [3]. In the case of fan or pump application, fixed speed motors can control air or liquid flow by adjusting inlet damper or throttle valve. These conventional control methods result in a lot of energy loss. However, MV drives fed by VVVF inverter control the air or liquid flow by varying rotating speed of the motors. It can save remarkable amount of energy cost, which would be 50% of total energy cost in the most of applications. Therefore, one of the largest markets of MV drives is market for retrofit applications [1].

Multilevel voltage-source inverters provide a cost effective solution in the MV drive market [4]. One of the most widely used multilevel inverter to MV drives is the Cascaded H-Bridge (CHB) inverter. CHB inverter has several notable features such as a higher degree of modularity, easier implementation of medium output voltage with only low voltage components, lower input current harmonic distortion, and higher availability [5]. Because of these advantages, CHB inverter has been widely employed as topology for MV drive applications by most of MV drive makers.

II. 5-Level Cascaded H-Bridge Topologies for Medium Voltage Drives

Conventional power cell structure of CHB inverter is H-bridge with two 2-level legs making 3-level output voltage. However, H-bridge with 3-level leg such as NPC (Neutral-Point Clamped) leg or T-Type leg can generate 5-level output voltage per one cell. In CHB inverter, each power cell requires isolated DC voltage source from multi-winding input transformer. By using 5-level H-Bridge power cell instead of conventional structure, it can reduce the number of secondary windings of the input transformer by half. Consequently, CHB with 5-level H-Bridge power cell can cut down the size and cost of input transformer that is the most expensive and bulky component of CHB. Fig.1 shows four 5-level structures under consideration in this paper. These structures could be employed as cell topology of 5L-CHB.

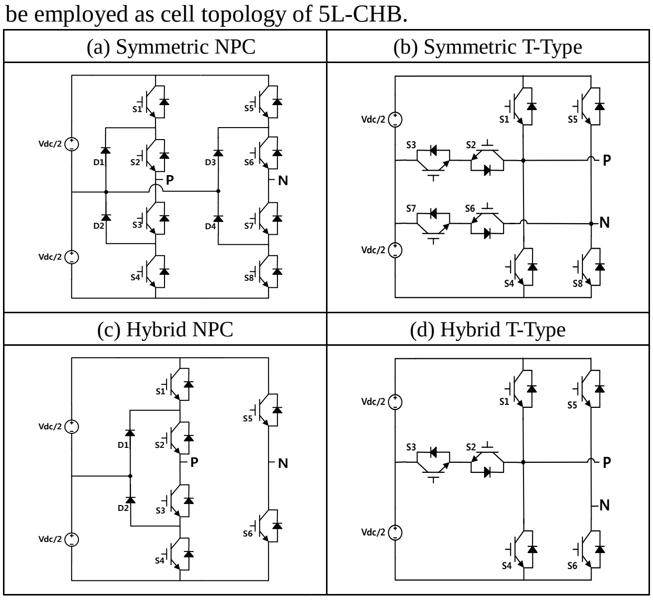


Fig. 1 Structure of 5L-CHB Topologies.

Symmetric NPC and symmetric T-Type have two 3-level NPC legs and two 3-level T-type legs, respectively. In case of hybrid NPC and hybrid T-Type, although one leg is 2-level leg, those topologies can produce 5-level output voltage. However, the number of power semiconductor and its associated control circuit can be reduced. Therefore, the structure of hybrid type could be simpler than that of symmetric type.

	Symmetric NPC	Symmetric T-Type	Hybrid NPC	Hybrid T-Type
1700V IGBT	8	4	4	2
3300V IGBT	0	4	2	4
1700V Diode	4	0	2	0

Table 1. The number of device with DC link voltage 2000[V]

III. Analysis of Loss Distribution of 5L-CHB topologies

Because Symmetric type topologies have two 3-level legs, the output voltage can be produced by level-shifted PWM which is shown in Fig.2. Level-shifted PWM produces gating signals, comparing the voltage reference with 4 in-phase carriers which are disposed vertically.

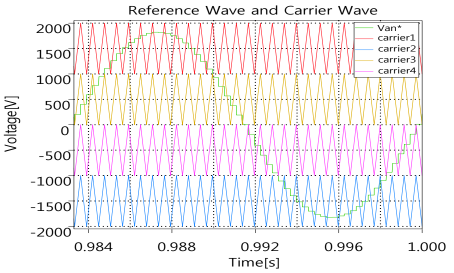
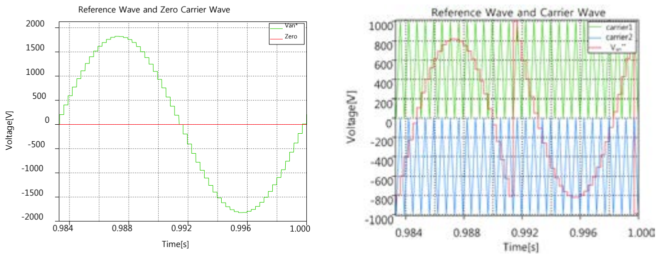


Fig. 2 Level-shifted PWM used in symmetric type topologies

In case of hybrid type topologies, it cannot be modulated with the same method. As shown in Fig. 3(a), 2-level leg synthesizes V_{dc} or $-V_{dc}$ synchronous to the polarity of voltage reference. And as shown in Fig3. (b), the rest of the reference wave, that means difference between the original reference wave and output of 2-level leg, can be modulated by 3-level leg using level-shifted PWM.



(a) (b)

Fig. 3 (a) PWM of 2-level leg (b) level-shifted PWM of 3-level leg

A. *NPC VS T-Type*

Comparing NPC leg and T-type leg, output voltage harmonics characteristics are totally equal. However, the loss distribution is different. In case of NPC leg, the middle switches (S2, S3 in Fig.1 (a) and (c)) always conduct regardless of switching state. But in case of T-type leg, the middle switches conduct only when switching state is 0. Therefore, conduction loss of T-type is lower than that of NPC.

In contrast, the switching loss of T-type is higher than NPC. The blocking voltage of the upper and lower switches (S1, S4 in Fig1. (b) and (d)) of T-type should be doubled compared with that of NPC. If the blocking voltage of the power semiconductor is higher, the switching loss is larger. Therefore, the switching loss of NPC is lower than that of T-type.

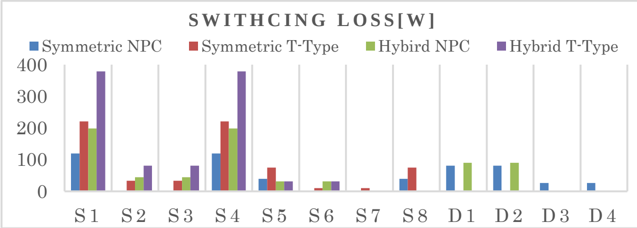
B. *Symmetric VS Hybrid*

As shown in Fig. 2, in case of symmetric type topologies, the first leg modulates output voltage by comparing with carrier 1 & carrier 2 and the second leg modulates output voltage by comparing with carrier 3 & carrier 4, to generate gating signals. Assuming the unity power factor, the first leg is switching when high current is flowing on the leg. So, the loss distribution between two legs is not symmetric. However, leg rotating technique that swaps the level of carrier waves can make loss distribution be balanced.

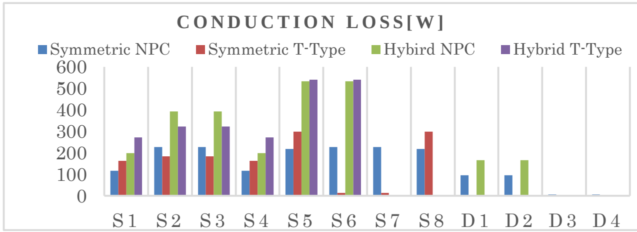
In hybrid type topologies, the switching loss of S5 and S6 (Fig.1 (c) and (d)) is almost zero because these devices on the 2-level leg switch per one output voltage period. Because each switch of 2-level leg conducts during half of one period, it results in high conduction loss. In contrast, switching frequency of devices in 3-level leg is a half of carrier frequency. So in 3-level leg, the switching loss is high. Also, the loss distribution cannot be balanced.

IV. Simulation Results

Simulation results and conditions are shown in the Table.2 and Table.3. Loss distribution of each topology is calculated by using PLECS ⓒ's thermal loss dissipation.



(a) Switching loss distribution



(b) Conduction loss distribution

Fig. 4 Loss distribution of 5L-CHB topologies (a) switching loss (b) conduction loss

	Symmetric NPC	Symmetric T-Type	Hybrid NPC	Hybrid T-Type
Total Loss[W]	2310	1977	3314	3248
THD_i[%]	5.5	5.5	5.5	5.5

Table 2. Total loss and output current THD of four topologies

Power	800[kW]	DC link Voltage	2000[V]
IGBT(1700V,400A)	FF401R17KF6C	Diode	FF401R17KF6 C(Diode Part)
IGBT(3300V,400A)	FD400R33KF2C	Carrier wave Frequency	1740[Hz]

Table 3. Simulation Conditions

V. Conclusions

This paper presents four 5L-CHB topologies with different cell structure and analyzes the loss distribution of them. As shown in simulation results, each topology has its own characteristic which is described in chapter III. The most efficient topology is the symmetric T-type topology. However, considering that the cost of 3300V IGBT device is more than twice of that of 1700V IGBT device, this topology is expected to be the most expensive one among 5L-CHB topologies, according to the Table 1. And hybrid type topologies are cost-effective compared to symmetric type topologies. But its efficiency is lower than symmetric type topologies. In conclusion, there is trade-off between the efficiency and the manufacturing cost.

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