Comparison between Cascaded H-Bridge and Neutral Point Clamped Topologies in Medium-Voltage Systems

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Abstract: - Medium voltage motor drives (MVD) come in various topologies that allow designers to choose the best option for their application based on technical and economic considerations. The Neutral Point Clamped (NPC) and Cascade H-Bridge (CHB) are the most particular topologies that have come to the fore. CHB and NPC MVD's primary operating principles, switching stress, topological complexity, and harmonic distortion of the inverter output will be presented in this article, along with a brief review of suitable modules. Even though the number of parts in a cascaded inverter is lower than that of a neutral point-clamped inverter, it has been demonstrated that the stress on the switches in both types of inverters is the same and that the resulting output waveforms are nearly identical in terms of harmonic distortion. The neutral point clamped topology requires less secondary winding from the transformer, fewer voltage-balancing capacitors, the same quantity of switches, and extra clamping diodes. Benefits of NPC include high-power-density inverters, enhanced output quality, reduced number of components, reduced heat losses, increased efficiency, elimination of common-mode voltages and currents thanks to an isolation transformer, and a remote transformer that allows for a more adaptable footprint. Additionally, the NPC drive rectifier system (Transformer and diode H-bridges) has the advantage of more simplicity, ease of assembly, fewer connections, fewer space requirements, and an expensive isolation transformer. The MATLAB simulation for both topologies was carried out, with 3 phase motor 3.8kV, 150 KW motor parameters.

Key-Words: - Voltage Source Inverter, Medium Voltage Motor Driver, Cascade H-Bridge, Neutral Point Clamped, topology, harmonic distortion, switching stress.

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1 Introduction

MVDs are often employed in the industrial sector using different topologies, operating principles, and unique semiconductor designs. Each topology has advantages over the others in terms of construction, design, dependability, and applicability for application. Harmonics, motor compatibility, regeneration capabilities, performance, and application requirements are comparative criteria. Depending on how the MVDs are meant to be utilized, specific difficulties may be essential and addressed using various design techniques, [1]. Waveform quality is an important topic that may be handled in multiple ways, but in many actual applications, the waveform can be filtered using capacitors and inductors. Filtering can be applied to a transformer's primary, secondary, or both sides if the design calls for one. Low-pass filters (LPFs) restrict the harmonic components' passage while allowing the waveform's fundamental component to pass to the output. As a result, the waveform's quality can be changed, [2].

Regular inverters always provide output waveforms of inferior quality, so An LPF is frequently inserted into the circuit to improve the output waveform's quality. The multiple-step voltage waveform created by the MVD may have variable and controlled frequency, phase, and amplitude; using several voltage levels, synthesize the stepped waveform. The multiple-step voltage waveform created by the MVD has a steady frequency, phase, and amplitude; using several voltage levels, synthesize the stepped waveform.

Several voltage steps or levels between the MVD's output terminal and a user-selected internal reference node are one way to characterize an MVD's level count. It is often a dc-link node, referred to as neutral and designated by the letter N, [3]. The output of the MVD, which consists of power semiconductor devices and capacitor voltage sources, creates voltages with stepped waveforms, [4]. The power semiconductors only need to endure lower voltages because of the switches' commutation, which allows the capacitor voltages to be added to achieve MV at the output. A two-level driver, for instance, produces a voltage with two stages (levels) concerning the capacitor's negative terminal, [5]. A nine-level driver has nine output voltages, unlike a three-level driver's three-level, [4]. Semiconductor devices are always connected to produce a certain level of voltage. The harmonic content in the output waveforms reduces as the number of steps or levels rises. As a result, the power quality of waveforms will dramatically improve, [6].

However, the number of levels has limitations due to the voltage limitations of semiconductors, control devices, capacitors... etc. The fundamental idea behind multilevel inverters is to generate a sinusoid waveform by combining many DC voltage sources, [7]. Power semiconductors and capacitive DC sources can be connected to provide multilayer output voltages. The most common multilevel MVD topologies are NPC and CHB. The MVD's unique properties, operating principles, multilayer waveform creation, modulation methods, and other details are illustrated, [8]. Therefore, it is crucial to investigate the traditional MVD with performances to be thorough and better grasp the developments in multilevel technology. The MVD topologies will be thoroughly examined, documented, market-studied, and utilized in real-world applications in the last ten years, [9], [10].

2 General, Marketing, and Design Comparison

2.1 Abbreviations and Acronyms Neutral Point Clamped Converter (NPC)

The five-level NPC motor driver is typical and well-recognized in the market, as shown in Figure 1. The 5-level NPC uses a high-voltage semiconductor like GCT or IGBT with a DC capacitor to operate at a medium voltage level. The switching devices generally work at (500-1000) Hz. NPC composition is challenging to scale and is often only provided up to 7.2kV, [11]. It is committed to using an LCL filter at the NPC driver's output, and its precise design is essential. But if the active front-end (AFE) filter is added to the NPC drivers, it will be a superior efficiency choice for the application. The standard motors frequently need an output filter to prevent long-term dielectric deterioration, [9]. The DC source in 5-level NPC is delivered from a 24-pulse diode rectifier to reduce the harmonics; however, 18-pulse or 12-pulse diode versions could be utilized if the input harmonics were reduced in another way, like filters. The NPC architecture gives exceptionally high torque/speed arrangement performance. Several manufacturers offer proprietary control techniques for NPC drivers. The NPC is suited for complex system applications, like motor drivers for paper mills. Due to the topology's near-optimal utilization of available semiconductor ratings, it may also offer advantages in 3.3 kV applications. Depending on the situation and the client's needs, the front end might be a 12-, 18-, or 24-pulse rectifier, [12].

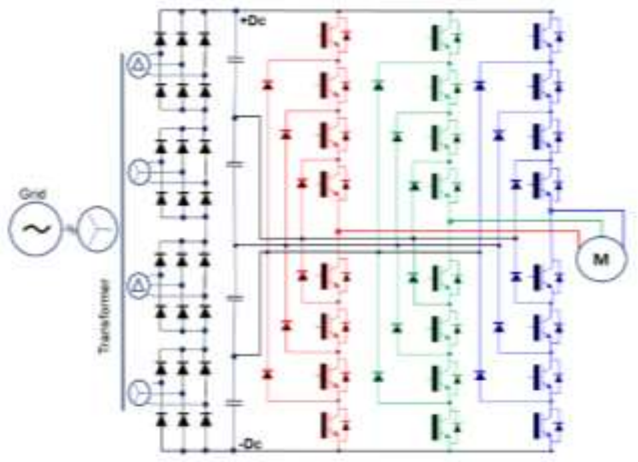

Fig. 1: The MVD type 5-level NPC

Using a three-level NPC for drives requiring four-quadrant reconditioned braking functionality is also possible. The MVD may employ any standard utility or motor voltages of 2.3, 3.3, 4.16, and 6.6 kV. For 2.3 kV applications, the NPC inverter consists of 3.3 kV IGBTs without devices linked in series. To power higher-voltage drives, the inverter's switch positions can each house two series-connected IGBTs, [13]. In actual applications, the transformer and diode rectifier system are located on the left of the driver enclosure. The NPC inverter power circuit or high-voltage semiconductor components are located in the middle of the enclosure, and the air-cooling system is typically situated above the enclosure. The digital controller of the drive is housed in front of the enclosure.

Output filters are located on the right side of the enclosure. In extensive applications, the output filters are often housed outside an appropriate enclosure and placed in the proper location. It is common practice in some situations to put the phase-shifting transformer for the rectifier on the outside of the drive enclosures.

2.2 Cascaded H-Bridge Converter (CHB)

The five-level CHB motor driver is shown in Figure 2. The CHB architecture has an electronic combination called "power cells" or "power module," which incorporates a low-voltage DC bus, H-Bridge semiconductor, and three-phase diode rectifiers. The current and voltage output waveforms improve as more power cells are linked in series, [14].

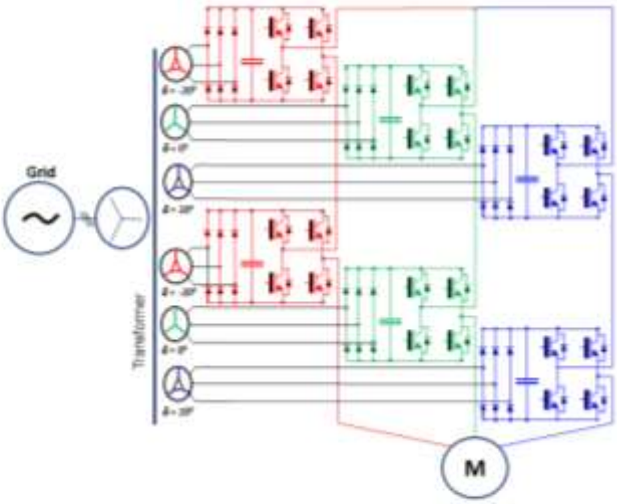

Fig. 2: The MVD type 5-level CHB

The current and voltage waveforms could have improved by connecting more power cells in series. The total harmonic distortion (THD), the DC link voltage, and the number of power cells linked in series all influence. It is still essential to take care of the PWM (pulse width modulation) structure of the output voltage for the motor. The inverter's operating frequency affects not only the step size of the output but also the input or DC link voltage. The THD is determined by the number of power cells connected in series, [15]. Also, the effect of brake resistors or other braking methods disperse the energy across the motor, causing some issues. The architecture with an active front-end filter may implemented, which is only sometimes a viable option from a commercial viewpoint, [16]. A series connection of many power batteries at the output creates the required medium voltage (for example, four power cells are connected per phase for 4.16kV applications, 6 for 6.6kV, and so on). When housed inside the power cell, IGBTs can typically switch at a frequency of 600 Hz. The waveform's high-quality waveforms and low THD output set the CHB driver apart from other designs. Due to the topology's near-optimal utilization of available semiconductor ratings, it offers advantages in 3.3 kV applications. The drive's output frequency, which may exceed 120 Hz, corresponds to the speed range of the majority of MVD, [17]. The main property of the CHB drive is modular construction.

The CHB is mass-produced with various power and voltage ratings, which helps keep manufacturing costs down because of the various comparable components of the 3x1 Power module. Cascaded 3x1 Power modules with a phase shift create a perfect output voltage waveform, lowering the dv/dt and the THD, [18]. The input current to each Power module is almost sinusoidal because of a phase-shifting transformer and a low-pass filter. Stacking low-voltage Power modules allows for the delivery of large AC voltages at the driver output. In the CHB drive, equitable voltage-sharing issues for switches linked in series are resolved. The CHB drive's primary shortcomings include the particular design of a phase-shifting transformer to generate a separate AC supply for the power modules, which raises the drive's manufacturing and maintenance costs. It has many components, such as needing significant numbers of IGBTs; for example, a 7-level CHB with nine modules needs 36 IGBTs, [19].

2.2.1 CHB and NPC Topologies Comparison

Typically, the most significant role in choosing an MVD topology is reducing losses, dimensions, costs, and the number of components, application, and the list of specifications. Table 1 lists the necessary passive and semiconductor components to guide the choice between the NPC and CHB multilevel topologies. According to the research, NPC and CHB converters require the same number of switches for a five-level strategy. However, the clamping components and quantity of DC sources are varied, [20].

Table 1. Comparison of NPC and CHB In Terms Of Components

Type	**NPC**		**CHB**	
Level	5	m	5	m
Switches	24	6(m-1)	24	6(m-1)
Clamping Diodes	4	3(m-1)(m-2)	-	-
dc-link Capacitors	4	m-1	6	3(m-1)(m-2)/2
Isolated dc sources	1	1	18	3(m-1)(m-2)/2

The NPC architecture provides an advantage over the CHB architecture when only one DC source is available. Due to necessitate a complicated transformer to deliver several independent DC sources in the CHB system architecture. As opposed to that, the CHB topology may be considered a viable option when several DC sources are accessible, as it needs the fewest parts. Since more than five levels of NPC drivers require many clamping components and present difficulty in balancing the DC-link and flying capacitors, although the Active-Neutral-Point Clamped (ANPC) driver utilizes more switches than the five-level approach, since there are no clamping diodes and just three floating capacitors, it is an acceptable substitute for the NPC driver. In ANPC, the DC-link is also divided into two capacitors, reducing the balancing difficulty. On the contrary, the CHB topology is feasible when numerous DC sources are available because it requires the fewest components. Various companies in the industry provide NPC and CHB drivers with a wide range of power ratings, front-end layouts, cooling systems, semiconductor devices, and control strategies. The three-level NPC and the five-level CHB are the most frequently multilevel topologies used in the market. It is difficult and unfair to compare the five-level CHB with the three-level NPC since the CHB will have a more complex circuit design, and the NPC will have worse power quality. The CHB uses low-voltage devices like Insulated-Gate Bipolar Transistors (IGBTs), and the NPC uses medium-voltage devices like power IGBTs and Integrated Gate-Commutated Thyristors (IGCTs). The CHB can generate greater voltage, power, and higher quality but at a higher cost because of the need for a unique design for a phase-shifting transformer. Since the NPC's circuitry is more straightforward, it occupies less room. The number of voltage levels produced by the two topologies may be the same, but commercially available CHBs provide finer control over the voltage NPC generates. The practical number of levels in NPC structure is constrained by the necessary number of series-connected clamping parts, even though NPC structures have been widely applied in industry. Table 2 shows a comparison of the characteristics of 4.16kV topology.

The CHB method has been used for topologies, extracting several benefits and vital points by unique structure. The multilevel topologies described vary, but all topologies need proper DC-link or floating capacitor voltage regulation. Regarding component counts and isolated DC sources, it is challenging to select the best topology. The NPC and the CHB drivers have the same number of switches for the three-level topology; nevertheless, there is a disparity between the two regarding the number of clamping elements and necessary DC sources. The CHB solution's drawback is that it needs two separate DC sources. The NPC is seldom used for the five-level topology since it requires many clamping parts.

Table 2. Characteristics MVD topologies 4.16KV system

Attribute	**CHB**	**NPC**
Voltage THD	Very good	Good
Current THD	Better than IEEE519	High voltage steps and dv/dt (filter required)
Max output voltage step	900V	2900V
dv/dt	Low	High
Torque/speed	Good	High Performance
Power Factor	>0.95 lag	>0.95 lag PF correction could be used with AFE
Regeneration capability	No	Yes, with AFE
Semiconductor	High (1700V)	Low (6500V)
Transformer less operation possible	No	Yes, with special design
High torque/ Low speed operation	Yes	Yes

3 MATLAB Simulation Comparison

The MATLAB simulation uses the pulse width modulation (PWM) method, the most popular control technique. The model of CHB and NPC is tested on an induction motor with a 3-phase, 3.8kV, 50Hz, 200HP, 1500 RPM, and 700Nm mechanical torque. Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10 shows the simulation results of CHB and NPC output voltages, stator current, electromagnetic, and output voltage THD, respectively.

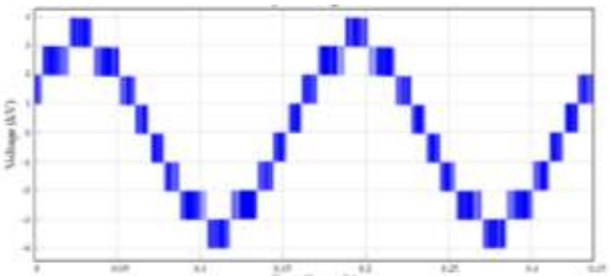

Fig. 3: Simulation result of five levels CHB output voltage

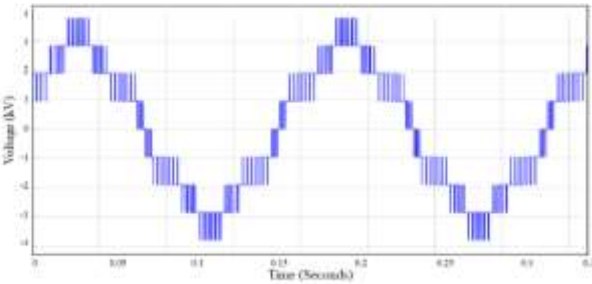

Fig. 4: Simulation result of five levels NPC output voltage

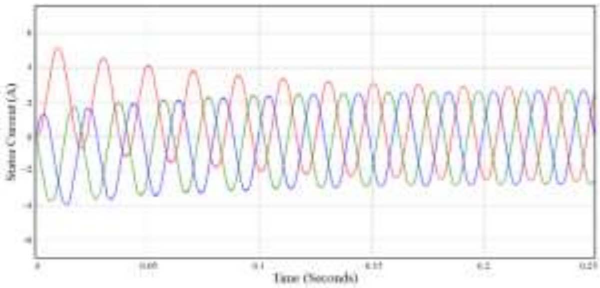

Fig. 5: Simulation results of CHB stator current

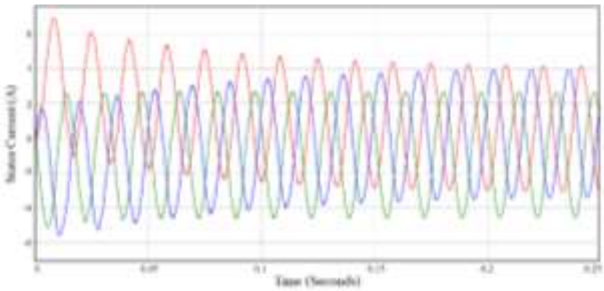

Fig. 6: Simulation results of NPC stator current

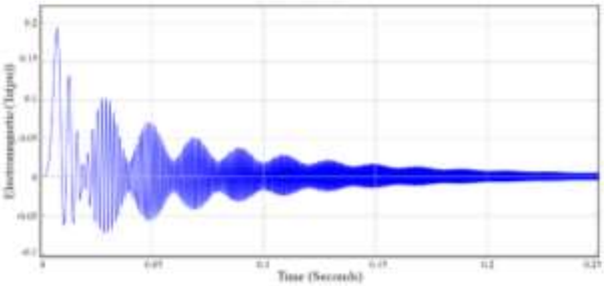

Fig. 7: Simulation result of five levels CHB Electromagnetic

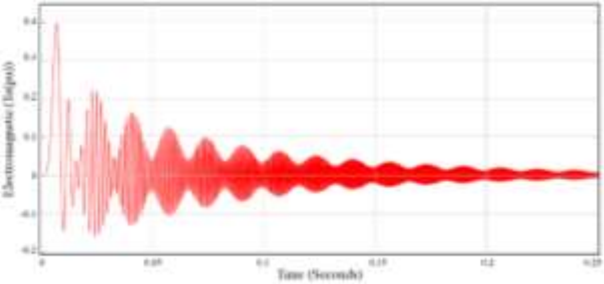

Fig. 8: Simulation result of five levels NPC Electromagnetic

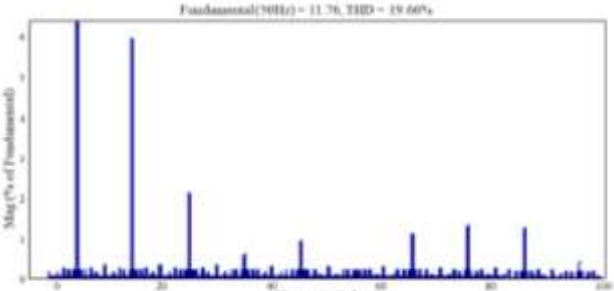

Fig. 9: Simulation result of five levels CHB output voltage THD

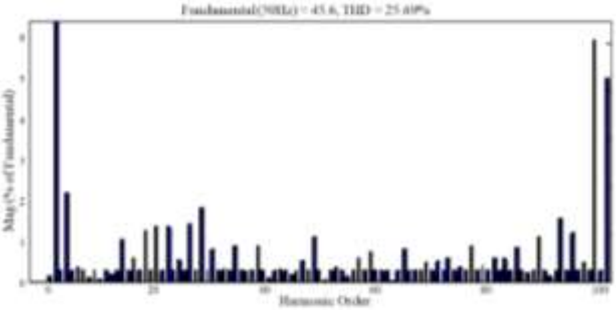

Fig. 10: Simulation result of five levels NPC output voltage THD

From the simulation results of both topologies, the performance of both drivers is not the same and has differences. Both the drivers give a suitable output voltage waveform, but the CHB driver waveform is almost sinusoidal. Both drivers provide the same amount of stator current, but the start-up of NPC is higher than CHB's. Regarding the electromagnetic torque, the CHB driver supplies less pulsation with maximum torque, which is opposite to NPC. It is observed that the CHB driver provides less harmonic distortion in output voltage than the NPC driver. NPC driver provides constant speed, whereas CHB provides variation speed. On the motor efficiency side, the CHB driver is better than the NPC driver since the NPC level requires more combinations, so there are more losses. Even simulation results are in an ideal environment and do not care about the actual action of drive and losses. However, the CHB drive has positive points over NPC in applications that need a variable speed and nonlinear motor load. At the same time, the NPC driver is suitable for constant speed and load.

4 Conclusion

In MVD industrial applications, CHB and NPC are essential. For a correct selection of drivers, positive points, negative points, and different architectures have been suggested for both topologies. The main disadvantages of NPC are the component requirements, high-current semiconductors, and control signals' design complexity. The MVD has a variety of topologies and control systems for its power converters. Each design has certain distinctive qualities but also some drawbacks. The expanded selection encourages both market competitiveness and the development of driving technology. The industry has increased the usage of multilevel inverters due to the capacity to synthesize a sinusoidal output voltage using more voltage levels. Multilevel inverters enable power devices with lower voltage ratings, resulting in decreased switching losses and electromagnetic interference effects and enhancing the spectrum quality compared to the traditional design. This paper provides a comprehensive technical overview of NPC and CHB MV motor drivers, the two multilevel MVD topologies used most often in industry. The NPC and CHB unique properties, operating principles, multilayer waveform creation, modulation methods, and other details are illustrated. Power semiconductors and capacitive DC sources can be combined to provide multilayer output voltages. This complete review of MVD includes market permission, drive system configurations, product analysis, power driver topologies, and essential manufacturers. A summary of the MVD's technological needs and difficulties is also provided. In this work, we compare two different kinds of inverters. An inverter with a unity modulation index and a switching frequency of 5 kHz is considered to record output waveforms, switch stress, and output waveforms harmonic. Additionally, the inverter topologies' topology complexity and overall harmonic distortion are compared. Even though CHB has fewer parts than the NPC driver, it has been shown that the stress on the switches of both designs is equivalent, and harmonics similarly distort the output waveforms of both.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare.