Advantages of ac-ac power converters based on ANPC topology for wind applications

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ABSTRACT

Wind energy conversion systems (WECS) are increasingly higher due to the great demand of wind energy. Thus, the power converter will play a more important role in the next generation of large WECS. Currently, the most accepted ac-ac power converter for WECS is the conventional two-level back-to-back (2L-B2B). However, 2L-B2B is expected not to provide an acceptable performance for the largest offshore WECS with the available switching devices. Therefore, the wind market is open for the multilevel power converters, among which three-level neutral-point-clamped (3L-NPC) topology is achieving interesting high wind market penetration. However, 3L-NPC enables some improvements regarding 2L-B2B, but it provides some intrinsic drawbacks as the uneven power losses distribution. Lately some investigations has been focused on analyzing the three-level active neutral-point-clamped (3L-ANPC) which provides enhanced features compared to the 3L-NPC thanks to replace the clamping diodes by bidirectional switching devices. Thus, 3L-ANPC can be understood as the natural evolution of the 3L-NPC.

1. INTRODUCTION

Currently, the most attractive ac/ac power converter solution in commercial market of WECS is the conventional two-level back-to-back voltage-source converter (2L-B2B) (Fig. 1) [1]. It is due to the fact that the 2L-B2B converter benefits from an extensive and well-established knowledge and it is based on a relatively simple structure with very few components, all contributing to a well-proven and reliable performance. However, taking into consideration the trend in which the power rating of the WECS is increasing, the 2L-B2B converters may suffer from large switching losses and low efficiency for the largest offshore WECS. Therefore, it is very difficult for a single 2L-B2B topology to achieve acceptable performance with the available switching devices for the largest offshore WECS, even though having the cost advantage [2].

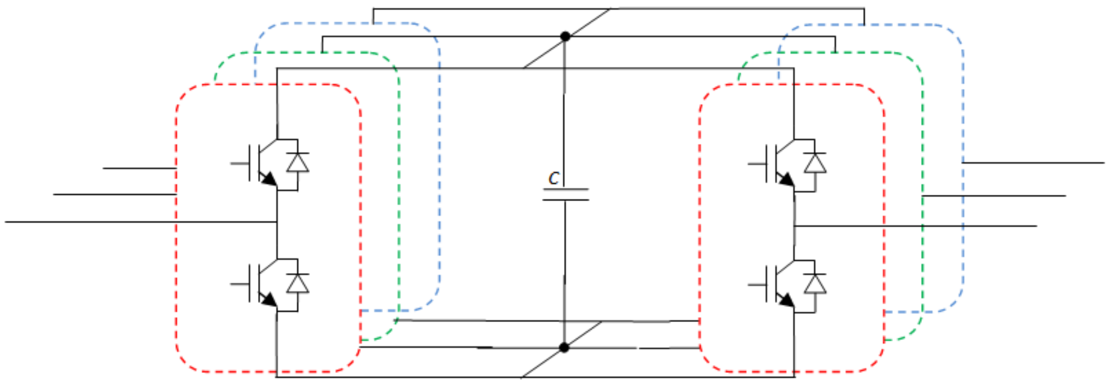

Fig. 1. Conventional two-level back-to-back voltage source converter.

Instead, multilevel converters enable a power increase without increasing neither current nor blocking voltage of the power semiconductors. Specifically, WECS based on three-level neutral-point-clamped (3L-NPC) (Fig. 2) are becoming an accepted solution due to its simple implementation and proper performance compared to other topologies, having a good penetration in wind market.

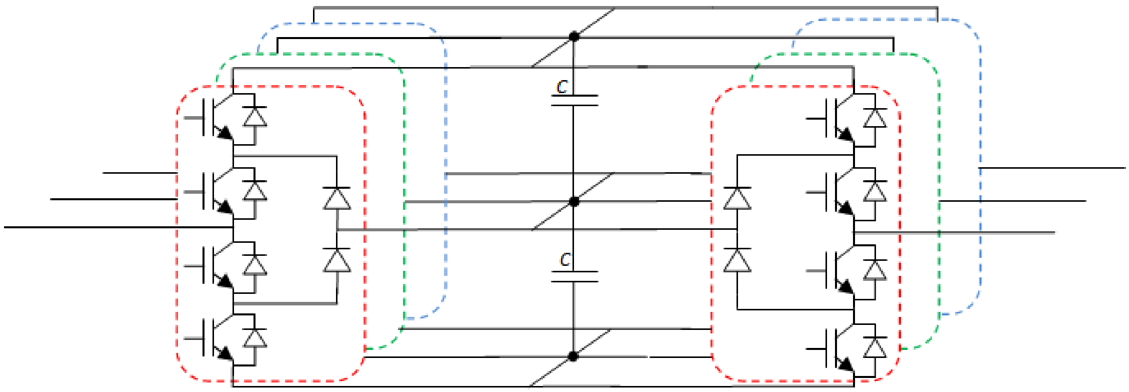

Fig. 2. Three-level neutral-point-clamped converter (3L-NPC).

2. COMPARISON 2L-B2B vs 3L-NPC

A qualitative comparison between the global performance of two-level and three-level converters is presented, supported by previous investigations [3], [4]. Besides enabling larger output power, the three-level converter has additional advantages:

- **Efficiency:** For the same output power and dc-link voltage, the three-level converter shows a better global efficiency than the two-level converter since lower-voltage-rated semiconductors can be used. The main advantage of the low-voltage-rated semiconductors resides in the reduction of the switching losses by a factor between 3 and 5 for contiguous semiconductor classes [3]. Thus, the higher the switching frequency is, the higher the efficiency increase of the three-level converter compared to the two-level case.
- **Common mode voltage:** The three-level converter produces a much smaller common-mode voltage. For the conventional sine-triangle modulation, a reduction of the common-mode voltage by roughly 25%–30% can be achievable for the three-level converter [3].
- **dv/dt filter:** Transient over-voltages caused by the pulse width modulation switching operation are a major concern for generators connected with long cables since the generator can suffer a full reflection and the voltage pulse amplitude would approximately double. With a three-level converter, the maximum voltage pulse is reduced a 50% compared to the two-level converter.
- **ac filter:** The higher the number of levels is, the lower the total harmonic distortion. Fig. 3 shows a comparison of the output phase voltage waveform with reference to the midpoint of the dc-link of a two-level converter (Fig. 3(a)) and three-level converter (Fig. 3(b)). The harmonic distortion in the three-level converter is clearly lower. This implies a great saving in cost, weight and size of the ac filter.

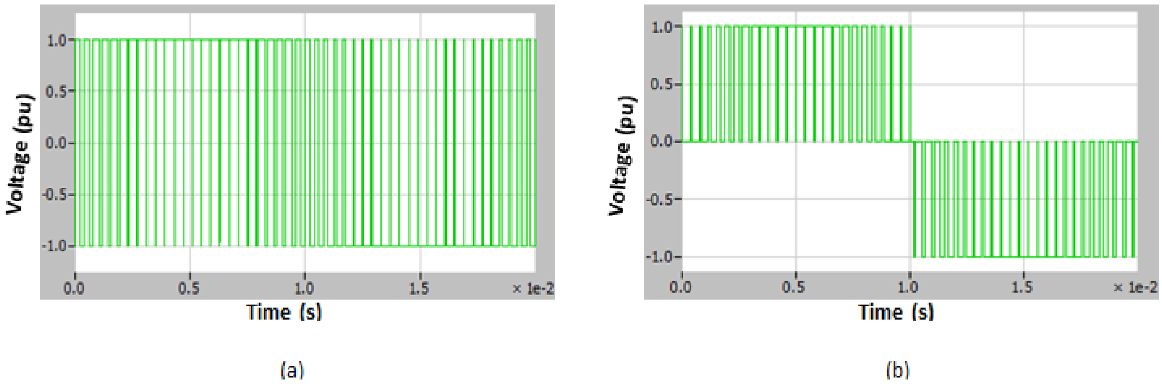

Fig. 3. Comparison of output phase voltage waveforms with reference to the midpoint of the dc-link. (a) Two level inverter. (b) Three level inverter.

In terms of cost and reliability, the three-level converter could seem less reliable and more expensive than the two-level converter because of the higher number of switching devices required. However, on one hand, the thermal performance could lead to lower device temperatures due to lower switching losses in three-level converters providing a higher reliability. On the other hand, the higher cost of switching devices could be compensated by a reduced ac and dv/dt filter and a more inexpensive cooling system. That is to say, it is not clear if the three-level converter is more expensive and less reliable than a two-level converter. There are several reasons that can lead three-level converters to present lower cost and higher reliability in spite of having more switching devices.

3. 3L-ANPC INTRODUCTION

In spite of the wide usage of 3L-NPC is some applications, one of their current drawbacks is that the power losses are unevenly distributed among the switching devices. This leads to an uneven thermal performance which limits the output power capability and could affect to the power converter reliability. There is a great deal of literature about this issue [2], [5], [6], [7], [8]. Unfortunately, this drawback cannot be avoided since it is intrinsic in the 3L-NPC topology.

Thus, in order to mitigate the mentioned drawback, the three-level active neutral-point-clamped (3L-ANPC) topology, depicted in Fig. 4, was proposed in 2005 [9]. The 3L-ANPC replaces the clamping diodes by switching devices with antiparallel diodes to provide a controllable path for the neutral current. Hence, 3L-ANPC is able to offer certain freedom to control the loss distribution among the switching devices. Thanks to it, the global thermal performance is more uniform and the output power capability is enhanced compared to the conventional 3L-NPC.

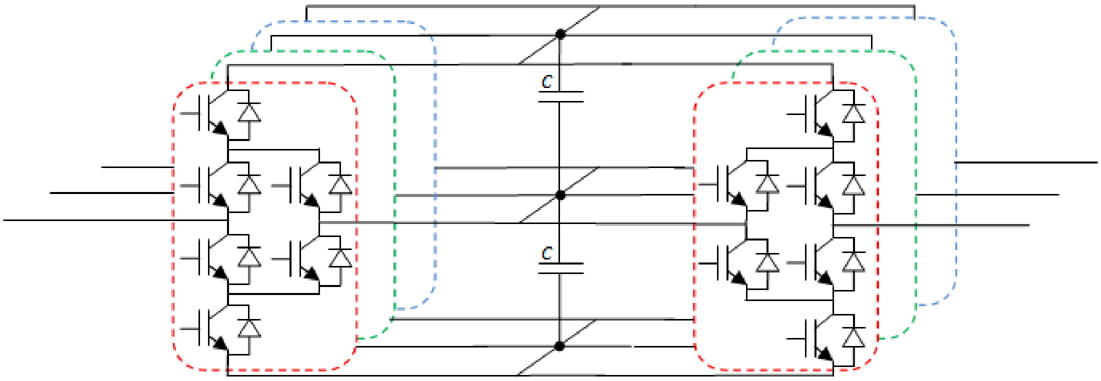

Fig. 4. Three-level active-neutral-point clamped (3L-ANPC).

As a first consequence to use bidirectional switches instead of clamping diodes is that an operating principle must be defined. The operating principle defines the sequence of turning on and off the switching devices to connect the output phase to the desired dc link voltage level. 3L-NPC does not require an operating principle since there is no freedom to turn on and off the switching devices, the sequence is always fixed.

Several investigations as [9], [10] and [11] have been focused on defining a proper operating principle for the 3L-ANPC. The novel feature of the 3L-ANPC to offer certain freedom to distribute the power losses among the switching devices can be used to enhance the efficiency or to improve the thermal performance. Normally, current investigations are more focused on improving the thermal performance. However, [11] proposes an operating principle focused on reducing the conduction losses by turning on the maximum possible switching devices to connect the output phase to the desired dc link voltage level. Moreover, [11] also allows certain freedom to distribute more evenly the power losses among the internal switching devices. Instead, [9] and [10] are focused on concentrating the power losses in the coldest switching devices, avoiding to heat even more the switching devices under high thermal stress. Thus, the aim of [9] and [10] is just to distribute the power losses more uniformly, not to reduce them. A more uniform power losses distribution could lead to a higher reliability due to the reduction to thermal stress.

The power converter limit is generally thermal, that is to say, if either the power losses or the global temperature are reduced, the power converter will be able to provide higher current ratings, leading also to a higher power density. Additionally, the switching frequency could be also increased in order to reduce the grid filter size, weight and cost. All of these advantages could be achieved using the 3L-ANPC instead of the 3L-NPC. Thus, the authors consider that the 3L-ANPC is the natural evolution of the 3L-NPC and could play an important role for the next generation of large offshore WECS.

4. CONCLUSION

The use of the 3L-ANPC topology in the largest offshore WECS instead of the conventional 3L-NPC topology leads to a higher controllability of the currents paths in the power converter, opening a new room for improvement in terms of reliability and thermal performance. The 3L-ANPC topology can be considered as the natural evolution of the 3L-NPC topology enabling novel and improved features for ac-ac power converter for wind applications.

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