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AN6447

Dynex Asymmetric Thyristors for Bypass Applications

Application Note

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***Abstract*—In modular multi-level converters, a bypass thyristor may be connected across the antiparallel diode of the IGBT to conduct the DC fault current. In these converters, the antiparallel diode clamps the forward voltage of the thyristor to the diode's forward voltage, which is typically between 1 to 3V. In such applications, since a high forward blocking voltage rating is unnecessary, the thyristor can be optimised to provide lower conduction and switching losses while maintaining the same reverse blocking capability. This application note offers a brief introduction to Dynex asymmetric thyristors and examines their advantages over standard thyristors in bypass applications.**

1 Introduction

Recent high voltage direct current (HVDC) applications, such as the grid connection of offshore wind farms, have exposed the limitations of traditional Line-Commutated Converters (LCCs), particularly their inability to operate effectively in weak AC systems. To address these issues, Voltage Source Converters (VSCs) have been adopted, as they can independently control active and reactive power and connect to weak AC systems. However, the voltage and power capacity of a single VSC are limited. Consequently, the VSC-based Modular Multilevel Converter (MMCs) have been developed to leverage the benefits of VSCs while achieving higher power and voltage levels. Despite the advantages of VSC-based MMCs, the use of IGBTs instead of thyristors increases the risk of cascaded failures due to over-current transients resulting from DC faults [1].

In VSC-based MMCs, DC faults can cause a short circuit current to flow through the IGBT’s diode. The fault current can be several times the rated current, persist for multiple cycles, and potentially destroy the diode before an AC circuit breaker can clear the fault. A common solution is to include a thyristor in parallel with the IGBT’s diode to divert the majority of the fault current away from the diode during such events [2].

The topology of a VSC-based MMC with bypass thyristor is presented in **Figure 1**. As shown, each sub-module features an IGBT that has its diode protected by a bypass thyristor, connected in parallel with the diode. During DC faults, the diode is exposed to a large fault current, typically lasting up to hundreds of milliseconds. Once this fault is detected and the voltage across the thyristor is sufficient, the thyristor is triggered, diverting a large proportion of the current until the fault is cleared.

During normal operation, the thyristor remains off and only needs to block a smaller forward voltage, equivalent to the diode's forward recovery voltage. Therefore, while the thyristor still needs to block a high reverse voltage, it does not need to block a high forward voltage. If thyristors do not need symmetric high voltage blocking capability, they can be redesigned to have lower conduction and switching losses. In other words, asymmetric thyristors can be developed with lower forward voltage blocking capability due to a thinner depletion layer, resulting in reduced conduction and switching losses.

In the next section, Dynex asymmetric thyristors are introduced. Section 3 shows the benefits of the asymmetric thyristor compared to the standard symmetric thyristors for bypass applications. Finally, Section 4 provides a brief conclusion of this application note.

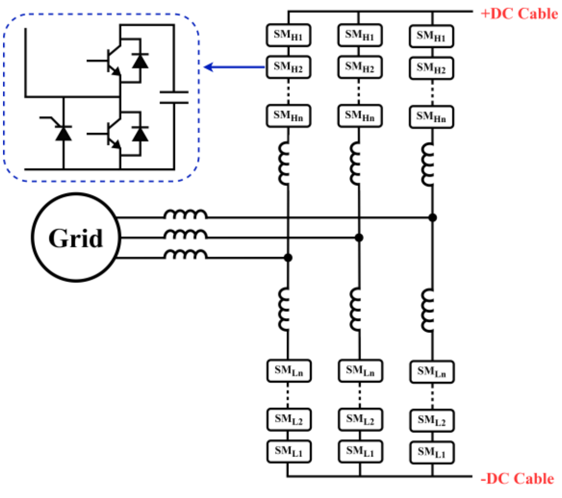

Figure 1. Schematic of a VSC-based MMC with bypass thyristor

2 Bypass Thyristors

There are several performance requirements for bypass thyristors in VSC-based MMCs applications which are presented below [3].

a) Survivability: It is crucial that the thyristor withstands the fault current that it diverts and is able to block the reverse voltage effectively.
b) Pickup voltage: This refers to the voltage between the anode and cathode at which the thyristor activates in response to a specific gate signal. This voltage arises from the on-state voltage of the diode as the fault current increases. Lowering the pickup voltage enables the thyristor to activate sooner, enhancing its responsiveness.
c) On-state voltage: The on-state voltage of the thyristor, when fully activated, influences the total I^2t endured by the IGBT diode.
d) Reliability: The reliability of these devices is impacted by cosmic ray-induced failures, particularly given their operational duty cycles. As a result, such devices are often rated higher in voltage to mitigate these risks.

At Dynex, our standard thyristors are designed with symmetric blocking capabilities, meaning they can block both forward and reverse currents equally. However, we have developed specific thyristors designed for bypass applications, where high forward blocking capability is not necessary. These specialised thyristors are optimised to achieve lower on-state voltage, lower pick-up voltage and improved Failure In Time (FIT) ratings, although this comes at the cost of reduced forward blocking capability.

Table 1 showcases Dynex's range of bypass thyristors alongside our Standard (S) thyristors with similar range. In our product range, we classify these devices as either Semi-Asymmetric (SA) or Reverse Asymmetric (RA), both of which are presented briefly in this section.

It should be mentioned that the voltage ranges for high voltage IGBT modules are 3.3 kV, 4.5 kV, and 6.5 kV, whereas for standard thyristors, the ranges are 4.2 kV, 5.2 kV, and 6.5 kV. In bypass applications, a bypass thyristor must have a reverse voltage rating, V_{RRM}, that is at

Table 1. Comparison of characteristics for various Dynex thyristors.

Device number	Range	*D* (mm)	V_{DRM} (V)	V_{RRM} (V)	V_{PU} (V)	V_T (V) at 5 kA	I_{TSM} (A)	d*V*/d*t* (kV/µs)
DCR3030V42	S	73	4200	4200	3	2.01	40600	1.5
ACR3200VR33	SA	73	1000	3300	2	1.80	43000	10
ACR3775VR33	RA	73	1000	3300	2	1.50	50000	10
ACR2700CR33	RA	63	1000	3300	2	1.75	36300	10
DCR2720V52	S	73	5200	5200	3	2.35	36700	1.5
ACR2900VR45	SA	73	1000	4500	2	2.10	39000	10
ACR3350VR45	RA	73	1000	4500	2	1.75	45000	10
ACR2400CR45	RA	63	1000	4500	2	2.05	32300	10
DCR2950W65	S	85	6500	6500	3	2.47	38900	1.5
ACR4000WR65	RA	85	1000	6500	2	1.80	54000	10

least equal to the forward voltage blocking rating of its corresponding IGBT module. Therefore, Dynex designs its bypass thyristors to have a reverse voltage rating range as the forward voltage rating of the IGBT modules.

2.1 Semi-asymmetric thyristors

Our semi-asymmetric thyristors, which are similar in structure to the standard devices, are optimised to offer a lower on-state voltage, V_T, pick up voltage, V_{PU}, and FIT rating. These units are also designed to be thinner, which enhances their surge current, I_{TSM}, capability.

As indicated in **Table 1**, Dynex offers two semi-asymmetric thyristors, ACR3200VR33 and ACR2900VR45, with voltage rating of 3.3 kV and 4.5 kV, respectively. As shown, they both provide slightly better characteristics (see d*V*/d*t*, V_{PU}, V_T and I_{TSM}) for bypass applications compared to their alternative standard thyristors (DCR3030V42 and DCR2720V52).

Both ACR3200VR33 and ACR2900VR45 have successfully passed all quality tests and are now available for production. Detailed datasheets for these devices can be accessed on the Dynex website.

2.2 Reverse asymmetric thyristors

Dynex has developed new structures for bypass thyristors that offer significantly lower on-state voltage and FIT ratings, as well as a markedly higher surge current capacity. Therefore, reverse asymmetric thyristors may also achieve comparable performance characteristics in a smaller device, which may result in lower costs and reduced volume of the final set-up. However, as mentioned, this comes at the cost of lower forward blocking capability, V_{DRM}.

As shown in **Table 1**, Dynex offers two reverse asymmetric thyristors for the 3.3 kV voltage range, ACR3775VR33 and ACR2700CR33, and two for the 4.5 kV voltage range, ACR3350VR45 and ACR2400CR45. These reverse asymmetric thyristors, compared to those with the standard structures, offer significantly higher surge current capacity and lower on-state voltage within the same diameter, *D*. Moreover, as mentioned, the use of a reverse asymmetric structure allows for similar performance characteristics to the standard thyristors but in a smaller diameter.

The device numbers ACR3775VR33, ACR2700CR33, ACR3350VR45, and ACR2400CR45 are currently under development. In the meantime, provisional datasheets can become available upon request.

Additionally, Dynex has developed a reverse asymmetric thyristor for the 6.5 kV range, with the device number ACR4000WR65. According to **Table 1**, the ACR4000WR65 offers significantly higher surge current capacity and lower on-state voltage compared to the standard 6.5 kV thyristor, device DCR2950W65.

The ACR4000WR65 has passed all quality tests and is now available for production; its datasheet is accessible on the Dynex website.

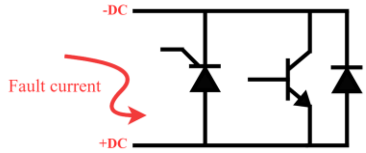

Figure 2. Simulated circuit.

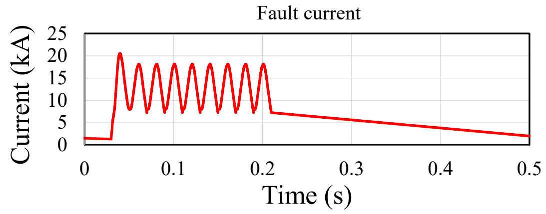

Figure 3. An exemplar DC side short circuit current.

3 Simulation Comparison

Table 1 shows that both semi-asymmetric and reverse asymmetric thyristors have lower on-state voltages than standard thyristors. Consequently, these thyristors are likely to conduct a greater proportion of the fault current. This means that, when asymmetric thyristors are used, the IGBT's diode will carry a smaller fraction of the fault current compared to using standard thyristors.

A simplified model of a VSC sub cell is simulated in PLECS, as presented in **Figure 2**, with the fault current shown in **Figure 3**. Although this simulation is comparative and the circuit is generalised, the objective is to closely represent an actual VSC-based MMCs under a fault condition.

The simulation employs thyristors from **Table 1** as bypass thyristors paired with IGBT diodes under specific configurations. Devices rated at 3.3kV were simulated with a 3300V, 1500A Dynex IGBT module (DIM1500ESM33-TL000), 4.5kV devices with a 4500V, 1200A Dynex IGBT module (DIM1200ASM45-TL000), and 6.5kV devices with a 6500V, 750A Dynex IGBT module (DIM750ASM65-TL000). A temperature of 125°C was maintained to simulate typical operating conditions.

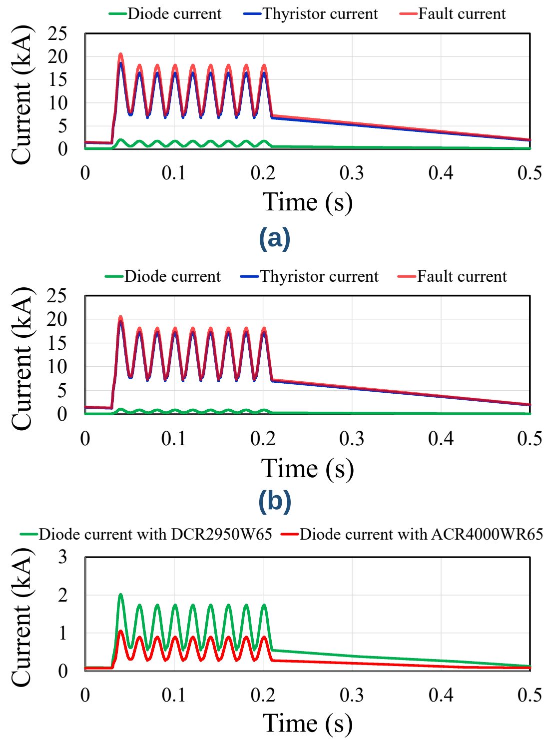

Figure 4. Comparison of diode current, thyristor current, and fault current using (a) a standard thyristor and (b) a reverse asymmetric thyristor, and (c) diode current comparison using either a standard or reverse asymmetric thyristor.

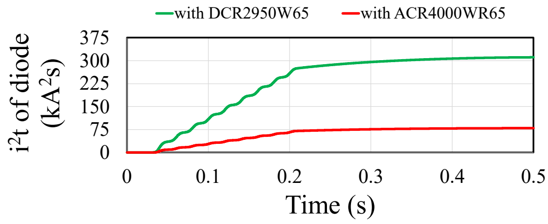

Figure 5. I²t through IGBT's diode with standard thyristor and reverse asymmetric thyristors.

For a 6.5 kV application, **Figure 4(a)-(c)** show the fault current, thyristor current and the diode current when standard (DCR2950W65) and reverse asymmetric (ACR4000WR65) thyristors are used as the bypass thyristor. As shown in **Figure 4**, while both thyristors can divert a considerable proportion of the fault current, the diode (DIM750ASM65-TL000) peak current is significantly lower when a reverse asymmetric thyristor is used.

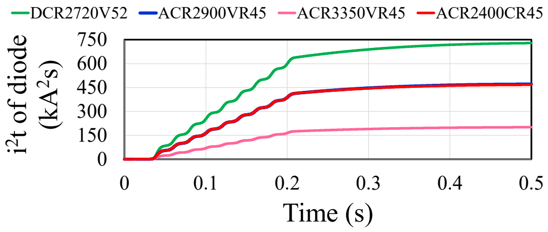

Figure 6. I²t through the IGBT's diode with standard and bypass thyristors for a 4.5 kV application, as presented in Table 1.

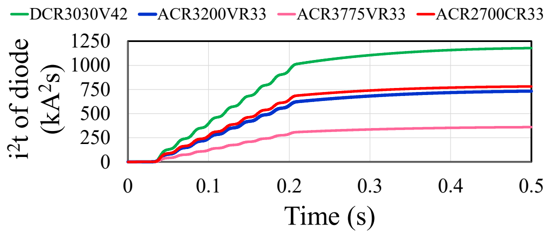

Figure 7. I²t through the IGBT's diode with standard and bypass thyristors for a 3.3 kV application, as presented in Table 1.

Figure 5 also shows the average I²t through the IGBT's diode using standard (DCR2950W65) and reverse asymmetric (ACR4000WR65) thyristors. As shown, there is a substantial reduction in current stress of the diode when using the reverse asymmetric thyristor.

Figure 6 and **Figure 7** show the average I²t through the IGBT's diode using thyristors listed in **Table 1** for 4.5 kV and 3.3 kV applications, respectively. These figures show that reverse asymmetric thyristors (ACR3775VR33 and ACR3350VR45) substantially reduce the current stress on the IGBT diode compared to both semi-asymmetric (ACR3200VR33 and ACR2900VR45) and standard thyristors (DCR3030V42 and DCR2720V52).

Moreover, reverse asymmetric thyristors ACR2700CR33 and ACR2400CR45 offer the same performance as their semi-asymmetric counterparts (which is better than that of standard thyristors) but in a more compact form. This shows that by employing a reverse asymmetric structure, it is possible to achieve comparable performance in a smaller thyristor, which also results in reduced costs.

4 Final Remarks

In this application note, we explored the use of bypass thyristors and their applications. We also introduced some of Dynex's recent developments in thyristors designed for bypass applications.

The use of Dynex asymmetric thyristors, specifically designed for bypass applications, has been demonstrated to significantly reduce the stress on the IGBT's diode under DC fault conditions. This offers substantial benefits for system designers dealing with fault currents of higher magnitudes and in higher voltage systems that require thyristors with increased current and voltage ratings. Furthermore, it has been shown that using smaller thyristors with equivalent surge current and voltage ratings is feasible, potentially leading to cost and size reductions in the final set-up.

Dynex asymmetric thyristors offer a comprehensive range suitable for a wide array of applications. Should you require any specific adjustments to meet unique requirements, please contact us. We are equipped to develop customised products tailored to your needs.

5 References

[1] Y. N. Abdelaziz, K. H. Ahmed, and B. W. Williams, 'New Hybrid Thyristor-Based Multilevel Converter With DC Fault Blocking Capability, for HVDC Applications', *IEEE Trans. Power Electron.*, vol. 39, no. 1, pp. 911–923, Jan. 2024, doi: 10.1109/TPEL.2023.3328058.

[2] 'Prospects and Challenges of 4H-SiC Thyristors in Protection of HB-MMC-VSC-HVDC Converters | IEEE Journals & Magazine | IEEE Xplore'. Accessed: May 28, 2024. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/9360510

[3] M. Spence, A. Plumpton, C. Rout, A. Millington, and R. Keyse, 'Design and Characterisation of Optimised Protective Thyristors for VSC Systems', in *PCIM Europe 2016; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management*, May 2016, pp. 1–8. Accessed: May 28, 2024. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/7499450

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