New Low Loss Thyristor for HVDC Transmission

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Abstract

Four inch thyristor in the package with 100 mm pole piece was developed and fully qualified for 8.5 kV voltage class. The maximal ON-state voltage has been reduced from V_{Tmax} = 1.95 V to V_{Tmax} = 1.70 V at I_T = 1.5 kA and T = 90 °C. Significant reduction of leakage current extended the blocking stability up to 115°C. The device proved its robustness and lowered losses during valve testing in 6-pulse back-to-back synthetic test circuit. The reduction of valve losses is estimated at 6 to 8 %. The 3rd Generation of PCTs for HVDC from ABB is established.

1. Introduction

Since sixty years the high-voltage direct current (HVDC) transmission technology demonstrates its advantages over the alternating current (AC) solutions, when

Fig. 1. New low loss 8.5 kV PCT at package with 100 mm pole piece.

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the transmission over long distances is matter of attention. This includes a better grid stability, much lower power losses over very long distances and narrower transmission corridors.

Increasing transmission efficiency belongs to the most important development trend in the contemporary HVDC technology. In 2013, the requirement of a much higher transmitted power led ABB to develop the second generation of phase controlled thyristor (PCT) platform at six inch wafer [1]. As a result, the PCTs with lower ON-state voltages (V_T) have been developed for the next generation inverter valves, which are being designed to fulfill the demands for >10 GW power transmission [2]. Now we are witnessing a similar situation with the four inch PCT platform, which is important for the efficiency of UHVDC systems designed for the power range of several GW. The aim of this paper is to present the new four inch 8.5 kV PCT with improved ON-state voltage drop V_T (see Fig.1). The very low ON-state voltage drop at high blocking capability indicate that the silicon thyristors will remain the devices with the lowest ON-state losses also in the future.

2. Thyristor Design

Being a non-punch through device, a thyristor is subject to the reach-through effect [3]. To avoid this effect up to the highest possible voltages, an optimal N-base thickness and resistivity must be chosen. This means that the thyristors for high blocking voltages require a thick N-base region, which implies a high ON-state voltage drop V_T. Because of the reach-through effect, one cannot simply reduce the N-base thickness to reduce the ON-state losses like in the case of a punch-through device. The only possibility is to reduce the thicknesses of the P-base and P-anode, if junction termination allows us to do that. A hybrid solution with thinned P-type layers only in the active region represents the concept used for the *New* PCT presented below (see Fig.2).

The *Classical* device under consideration has the negative bevels at anode and cathode sides. To assure blocking capability up to 8.5 kV with sufficient margin, both the P-anode and P-base have corresponding thickness and doping profile. However, for the required blocking capability, the relatively high thickness of p-type layers is needed only at the bevel region. In the *New* design, the original thickness of p-type layers is maintained only at the bevel, while reduced in the active region using a special diffusion process through a mask [4]. The original thickness of the N-base $w_{N\mathit{old}}$ in the active part is increased to $w_{N\mathit{new}}$, while it is unchanged at the bevel region (see w_{JT} in Fig.2). As a result, the breakdown voltage of the *New* device increases. This is possible, because there is a very small contribution from the

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reach-through effect at bevel to the total leakage current. This is because the thicker N-base (see w_{New} in Fig.2 right) occupies most of the device area. The benefit of the increased breakdown voltage can be utilized in the reduction of total device thickness. One can design the PCT with reduced thickness and lower V_T, while maintaining the original blocking capability. Further details on the new junction termination can be found in [5].

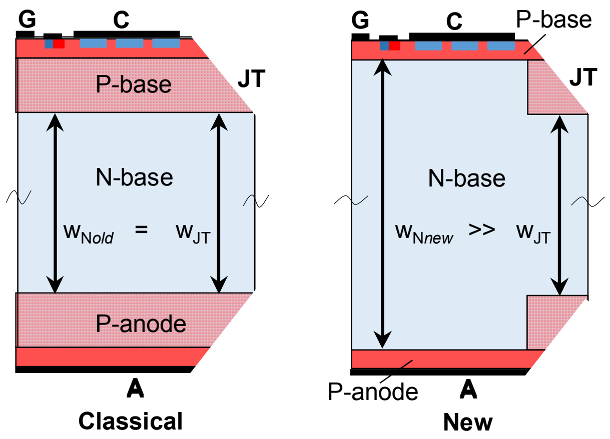

Fig. 2. Thyristor structure with *Classical* (left) and *New* negative bevel concept (right) for HVDC.

3. Experimental results

The static blocking characteristics of *Classical* and *New* devices are compared in Fig.3. The devices have about the same blocking voltage, although the device with the new junction termination is by 7 % thinner. The reduction of leakage current of the *New* device results from the missing reach-through effect in the active region depicted in Fig.2 (right). The impact of this feature on the ac blocking capability is demonstrated in Fig.4, which shows the dependence of leakage current on junction temperature in the regime of repetitive forward blocking. Since the anode and cathode-side junction terminations are equal, the graph for repetitive reverse blocking (not shown here) looks analogous. This measurement proves stable device operation at temperatures up to 115 °C. It is worth mentioning that for application reasons, the devices for HVDC are typically rated at maximal junction temperature of 90°C. The safety margin of operation temperature therefore amounts to 25 °C.

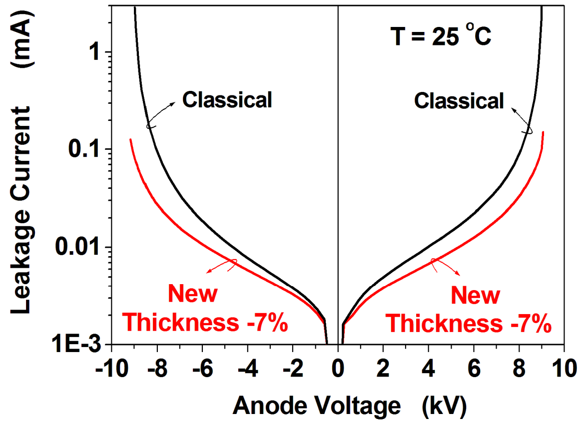

Fig.3: Blocking characteristics of *Classical* and *New* 8.5 kV PCTs.

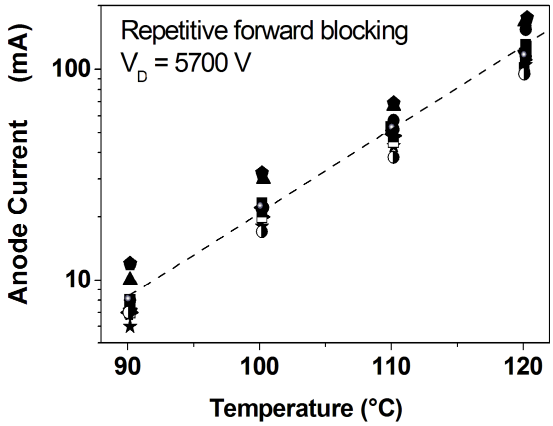

Fig.4: Leakage current at repetitive forward blocking vs. temperature (*New*).

Fig.5 shows the measured dependence between V_T and reverse recovery charge Q_{rr} for the *Classical* and *New* device. For the new device, the $Q_{rr} – V_T$ points are shown after processing and two different doses of electron irradiation as well. For the same Q_{rr}, we obtain the reduction of $V_{T\,max}$ by 250 mV and $V_{T\,mean}$ by ≈300 mV. We can estimate that the replacement of classical device by the new one can reduce the overall valve losses by 6 – 8 %.

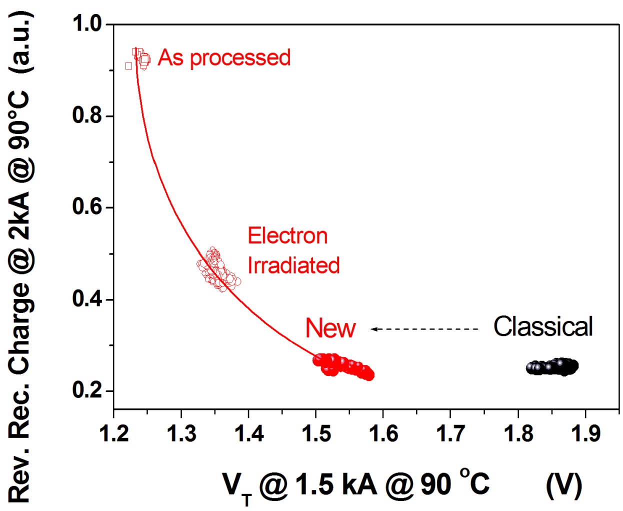

Fig.5: Trade-off curves between V_T and Q_{rr} for *Classical* and *New* 8.5 kV PCTs. Every circle/cube represents one device.

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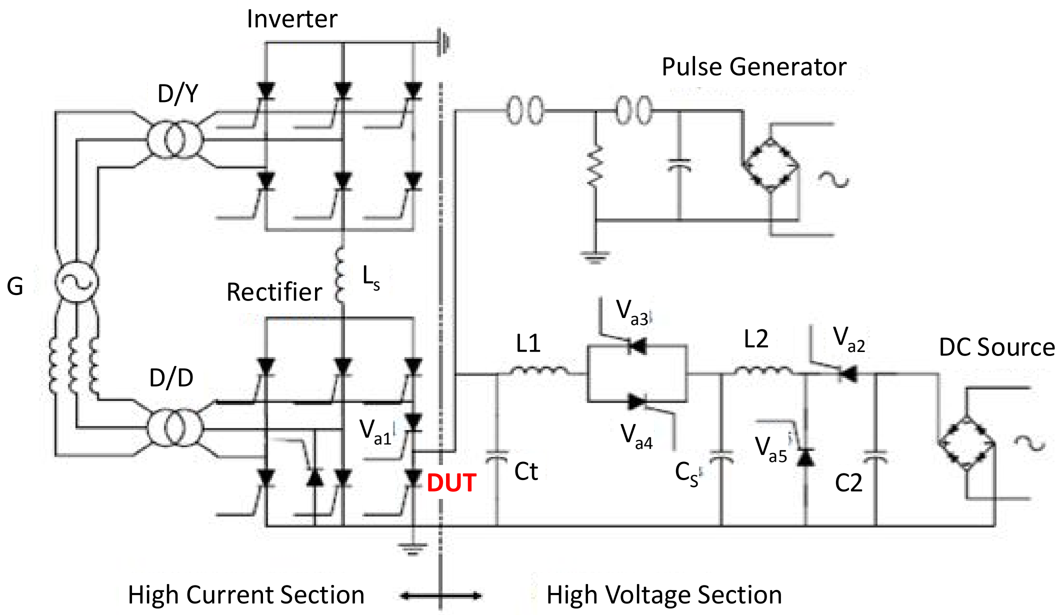

Fig.5: Synthetic test circuit for the operational test of *New* 8.5 kV PCTs. Device under test (DUT) is a stack with ten serially connected PCTs from Fig.1. C_t represents the stray capacitance in service, L_1 is the synthetic turn-off di/dt inductance.

In order to verify the design of the valve with the new PCT regarding its performance under normal conditions, abnormal conditions and transient fault conditions, the devices were mounted in a stack of nine with a single valve reactor in series. This stack was subjected to the operational valve test in the synthetic 6-pulse back-to-back circuit from Fig.5 [6]. The High Current section, scaled down directly from the actual converter station, brought the required test equivalence to real operation conditions. The Pulse Generator enabled us to verify a reliable valve operation under transient faults like the ones appearing when a lightning strikes the transmission line. The current injection section with the valves V_{a2} – V_{a5} enabled us to perform the complete set of standardized tests with a high degree of equivalence to real operation conditions, like for example that of the periodic firing and extinction, maximum continuous and temporary operation duty, intermittent direct current at α-90 or a minimum delay angle, one-loop and multiple-loop fault current with or without re-applied voltage forward or reverse voltage, etc. Passing all the tests above confirmed the high ruggedness of the new device with lower losses, which is required for the future HVDC systems.

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4. Conclusions

New PCT with repetitive peak blocking voltage of 8.5 kV has been developed for the next generation converter valve with increased efficiency. This is possible thanks to the reduction of device thickness by 7 % leading to the reduction of the maximal ON-state voltage V_{Tmax} by 13 %. The estimated reduction of the overall valve losses at 6 - 8 % is sufficient to define the 3rd Generation PCT technology for HVDC from ABB.

5. Reference

[1] J. Vobecky, T. Stiasny, V. Botan, K. Stiegler, U. Meier, M. Bellini, New Thyristor Platform for UHVDC (>1 MV) Transmission, Proceedings PCIM 2014, Nuremberg, pp. 54 – 59.

[2] J. Cao, J. Cai, "HVDC in China", 2013 HVDC and FACTS Conference, Palo Alto, CA, USA, August 28-29, 2013.

[3] B. J. Baliga, Fundamentals of Power Semiconductor Devices, Springer, 2008.

[4] J. Vobecky, M. Rahimo, Bipolar Non-punch through semiconductor device, US Patent 8,803,192 B2, 2014.

[5] J. Vobecky, V. Botan, K. Stiegler, U. Meier, M. Bellini, A Novel Ultra-Low Loss Four Inch Thyristor for UHVDC, Proceedings ISPSD´2015, Hong-Kong, to be published.

[6] B. Sheng, H. - O. Bjarme, H. Johansson, Reliability Enhancement of HVDC Transmission by Standardization of Thyristor Valves and Valve Testing, Proceedings of the 6th International Conference on Power T&D Technology, Guangzhou, 2007.

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