Thyristors for >10 Gigawatt Power Transmission

A new thyristor platform with voltage ratings 6.7 kV, 7.2 kV and 8.5 kV was developed to enable an optimal design of converter valves with DC link voltages above 1 MV. Maximal area utilization of 150 mm silicon wafer and optimized cathode layout of the electrically triggered thyristor improved on-state current ratings by >20 % thanks to a reduced on-state voltage drop by 10 %. The new platform provides more efficient and powerful converter valves for the next generation UHVDC systems with rated power ranging from 8 to 13 GW. Prof. **Dr. Jan Vobecky, Dr. Chunlei Liu, ABB Switzerland Ltd., Semiconductors**

For long-distance and multi-gigawatt power transmission, Current Source Converters (CSC) with large-area Silicon phase-controlled thyristors (PCT) are used due to overall low system losses. As the length of these transmission lines can reach over 2,000 km, extreme demands are laid on energy efficiency. This dictates the usage of direct current (DC) transmission line cables operating at ultra-high voltages (UHV). These systems are therefore called UHVDC systems.

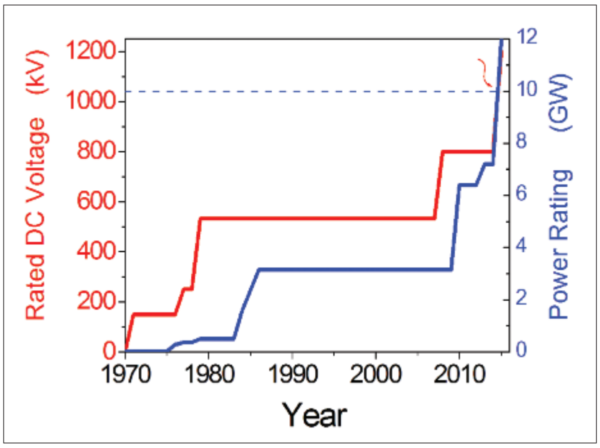

Figure 1: Evolution of maximal ratings in HVDC technology

Most of the UHVDC systems are nowadays installed and further planned in China, where bulk energy sources of hydroelectric power are available in the west, while the industrialized regions with high consumption of electrical energy are located in the east and south. Following the success of UHVDC lines operating with a rated DC voltage of ~800 kV and a rated power of 7 GW, China is investigating the possibility of increasing the voltage rating up to 1,100 kV for power transmission breaking the 10 GW limit [1]. This intention manifests itself in the steep rise of ratings in Figure 1, which shows the evolution of HVDC technology.

Figure 2: New six inch PCT for UHVDC technology

Demands on thyristors for future UHVDC systems

UHVDC systems for transmitted power over 10 GW lay new demands on converter valve, valve hall, transformer, transformer and wall bushing, by-pass switch, surge arrester and DC yard.

Regarding the converter valve, a new PCT platform with higher rated currents for the same blocking voltages had to be developed. To fulfill this demand, the PCTs with lower on-state voltages (V_T) for equivalent turn-off losses and recovery charge Q_{rr} were designed and qualified. Since the PCT is a non punch-through device, higher blocking voltages require thicker Silicon, which increases the V_T and reduces the rating current. Assuming the same thermal resistance of an available package, the maximal rated current then decreases with an increasing rated blocking voltage.

The optimal voltage class of the PCT for

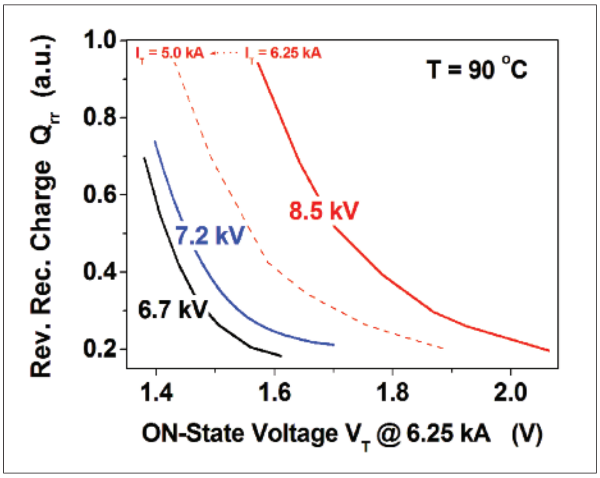

Figure 3: Trade-off curve between V_T and Q_{rr} for the new PCT platform

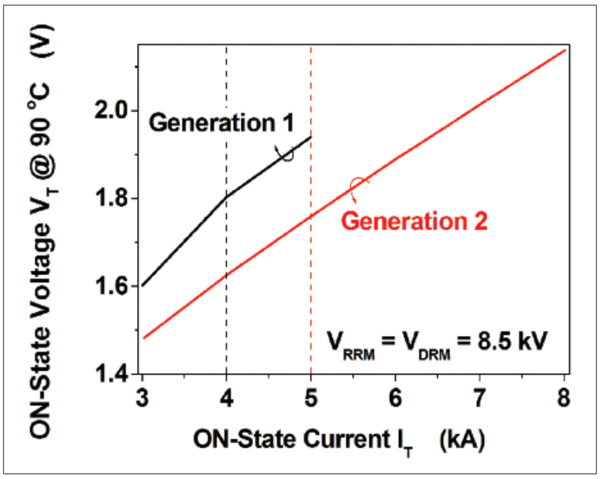

Figure 4: Improvement of on-state voltage drop (mean value) at the new 8.5 kV generation

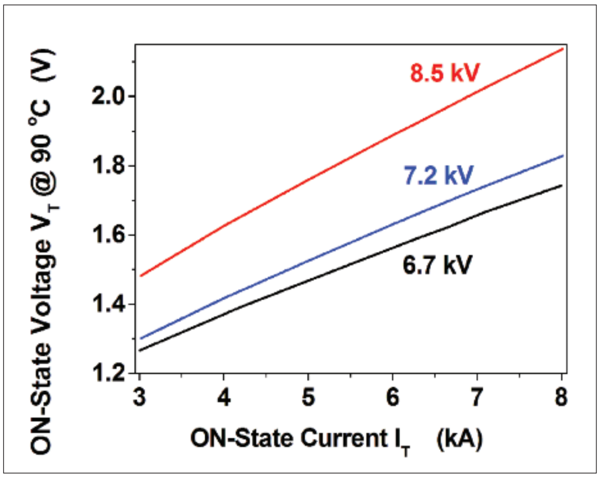

Figure 5: Mean value of on-state voltage drop vs. on-state current for the new PCT platform

given valve target parameters can be rigorously chosen only when the current rating of the HVDC system is known. In reality, the development of a new PCT generation starts before the maximal rating current of a given target application is confirmed. It is therefore advantageous to develop a new PCT platform, which comprises several voltage classes, because it provides flexibility in valve design. For this purpose, ABB has developed a new PCT platform with three voltage classes, namely 6.7 kV, 7.2 kV and 8.5 kV with improved ratings of the on-state current (see Figure 2).

The maximal rating current of the new PCT is over 6 kA for voltage ratings of 6.7 kV and 7.2 kV PCTs, and 5 kA for 8.5 kV. For an UHVDC system with the maximal rating current over 6 kA this means that valve designers can use PCTs with 6.7 kV or 7.2 kV voltage ratings. In case that minimal count of PCTs in series is favored, fewer serially connected 8.5 kV PCTs can be used provided that the maximal rating current is limited to 5 kA.

New thyristor platform characteristics

Processing of six inch PCTs with repetitive peak blocking voltages up to 8.5 kV is attributed by the use of

1. high purity float zone neutron transmutation doped (FZ NTD) silicon wafers with optimal resistivity and thickness,
2. advanced diffusion techniques, which provide the required purity after long-running diffusion,
3. a high quality junction termination including surface passivation for stable forward and reverse blocking,
4. an electrically-triggered thyristor design which provides maximal cathode area for conduction of the on-state current,
5. optimal lateral structuring of amplifying gate and cathode shorts for lower V_T, robust turn-on and turn-off capability,
6. maximal utilization of 6" wafer,
7. optimal parameters of lifetime control for the banding of reverse recovery charge Q_{rr},
8. a housing with low thermal resistance and high surge current capability.

The items 1 - 3 above assure us the achievement of stable DC and AC blocking characteristics with low leakage currents and rugged dynamic blocking in case that the valve converter is subject to a lightning strike and the PCTs are driven to avalanche regime.

The Q_{rr} banding (item 7) is dictated by the fact that the PCTs are connected in series to support the rated valve voltage. If they have similar magnitudes of Q_{rr}, less additional PCTs must be added into the stack to compensate for non-uniform voltage sharing. Narrowing of the Qrr band is achieved using the classical electron irradiation technique with optimized energy and dose.

The items 4 – 6 are important for the achievement of smallest possible electrical valve losses caused by the PCTs. To judge these losses at thyristor level, the trade-off curves between V_T and Q_{rr} are usually used. For the new PCT platform, they are shown in Figure 3. These curves show that lower turn-off losses (characterized by Q_{rr}) provide higher on-state losses (characterized by V_T) and vice versa. It also implies that PCTs of a higher voltage class give higher overall losses, because the higher blocking voltage requires a thicker Silicon wafer which causes a higher V_T.

Using the improved press-pack housing with lower thermal resistance for the new PCT platform (item 8) together with lower VT (items 4 - 6), the maximal current rating of the PCT of the 8.5 kV class has increased from 4 kA to 5 kA. At the same time, that of the 6.7 kV or 7.2 kV PCTs could be specified at more than 6 kA. The

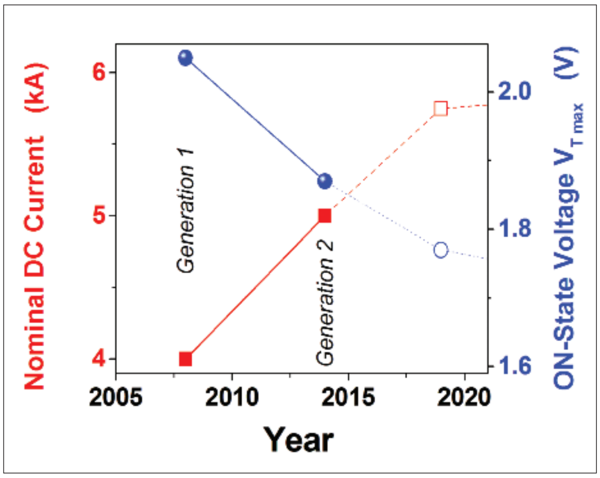

Figure 6: Evolution of 8.5 kV PCT capability with outlook to the future

surge current capability then increased around 10% compared to the first generation. The improvement between the first and second 6" PCT generations is illustrated in Figure 4 for the voltage class 8.5 kV with an equivalent Q_{rr} band. This figure shows that the reduction of V_T by 10 % allows us to increases the maximal current rating from 4 kA to 5 kA.

The dependence of V_T on on-state current is shown for the whole PCT platform in Figure 5. It is evident that the significantly lower V_T of 6.7 kV and 7.2 kV voltage classes predetermine these parts for the usage in the UHVDC systems with the highest current ratings (> 6 kA) and therefore with the highest power ratings (> 10 GW).

Outlook

The UHVDC systems, which require PCTs described in this paper, are installed mainly in China. Today´s installed capacity of 800 kV DC transmission systems is more than 20 GW. The total planned capacity up to 2020 is over 100 GW [2].

To satisfy these demands, the new PCT generation has been developed for UHVDC lines operating with a rated DC voltage of 1,100 kV with higher current-carrying capability as presented in this paper.

For the periods beyond 2020, further development of UHVDC systems is needed. From the perspective of PCTs there is still room for further improvement in on-state voltage drops and on-state current ratings to support further improvement in energy efficiency. This prediction is illustrated in Figure 6 for the 8.5 kV voltage class processed from six inch silicon wafers as presented above. The voltage classes 6.7 kV and 7.2 kV should behave accordingly with correspondingly lower on-state voltage drops and higher nominal rated currents.

Literature

[1] R. Montano, B. Jacobson, D. Wu, L. Arevalo, "Corridors of power", ABB Review, Special Report: 60 years of HVDC, 2014.

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