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GROUP REF. : A2
PREF. SUBJECT : 2
QUESTION N° : 6

Q2.6 - What prospects are there for development and use of electronic or solid-state transformers?

A solid-state transformer (SST) is essentially a modular power electronics converter that uses a medium frequency transformer (MFT) to provide galvanic insulation and input-output voltage matching, as shown in figure Fig. 1 (a). Depending on the SST cell structure (Fig. 1 (a)), it can be designed for connection between any two electric systems AC-AC, AC-DC or DC-DC, while providing full controllability in terms of power flows, voltages and/or currents and phase in case of the AC system. Through modularity, series connection of identical cells, it can scale up the voltage to MV levels.

Fig. 1 – (a) Functional scheme of an SST cell. Several cells can be connected in series to reach MV. (b) Illustrative example of transformer frequency scaling, where MFT with same power and voltage rating features 95% weight reduction as compared to LFT.

SST is a key enabler of DC/DC power conversion at MV level and thus an enabler of the MVDC distribution and all its benefits [1]. Thanks to the fast switching of modern semiconductors within the SST (several kHz), a dramatic reduction of transformer size can be achieved, as shown in Fig. 1 (b).

In order to evaluate the potential for SST development, three main application scenarios are analyzed based on several high level KPIs, as shown in Fig. 2.

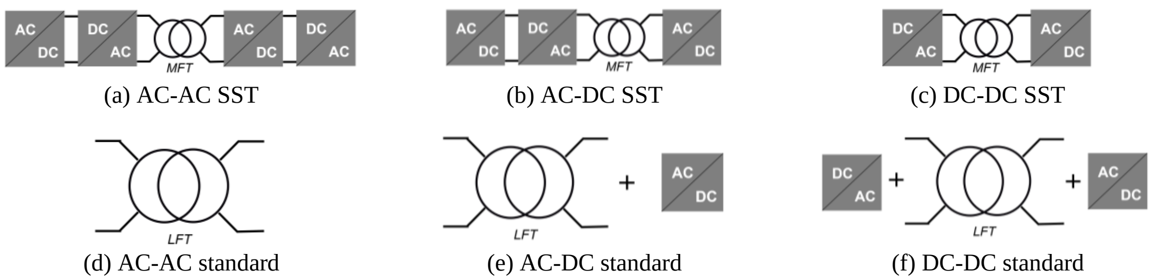

Fig. 2 – Comparison of SST vs. standard solution for all three relevant combinations of electrical system interconnection.

In case of AC-AC conversion, the AC-AC SST is backward compatible with existing MV AC infrastructure. It provides full controllability: power, phase and voltage. However, with 5 conversion stages, it is difficult to compete with a single stage low-frequency transformer in terms of cost and efficiency. Moreover, possible weight decrease is not the most important KPI in utility applications. An interesting solution for such applications is the “Hybrid transformer” for the AC/AC applications [2].

In case of AC-DC conversion, the AC-AC SST is backward compatible with existing MV AC infrastructure. AC-DC is more favorable for SST as compared to AC-AC as in this case, the SST has one conversion stage less while the LFT has one conversion stage more. AC-DC SSTs can be interesting solution in applications where the efficiency vs. weight ratio is challenging (railway [3]) or when multiple LVDC outputs are needed (e-mobility [2])

Finally, SST is the natural solution for DC-DC conversion and thus an enabler of the MVDC distribution. State of the art 50Hz devices can also be used for the sake of availability, but SST will ensure better efficiency and lower cost in the DC-DC applications. Efficiency up to 98,9% at full load can be reached by the SST for the full DC-DC.

The many benefits of MVDC distribution, as shown in Fig. 3 are well known. It provides a more efficient power distribution featuring higher power throughput per cable cross-section, reduced cabling cost and reduced cabling losses. Moreover, reduced conversion losses from DC source to DC load, less power quality management issues, no frequency synchronization needed, controllability enabled by SST, link between AC grids with different properties etc. Detailed analysis of MVDC applications and SST topologies is available in [1].

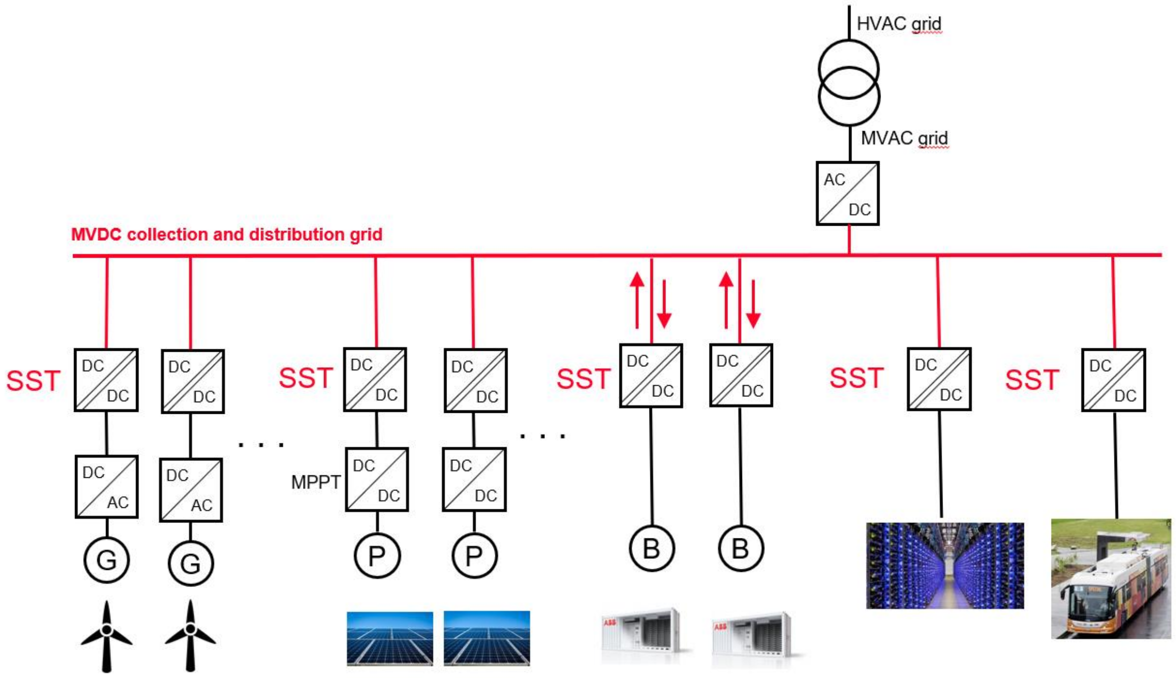

Fig. 3 – Future MVDC distribution enabled by SSTs, interconnecting all DC sources and DC loads over a MVDC link.

Based on this high-level analysis, it can be concluded that, AC-AC MV applications are unlikely to drive the SST development. Due to backward compatibility with MVAC distribution, applications such as railway and e-mobility may be the first adopters of the SST technology. Finally, MVDC distribution will be the main driver of SST in the medium to long term.

References

[1] "*Medium Voltage DC Distribution Systems*" CIGRE Technical Brochure C6/B4, July 2022, Reference: 875

[2] J W. Kolar, J. E. Huber, "*Next-Generation Datacenter MV Interfaces - Will Solid-State Transformers Meet Their Waterloo?*", Ind. session presentation, APEC 2022

[3] D. Dujic, F. Kieferndorf, F. Canales, and U. Drofenik, "Power electronic traction transformer technology," Power Electronics and Motion Control Conference, Jun. 2012