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Multi-megawatt charging to foster the mobility transition

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Since the European Commission released "Fit for 55" [1] as their strategic plan, including measures to reduce GHG emissions by 55% by 2030 with reference to the emissions from 1990, European countries such as Austria are urged to accelerate their engagements in all contributing sectors such as energy generation and transportation.

Even though the electric mobility sector is significantly growing, electric vehicles still show a rather low absolute share of the total number of available vehicles. One of the major drawbacks for most customers is that the national charging infrastructure is not yet elaborate, mature, and meshed enough compared to the one for combustion engine vehicles. Furthermore, charging power in the megawatt range is demanded by customers operating bus or heavy-duty fleets to minimize downtimes of personnel and vehicles. Ideally, such a charging station also allows distributed charging of several buses and trucks to optimize the demand per driver.

Concurrently, megawatt charging stations can heavily impact the grid voltage, frequency, and nearby loads if they are connected to a low-voltage point of common coupling. Thus, it is recommended to guarantee a connection to the distribution grid, which can lead to increased complexity in terms of installation and equipment licensing.

In principle, there are two different major strategies that allow the implementation of multi-megawatt fast chargers or infrastructure:

- either via an MV/LV low-frequency (e.g., 50 Hz) transformer followed by low-voltage power electronics equipment or
- via a direct connection of the power electronics input stage to the medium-voltage grid (omitting the 50 Hz transformer) shifting isolation towards the DC stage realized via solid-state transformer (SST) technology (medium or high frequency).

Those concepts focused on the *50 Hz transformer approach* generally benefit from decent to high efficiency between around 97–98% (depending on the transformer technology, cable length, switching frequency, semiconductor technology, and voltage levels), a rather low level of complexity regarding design, control, and isolation coordination, as well as a sheer unlimited amount of commercially available low-voltage components, generally short lead times of the latter, standardized packages, and safety equipment. The transformer's secondary low-voltage side usually supplies either 400 V or 690 V line-to-line quantities (690 V preferred for megawatt power ratings). Low-voltage input stage topologies normally range from passive or line-commutated multi-pulse solutions (with optional active power factor correction circuits) to active standard two- to multi-level converters. Still, the disadvantages of this approach are the large transformer volume and weight and high currents due to the low voltage, which results in additional copper mass and losses, especially for cables covering longer distances. This is mainly dependent on the location of the charging station and the transformer (i.e., the point of common coupling).

The second breed of solutions, where *power electronic converters are directly connected to the medium-*

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voltage grid, can be further separated into two different categories:

- medium-voltage converters followed by solid-state transformers and
- multi-level multi-cell converters with integrated solid-state transformers.

Before looking into the main differences between both groups, their commonalities are discussed (both pros and cons).

Similar to the aforementioned low-voltage approaches, the SST-based solutions would allow the integration of various topologies. Both silicon and silicon-carbide semiconductors are a feasible match for either low cost or optimized efficiency and volume, respectively. Si and SiC semiconductors with high current ratings and blocking voltages (up to 6.5 kV commercially available and 10 kV per sample request) allow low conduction losses and attractive switching frequencies (in the range of a 10th of a kilohertz for silicon carbide devices). Furthermore, the ascending demand for SiC MOSFETs in the 3.3 kV area led to a technology push towards all-in-one solutions for required gate driver circuits, i.e., small-wattage DC/DC converters with high isolation requirements.

Theoretically, GaN transistors could be applied as well. However, GaN transistors would lead to a larger cell count due to the limited voltage-blocking capability of commercially available GaN semiconductors. Because of the stringent requirements regarding the isolation of the medium frequency transformer (MFT) and the concurrent need to maintain a low MFT volume, it is preferred to keep the number of switching cells as low as possible and optimize the switching frequency of available semiconductors at the same time. If this can be achieved by design, SSTs come with a significantly lower volume than their low-frequency counterparts. The drawbacks of these medium-voltage solutions are increased complexity and isolation coordination.

A medium-voltage rectifier followed by an MMC SST, as shown in Fig. 1, benefits from two separate DC links (medium voltage: primary side, low voltage: secondary side), which allow the integration of renewable energy systems (RES) on either side of the equipment (marked in green). Thus, in case of an AC-side grid outage, the system at hand could still operate. Moreover, the MV rectifier can be positioned close to an MV AC bus. The SST can be located close to a vehicle or charging station/building (long cables from the MV rectifier to the SST with low copper mass). Eventually, more isolated DC chargers can be easily integrated due to the existing common MV DC link.

A medium-voltage multi-megawatt fast charger based on a modular multi-cell converter with an integrated SST is depicted in Fig. 2. Due to the combined modular approach of both the rectifier and the SST, the design and implementation of the total system are considerably simplified. Modules can be connected either in series or parallel, dependent on the

Fig. 1 Medium-voltage high-power charging infrastructure based on a medium-voltage rectifier followed by a solid-state transformer

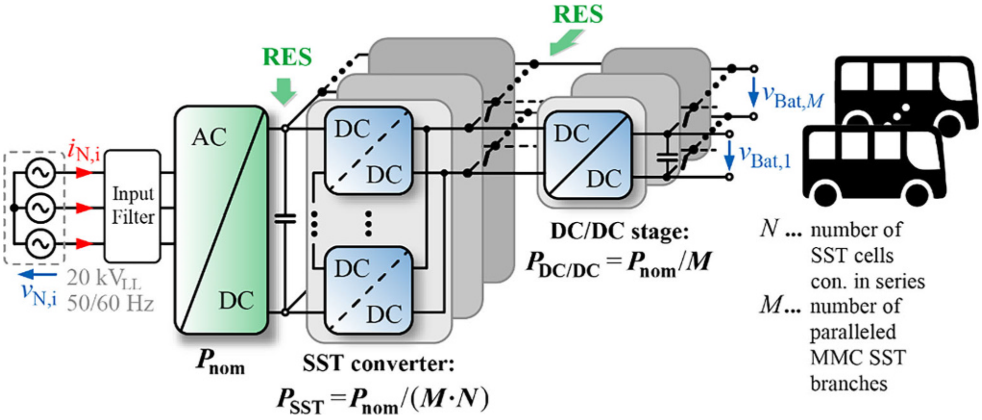
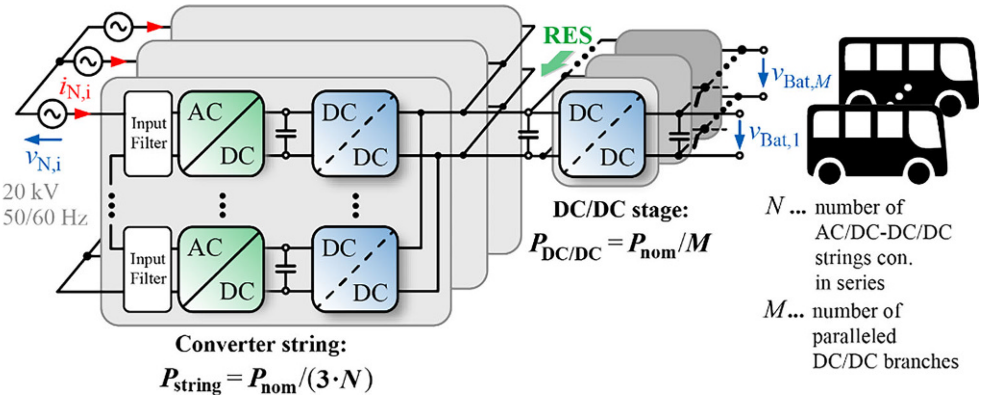


Fig. 2 Medium-voltage high-power charging infrastructure based on a modular multi-cell converter (wye-connected) with an integrated SST



required voltage and power rating. Dependent on the topology and grid-side connected methodology (wye or delta connection), a wye-connected solution results in lower DC link voltages per cell and, thus, a lower number of cells and SSTs. The disadvantage is the single-phase origin of each module. This results in a 100 Hz power ripple that has to be processed by each of the available modules. If no additional filtering approach is implemented at the power factor correction stage at the input, the 100 Hz and 120 degrees phase-shifted AC power fluctuations will eventually eliminate each other at the paralleled output. This would limit the performance of the SST. Thus, either complex active or bulky passive damping is required. Furthermore, an additional connection to a DC grid or renewables is only possible via the low-voltage DC link at the low-voltage output of the power stage.

Looking at the power electronics, topologies that could be used to implement these types of medium-voltage architectures mainly depend on the respective use case itself. More promising solutions to realize SSTs are, for example, the LLC converter (unidirectional) or dual active bridge DAB (bidirectional) topology. However, which one should be chosen heavily depends on customer specifications, required resonance, switching frequency, and transformer design knowledge. Another important aspect is whether a wide charging voltage range (200–1250 V) or a fixed DC link voltage is required. If, for example, a wide output voltage variation and bidirectional power flow are required, the DAB is preferred to the LLC converter. A DAB operating under zero voltage switching conditions could be an attractive alternative to further optimize the total system efficiency.

To sum up, these types of medium-voltage multi-megawatt stations, especially those utilizing solid-state transformers, can be an attractive solution for, e.g., urban areas or industrial environments with limited space constraints. The technology allows optimizing the on-site equipment while still enabling distributed fast charging of several cars/buses in the high kW range up to the MW range with reduced impact on LV loads or grids as it is directly fed by a medium-voltage port.

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Conflict of interest M. Makoschitz declares that he has no competing interests.

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