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1. Truck Charging in the renewable energy system

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3. Executive Summary

Heavy commercial vehicles are responsible for about a third of traffic-related emissions and energy consumption. Commercial vehicles are still largely powered by diesel engines, with a share of ~97%. Electrification of this transport sector has been struggling so far due to high range requirements and the associated high vehicle battery cost in an investment cost sensitive business segment. The requirements of fleet operators for payload and range can be quantified as basis to find feasible strategies for battery electric truck deployment. The two key levers for solving the range problem are:

- On the one hand higher capacity energy storage in the vehicles, which poses a vehicle cost challenge.
- On the other hand, efficient, coordinated charging concepts taking grid supply and grid load into account.

This paper covers the use case of Mega-Watt truck charging embedded into smart solutions and scenarios with renewable energy supply and the required stationary buffer storage solutions for the charging point.

Keywords: Heavy Duty electric Vehicles & Buses, Fast and Megawatt charging Infrastructure, Sustainable Energy, AC & DC Charging technology, V2H & V2G

1 Upcoming Mega-Watt Charging System

The upcoming Mega-Watt Charging System (MCS) standard paves the way and sets the framework for charging concepts that allow effective operation of heavy-duty on-road vehicles. To be competitive with diesel- engine powered vehicles, a charging capacity of more than 1 MW is required so that the BEV truck battery can be recharged within 45 minutes, which is the break period mandated by EU-law after 4,5 hours of driving. This use case can only be realized if the challenges on the vehicle, charging infrastructure and logistics hub side are solved: Solutions for intelligent energy management systems are needed to reduce the high investment costs for the infrastructure. New thermal management concepts for BEV vehicles must be developed to ensure the efficient handling of high currents during the charging process. In addition, the reduction of switching losses in semiconductors of the charging point power electronics through special design processes can be an important factor for improved energy efficiency, and, hence, energy cost. Efficiency can be increased and fast charging times can be guaranteed. Furthermore, the total cost of ownership can be reduced. [14] [1]

2 Demonstration example bi-directional charging in the NEFTON project

To be able to map long-distance transport without any loss of time, charging capacities in the megawatt range are required. To make this a reality, many components of the charging path must be integrated and adapted. The R&D project “NEFTON” (funded by BMWK, project management agency DLR) is investigating these challenges and possible solutions. The consortium has set itself the goal of demonstrating MCS charging with a prototype truck and a charging station that can charge at more than 1 MW by the end of the project. [1]

The MCS charging demonstrator was implemented externally in a standardized container as part of the project (see Fig 2.). This configuration facilitates swift and adaptable installation, obviating the need for cumbersome bureaucratic processes. The charging container's internal architecture (see Fig.1) is characterized by the intelligent integration of power electronic modules via a switching matrix, thereby implementing a flexible solution internally. This switching matrix facilitates the connectivity between power units and charging points within a charging park, ensuring seamless integration and operational efficiency. The configuration of the switching matrix can be tailored to meet the distinct power demands of each vehicle, ensuring an efficient and customized charging experience across the entire charging park. The switching matrix facilitates the addition or removal of power units during the charging process, ensuring operational flexibility. This feature ensures the effective utilization of existing hardware, facilitating the operation of power units at their optimal performance points with enhanced efficiency. The NEFTON charging system

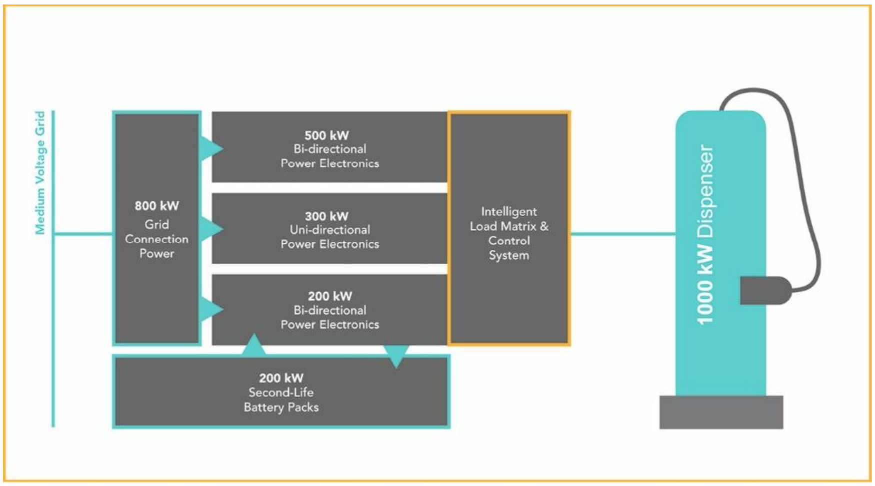

Figure 1 Efficient architecture of the stationary MCS station for trucks

is equipped with an integrated buffer battery comprising three battery packs. This configuration enhances the reliability of the charging resources and offers numerous possibilities for optimizing energy consumption and cost efficiency. Furthermore, it facilitates the use of renewable energy into the fleet depot, thereby enhancing the sustainability of the system. AVL is implementing a control system for the NEFTON MCS charging station that utilizes a modular master-slave ECU architecture. The master charging control unit (MCCU) is responsible for facilitating communication with the power electronics and the battery management system (BMS) of the buffer storage, as well as the higher-level control of these components. Additionally, it oversees the control of auxiliary units, including the human-machine interface, measurement devices, and, when necessary, cooling systems. Energy management, which encompasses the monitoring and coordination of the power grid, local energy storage, and the potential implementation of bidirectional charging, is facilitated by this control unit. In the event of a malfunction, an emergency line signal is utilized to promptly initiate the shutdown of power electronics. The MCCU is implemented in Windows on an industrial PC with real-time-capable TwinCat. The SCCU is responsible for all charging communication with the vehicle, encompassing both megawatt charging in accordance with the novel MCS standard and bidirectional CCS charging in accordance with the ISO 15118-20 standard. [1]

The MAN truck is equipped with two distinct charging connectors, designated as CCS and MCS, respectively. Each connector is linked to a dedicated charging control unit. Each charging control unit is connected to a variety of sensors and actuators that collect real-time data of the charging status, component temperatures, and other important variables. This array of sensors facilitates precise monitoring and control of the charging process. The communication processes between the charging control units and the charging station are based on the respective standard (CCS or MCS). [1]

Figure 2 left: Project site view container, right Project site view buffer battery

The NEFTON project took a holistic approach to the charging ecosystem. It demonstrated bi-directional energy flows involving stationary energy storage and electric trucks. Various locations have limited energy supply capacity and need, therefore, solutions supported by local PV, buffer storage and a transformation of the energy system in the long-term.

3 Transformation of energy systems for de-fossilization

The energy system has developed over many decades by continuous evolution and is now required to undergo a transformation process. For many years we have followed a demand driven and centralized approach for the energy supply which has been secured by large power plants, a one-way grid and passive consumers. The ongoing shift to an increased share of renewable energy sources adds volatility of supply and the need for demand management. Future grids need to support a two-way supply as well as decentralized generation. Examples of decentralized generation include solar panels, wind turbines, microgrids, and biogas plants, which collectively contribute to a more resilient and sustainable energy infrastructure. Variable pricing schemes will follow. China, for example, aims to establish a national unified power market by 2030, with significant reforms already underway [2]. These reforms include the liberalization of coal-fired power trading, the introduction of green power contracts, and the development of provincial spot markets The U.S. and China have both undertaken significant energy reforms, but their approaches and progress differ. While both countries aim to enhance renewable energy integration and efficiency, China's focus on market reforms and rapid capacity expansion contrasts with the US's legislative-driven approach and state-level initiatives. Figure 3 illustrates the changes needed in the energy system. From the traditional demand driven approach to the future volatile energy system with increased need for storage and 2-way grids.

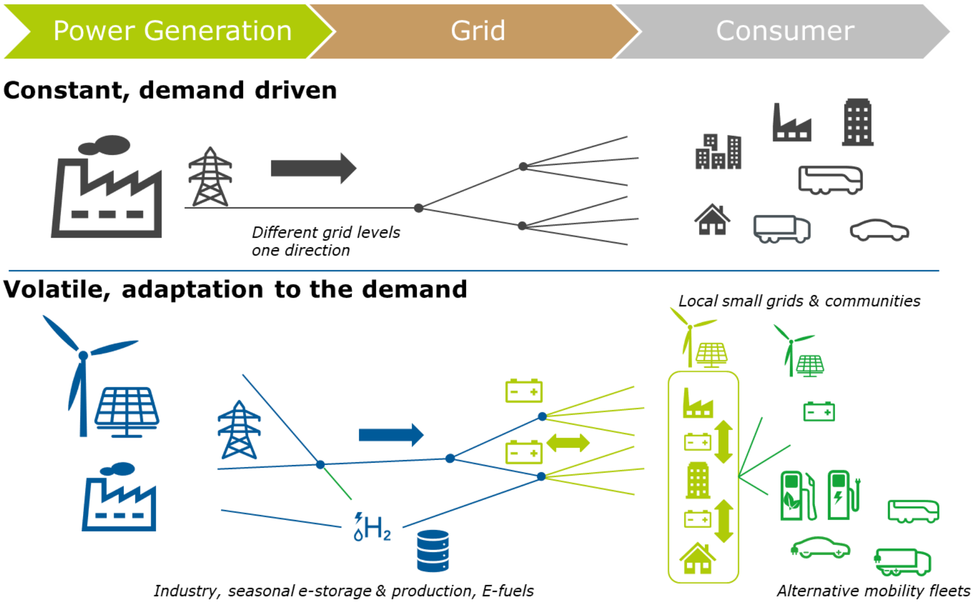

Figure 3: Transformation of Energy Systems for de-Fossilization [3]

3.1 The rise of virtual power plants

Virtual power plants (VPPs) have emerged as a transformative solution in power system management, addressing challenges related to renewable energy integration, grid stability, and demand-side management. Initially conceptualized to aggregate small-scale distributed energy resources (DERs), VPPs now encompass diverse energy assets such as solar panels, wind turbines, battery storage systems, and demand response units. [4] Their development has been driven by the need for dynamic and flexible energy systems capable of optimizing grid management and enhancing sustainability.[4][5] An advancement in VPPs is the integration of vehicle-to-grid (V2G) technology, which allows electric vehicles (EVs) and truck batteries to supply power back to the grid. This bidirectional charging capability helps stabilizing power supply and reduce peak demand.[6] For instance, the U.S. has around 2.1 million battery electric vehicles, potentially providing up to 126 gigawatt-hours of storage capacity.[6] Current examples of VPPs include Sunrun in the U.S., which operates 16 VPP programs with over 20,000 households, and Next Kraftwerke in Germany, the largest VPP in Europe with 13.5 GW of capacity.[7] The global VPP market was valued at $3.42 billion in 2022 and is projected to grow at a compound annual growth rate (CAGR) of 22% from 2023 to 2030. [8]

4 Intermittency and the need for buffer storage

4.1 Intermittency

Intermittency in the context of renewable energy refers to the fluctuations in power generation due to the variable nature of renewable energy sources like solar and wind. These fluctuations occur because these sources are dependent on natural phenomena that are not constant.

4.2 Excess energy from renewables

Excess energy from renewables refers to the surplus electricity generated by renewable energy sources, such as solar and wind, that exceed the immediate demand of the power grid. This situation typically occurs during periods of high renewable energy production and low electricity consumption. As shown in Figure 4 for Germany, the gradual phase-out of nuclear energy and the increased feed-in of electricity from renewable sources are affecting load flows in the grid and mean that grid operators have to carry out redispatch measures more often than before. The unused excess energy in Germany has more than doubled between 2015 and 2023.

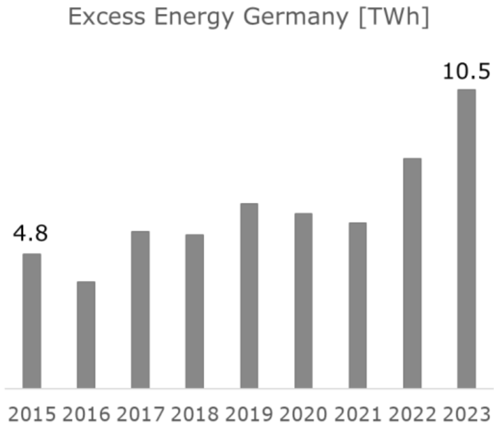

Figure 4 Excess Energy from Renewables in Germany [9]

4.3 Future trend

Overall, the increase in renewable energy production is leading to more frequent occurrences of excess energy. Effective management through advanced storage technologies and innovative grid solutions is essential to harness this surplus and ensure a stable energy supply.
In addition, increasing occurrences of negative wholesale prices in areas like Victoria, South Australia, southern California, and various European countries highlight the need for greater system flexibility. Negative prices can incentivize flexible supply and demand and storage solutions, but regulatory frameworks, market designs, and tariff structures are crucial for enhancing system flexibility.[10]

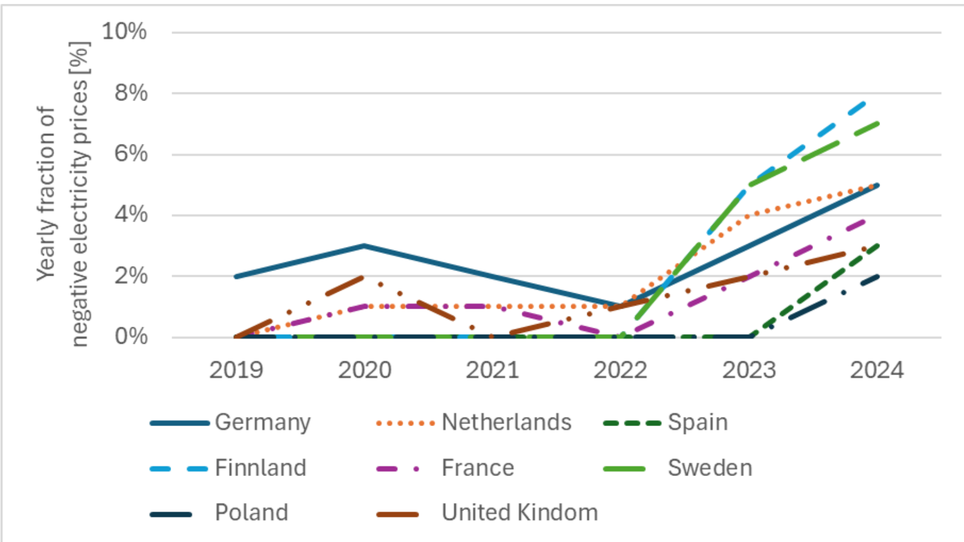

Figure 5 Fraction of negative hourly wholesale electricity prices in Europe, 2019-2024 [11]

4.4 Storage Systems

Based on the different types of intermittencies, the storage systems must be applied accordingly. This storage must be available not only throughout the day, but also throughout the seasons. According to a study by Dena [12] for the energy transition e.g. in Germany, storage of 30 TWh will be necessary in 2050.
The study emphasizes the importance of sector coupling, renewable energy expansion, and energy efficiency improvements to achieve climate targets. It outlines various scenarios and strategies for integrating renewable energy sources into the electricity, heating, and transportation sectors, highlighting the need for technological innovation, regulatory adjustments, and investment in infrastructure. The report also stresses the role of digitalization and smart grid technologies in enhancing system flexibility and reliability. Smart grid solutions in which battery electric vehicles, both passenger cars and commercial vehicles, not only charge on the grid but can also supply the electrical energy stored in their batteries back to the grid have to be considered.

As shown in Figure 6, the required storage capacity of 30TWh in 2050 is set in relation to existing and future storage options for Germany.

This assumption is reasonable if we consider that the expansion of the battery electric vehicle fleet is advancing in accordance with market penetration in passenger cars. If 30% of the battery capacity is allocated for grid balancing, this would result in a capacity of 140 GWh annually in 2050. The calculated number refers to passenger cars only. An uptake of battery electric trucks will further increase the available storage capacity.

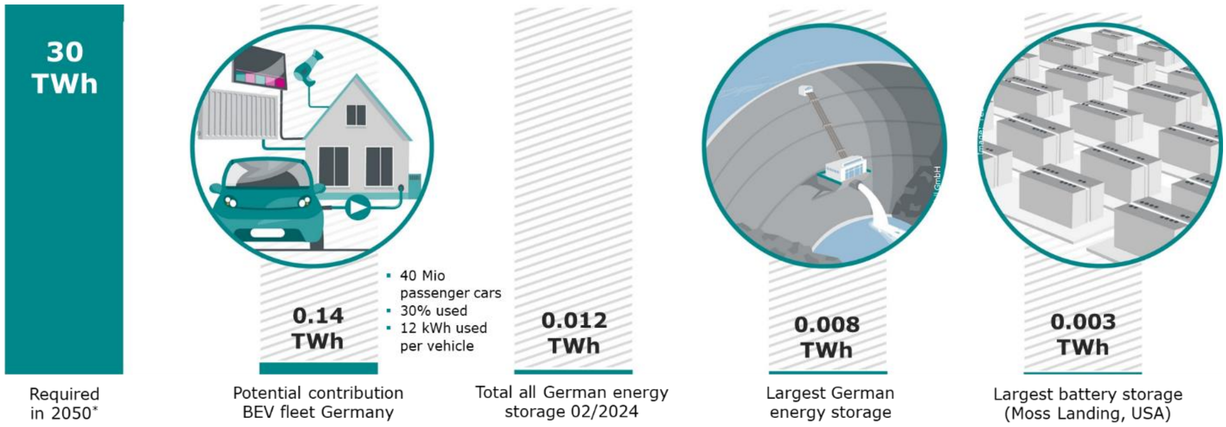

Figure 6 The major challenge energy storage - Scenarios 2050

4.5 Advantages of commercial trucks in a vehicle-to-x application

By 2040, bidirectional charging for trucks could save up to €22.2 billion annually, while also supplying substantial power during peak periods to aid grid stability. Additionally, trucks equipped with V2X can help nearly double the EU's solar PV capacity and reduce stationary battery storage needs by up to 92%. Truck operators could benefit from 4-52% savings on annual electricity bills, and the integration of V2X technology could lead to potential savings in grid expansion costs of €9.8 billion by 2040. Furthermore, bidirectional charging can extend truck battery life by up to 9%. These findings underscore the economic and environmental benefits of integrating V2X technology in electric trucks.[13]

5 Outlook: Bi-directional truck charging in the renewable energy system

Bidirectional charging, or vehicle-to-grid (V2G) technology, allows trucks to not only draw power from the grid but also return stored excess energy back to it. This capability can significantly reduce energy costs for logistics companies by enabling trucks to act as mobile energy storage units, providing power during peak demand periods and recharging during off-peak times.[14]

Key use cases include:

1. **Energy Cost Reduction**: By leveraging V2G, companies can lower their total cost of ownership (TCO) by selling stored energy back to the grid during high-demand periods, thus offsetting operational costs.
2. **Grid Stability**: Trucks can help stabilize the grid by supplying energy during peak loads, reducing the need for additional power plants and enhancing the integration of renewable energy sources.
3. **Emergency Power Supply**: In case of power outages, trucks equipped with V2G can provide critical backup power to facilities, ensuring continuity of operations.
4. **Optimized Fleet Management**: Intelligent fleet management systems can schedule charging and discharging cycles to maximize efficiency and minimize downtime, enhancing overall operational efficiency.

All of the aforementioned use cases can be implemented from a technological standpoint at this time. The primary responsibility of politics and the responsible national authorities will be to establish a set of regulations and remuneration incentives to facilitate the large-scale implementation of bidirectional charging.

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7 Presenter Biography

	**Benjamin Langer** is Head of Product Line E-Drive and Innovation Management at AVL, in Regensburg, Germany. Benjamin started his career in the renewable energy sector. He joined AVL in 2013. After several position he became team leader of charging and was responsible for on- and off-board charging systems and components. Together with his team and partners of the NEFTON research project he developed a MegaWatt Charging infrastructure system for BEV trucks. Since July 2022 Benjamin is responsible to drive innovation within AVL and developing AVL's electric driveline portfolio further. Benjamin holds a degree in electrical engineering.
	**Martin Rothbart** is Senior Product Manager for Energy and Sustainability for the Mobility engineering division of AVL, in Graz, Austria. Martin started his career in semiconductor manufacturing. He joined AVL in 2000 and has held several positions in the company. For more than six years, Martin is responsible for business development in the areas of energy, hydrogen, alternative and synthetic fuels as well as the sustainability in the product lifecycle. That includes predictions and the analysis of future market potential in various global regions. Martin holds a degree in automation technology and a MBA in economics from California State University, East Bay, USA.