Charging infrastructure for vehicle charging at 400 kW and beyond from a multiport refuelling hub similar to today's ICE fuel stations will reasonably require at least 1 MW of power conversion capability. A load of this magnitude is expected to require a primary voltage service from the electrical distribution infrastructure. While this could be served by onsite low-frequency transformers, this has been identified as an opportunity to investigate medium voltage connected power electronics. The following sections provide a summary of US Department of Energy (DOE) industry-led efforts which are developing designs for light-duty vehicle charging stations to deliver at least 1 MW of combined load or connect directly to medium voltage grid feeds.

SYSTEM ARCHITECTURES

Vehicle charging at power levels from 350 to 400 kW per vehicle at a refuelling hub with 4 to 12 charging ports would lead to a site design with a power conversion and grid capacity of between 1.4 and 4.8 MW. This calculation implies that the power conversion at all ports would occur at peak power at the same time; however, this might only be between 33% and 47% of the peak rating based on the charging profile and coincidence arrival times of the vehicles[1]. In consideration of the coincident peak power from all charging ports and a desire to include integration with local distributed energy resources (DER), such as photovoltaics or stationary electrochemical energy storage, leads to a design in which the required input power conversion from the grid can be lower than the sum of the charging ports. A similar power conversion architecture has resulted from these constraints in the DOE industry-led efforts as shown in Figure 1. This architecture includes an input solid-state transformer (SST) conversion from medium voltage AC at the grid to a common dc bus in which DC-DC converters for each vehicle charging port and the DER are connected.

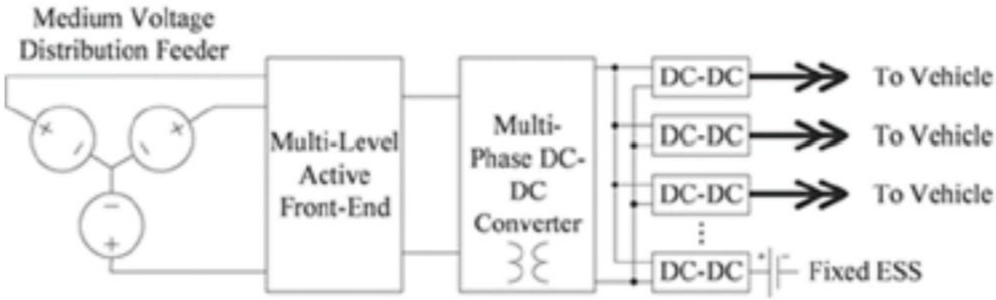

Figure 1 Block diagram schematic of an XFC refuelling plaza[2]

The SST portion of the system is the medium voltage input from the grid to the common DC bus that consists of three conversion stages in these systems. The stages (1) AC-DC conversion in the Active Front End (AFE), (2) a dual active bridge DC-DC primary-side stage and (3) secondary side stage with a high frequency transformer in between for galvanic isolation. These stages are configured in an input-series output-parallel approach to allow for the input ac grid voltage to be divided into a smaller voltage and lower power rating for conversion to a common output. This division allows for a modular approach in which the conversion hardware can be configured for all possible medium voltage inputs from 4.16kV up to 13.8V at scalable power conversion levels based on the site (or port count) requirements. The following table provides a comparison of the topology, switching devices, and voltage of each stage of the SSTs in the DOE industry-led efforts.

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[1] E. Ucer, I. Koyuncu, M. C. Kisacikoglu, M. Yavuz, A. Meintz and C. Rames, "Modeling and Analysis of a Fast Charging Station and Evaluation of Service Quality for Electric Vehicles," in IEEE Transactions on Transportation Electrification, vol. 5, no. 1, pp. 215-225, March 2019.

[2] Jonathan Kimball, 2019, "Enabling Extreme Fast Charging with Energy Storage" Vehicle Technologies Office Annual Merit Review, Washington DC.

Project	AC/DC (AFE)	DC/DC Primary	DC/DC Secondary
High-Efficiency, MV-Input, Solid-State-Transformer-Based 400-kW/1000V/400A Extreme Fast Charger for Electric Vehicles	Diode Neutral Point Clamped (DNPC) Full Bridge	Half Bridge	Full Bridge
	1.2 kV SiC MOSFET	1.2 kV SiC MOSFET	1.7 kV SiC MOSFET
	Input: 0.8 to 1 kV	2 kV	Output: 1 kV
Intelligent, Grid-Friendly, Modular Extreme Fast Charging System with Solid-State DC Protection	Neutral Point Clamped (NPC) Full Bridge	Neutral Point Clamped (NPC) Full Bridge	Full Bridge
	1.7 kV SiC MOSFET	1.7 kV SiC MOSFET	1.2 kV SiC MOSFET
	-	1.6 kV	Output: 0.75 kV
DC Conversion Equipment Connected to the Medium-Voltage Grid for XFC Utilizing Modular and Interoperable Architecture	Full Bridge	Full Bridge	Full Bridge
	-	-	-
	-	-	Output: 1 kV
Enabling Extreme Fast Charging with Energy Storage	Full Bridge	Full Bridge	Full Bridge
	-	-	-
	-	-	Output: 1.15 kV

SYSTEM PERFORMANCE

The medium voltage connected power electronics explored in these efforts is a new approach to XFC systems which would traditionally be served by an onsite low-frequency transformer stepping the voltage down to 480V. The primary benefits of this approach are the removal of bulky transformers and reductions in the associated AC wiring as the higher voltage allows for smaller conductor sizes. This high-frequency approach has been investigated and shows promise in reducing the volume, mass, efficiency, and equipment footprint as seen in Figure 2. The conventional system in the figure is composed from left to right with a transformer, AC switchboard, and the charging hardware. The proposed system is composed from left to right with a medium voltage fuse metering enclosure, switch gear, and the charging hardware.

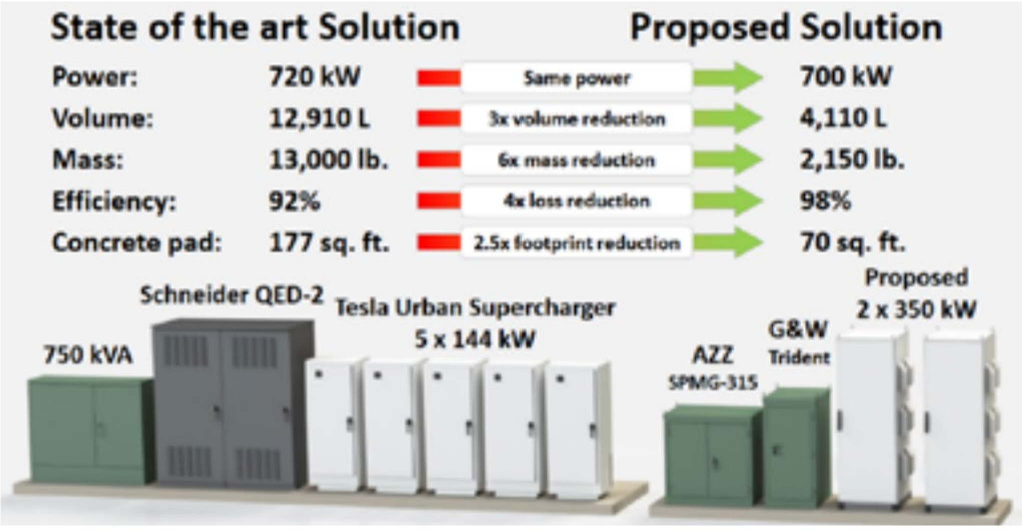

Figure 2 Benefits of Medium Voltage[3]

NEXT STEPS

Thus far, Task 37 has identified the following key challenges for the task to investigate critical barriers to the widespread deployment of extreme fast charging:

Medium-voltage power conversion equipment - Design of charging equipment that directly connects to the MV distribution may improve operating cost through more efficient power conversion and reduce capital costs by reducing the footprint of the installed equipment on the site.

Integrated charging sites - Charging sites that incorporate onsite generation and storage technologies may benefit from reduced electricity costs by shifting load. Development of these sites in conjunction with existing large load facilities may prove beneficial if controllable load, generation, and storage resources can be leveraged across the site.

Grid interaction and interconnection - Connection of highly dynamic large (>1 MW) non-linear load will require utility assessment and may require costly infrastructure improvements to ensure stable operation of the distribution system. A foundational understating of the grid integration of extreme fast chargers is needed to develop a harmonised interaction of the charging hardware and support rapid growth of extreme fast charging sites. The task is working to gain participation from other countries to further investigate and refine these objectives.

The task is working to gain participation from other countries to further investigate and refine these objectives. Future meetings and workshops will be scheduled with input from members.

[3] Srdjan Lukic, 2019, “Intelligent, grid-friendly, modular extreme fast charging system with solidstate DC protection” Vehicle Technologies Office Annual Merit Review, Washington DC