



Extreme Fast Charging: Challenges and Potential

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- High-Level Goals
- **Grid Support Functions**
- Power Conversion Topologies and Control
- Summary and Next Steps



Project Goals

Extreme Fast Charging of Electric Vehicles

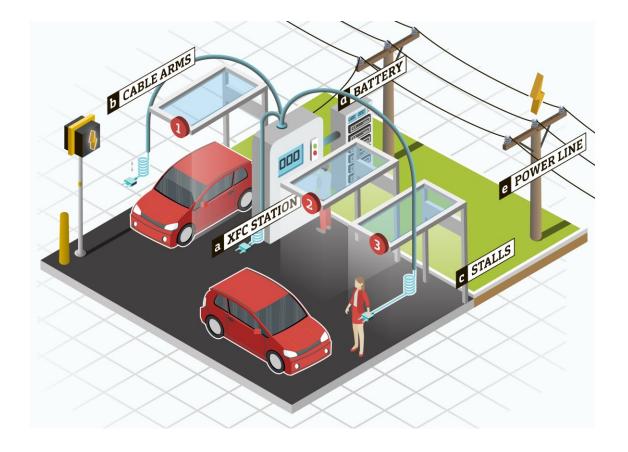
Achieve bulk charge in a time similar to refueling conventional vehicles

Peak Power Demand of 350 kW per charge port

Provide Grid Support Functions

Connect Directly to Medium-Voltage Feeder

Mitigate Battery Wear-out





Grid-Side Challenges

Intermittent nature and large-scale XFCS demand \rightarrow increased daily demand peaks, feeder overloading, increased power losses, and power quality issues in host power grids

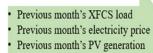
Overall operational cost minimization

- energy arbitrage
- reduction of demand charges cost
- feeding excess generation from PV to grid



Multi-Level Energy Management Framework

Timescales from milliseconds to months



Long-term forecast of XFCS load

Long-term forecast of energy price Electricity price of PV generation

Short-term forecast of XFCS load

Short-term forecast of PV gen.

Monthly Layer (ML): Computes Historical Demand Charge Threshold

Simulates the MILP model for a whole month using previous month's data
Outputs optimal average power imported from the grid which is used to get historical demand charge threshold (*DCT^{hist}*)



Upper Scheduling Layer (USL): Optimal Scheduling of Energy Resources

- Mixed integer linear programming (MILP) optimization model
- Bigger time step (15-mins) with longer horizon (24-hours ahead)
- Rolling horizon-based approach considering long-term forecast errors
- Exploitation of energy arbitrage opportunities
- · Consideration of demand charge reduction based on realistic utility tariffs

OCPEF

DCT^{cur}

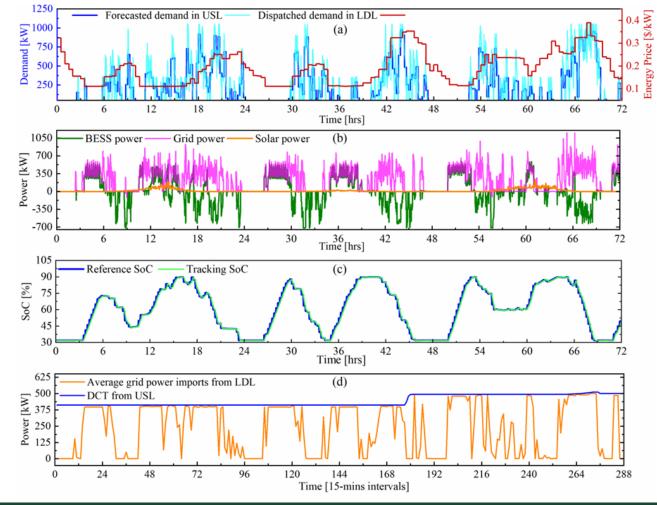
Comprehensive BESS degradation modeling

Updated SOC & P^{LDL} ava

Lower Dispatch Layer (LDL): Real-time Dispatch of Energy Resources

- Multi-objective model predictive control (MPC) approach
- Smaller time step (1-min) with shorter prediction horizon (15-mins ahead)
- Tracks the SOC_{REF} and sends latest SOC back to upper layer (USL)
- Keeps the average grid power imports (P_{ava}^{LDL}) less than the DCT^{curr}
- Send the latest P_{ava}^{LDL} , as a result of real-time operation, back to USL







Active and Reactive Power Management

Q-compensation \rightarrow to mitigate steady-state voltage violations

Deadband on voltage; enable outside of bounds, disable on change of sign of Q

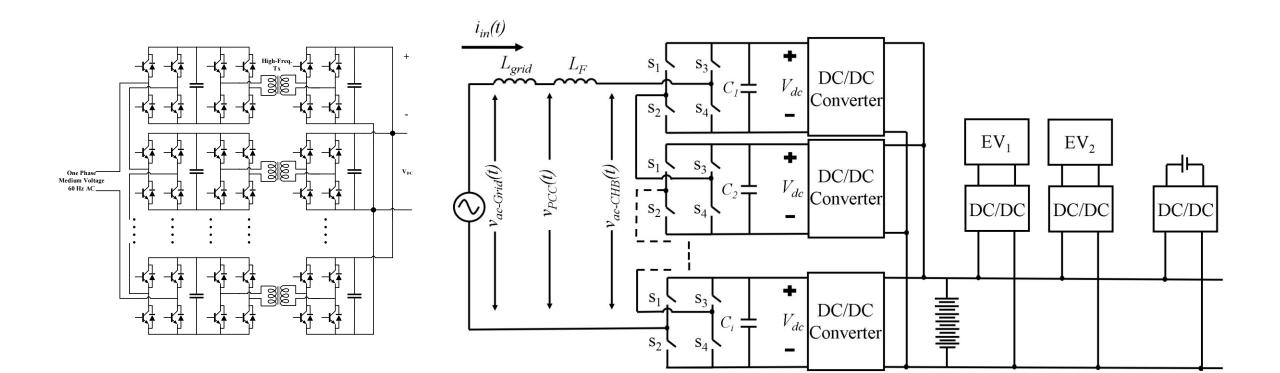
Power converter limits affect the active power imports from the grid \rightarrow ESS may function as a load-sharing device to provide supplemental power to satisfy EV demand

Power buffering of the ESS \rightarrow to buffer the power swings and mitigate the dynamic impact on the grid's power quality



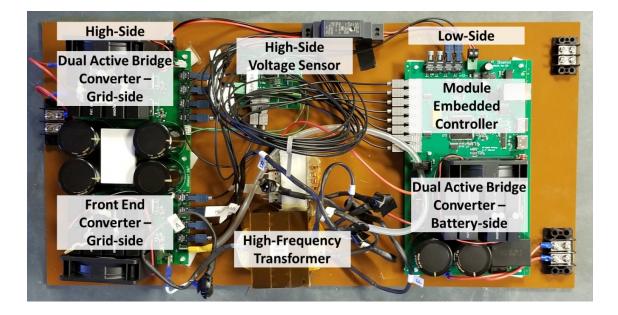
Power Conversion

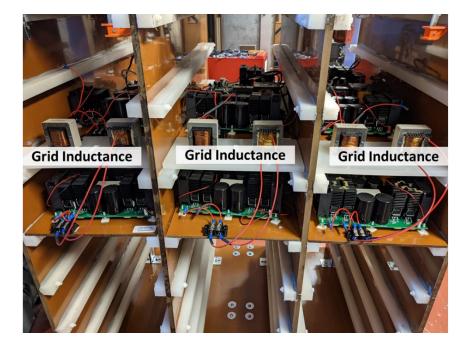
Goal: Connection to medium-voltage feeder (12.47 kV 3Φ)





Low-Voltage Prototype







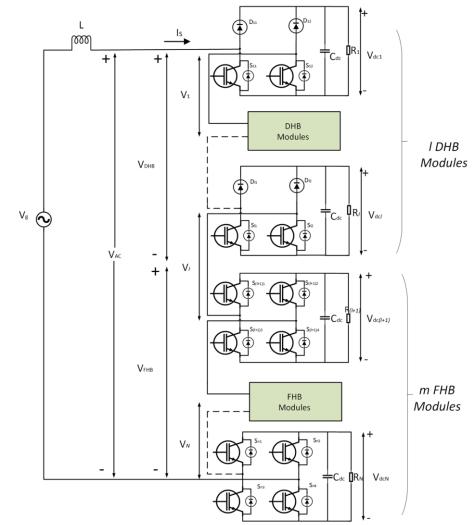
AFE Topology Option: Cascaded Bridgeless Multilevel Rectifier

Replace some full H-bridges with diode H-bridges

Fewer gate drivers and signals, so easier control

Limited range of Q; P > 0

Limits grid services that can be provided





DC-DC Topology Option: LLC

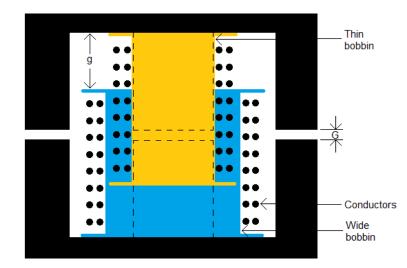
Or CLLLC for bidirectional power flow

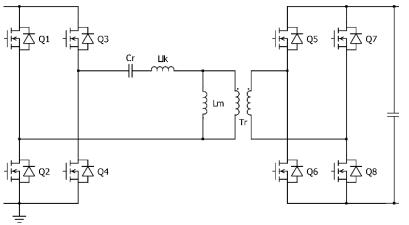
Resonant converters are controlled by frequency

Gain determined by inductances

Propose novel variable transformer to vary magnetizing & leakage

Introduce new hybrid 2D model for leakage inductance; also useful for any transformer where windings do not fill the window



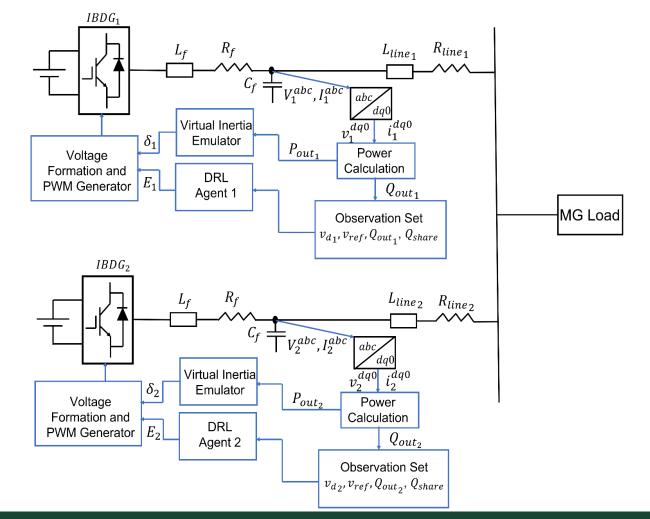




Virtual Synchronous Generator

Emulate exciter, inertia of a rotating generator

Use reinforcement learning to achieve accurate voltage regulation, frequency regulation, active power sharing, and reactive power sharing





Example Results

Voltage Regulation and Reactive Power Sharing

Droop vs. MADRL Load Change Scenario MADRL **Droop Based** 1.05 DG1 DG1 (IZ) 60.05 (Hz) 60 60 59.95 Erequency (Hz) 60 59.9 59.8 1.1 DG2 DG2 DG1 DG2 DG3 - - Upper Limit - - Lower Limit 1 Voltage Voltage DG1 DG2 DG3 - - Upper Limit - - Lower Limit 1.05 0 2 4 6 8 0.95 2 4 10 0 6 (i) (i) $\times 10^5$ Active Power (W) $\times 10^5$ Active Power (W) 0.9 0.9 7 7 5 6 4 5 5 4 6 Time Time **Droop Based** MADRL $\times 10^5$ $\times 10^{5}$ -DG2 -DG3 DG1 -DG1 ____ DG2 ___ DG3 4 2 8 0 4 -DG1 -DG1 0 2 8 10 6 4 6 (ii) (ii) Reactive Power Reactive Power DG2 DG2 DG1 DG2 DG3 - Percentage Error Limit -DG1 -DG2 -DG3 50 % Errors % Errors 50 10 0 4 6 2 \cap (iii) (iii) Time Time 7 7 5 3 4 5 6 4 6 Time Time



10

10

10



Summary and Next Steps

Effective integration requires a multi-timescale approach, from milliseconds to months

A variety of topologies provide a range of capabilities

- Cascaded H-bridge plus DAB is the most promising
- Medium-voltage challenges remain

Deep reinforcement learning can enhance coordination among multiple large power converters on the grid

More work is needed to scale up



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