DC Conversion Equipment
Connected to the Medium-Voltage Grid for Extreme Fast Charging
Utilizing Modular and Interoperable Architecture

DE-EE0008448

2018 DOE Vehicle Technologies Office Annual Merit Review Presentation

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EPRI

Project ID: elt 236

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Overview

Timeline
- Project start date: Oct 2018
- Project end date: Dec 2021
- Percent complete: <5%

Relevance to DOE Established Barrier
- Enabling Technologies - Establishing a foundational system for DC connected EV-charging that integrates with devices such as distributed energy resources, solar, wind and energy storage.

Budget
- Total project funding
  - DOE share: $2,601,500
  - Contractor share: $2,601,500
- Funding for FY 2017: n/a
- Funding for FY 2018: $0

Partners
- EPRI – Project Lead
- Eaton Corporation
- Tritium
- NREL
- ANL
Relevance

Overall Objective

- Develop and demonstrate medium voltage Silicone Carbide (SiC) -based AC-DC conversion equipment and the DC-to-DC head unit for use in extreme fast charging (XFC) equipment capable of simultaneously charging multiple light duty plug-in electric vehicles (PEV)s at rates of ≥350 kW and a combined power level of ≥1 MW while minimizing the impact on the grid and operational costs.

Relevance to DOE’s Grid and Charging Infrastructure Program Goals

- Extreme Fast Charging – Develops and tests Direct Current technologies for Extreme Fast Charging while minimizing impacts to the grid. Research could be serve to identify opportunities for interoperability and technical transfer activities.
- EV Grid Integration and Services – Direct Current technologies could facilitate the integration of distributed energy resource to minimize the impact on the grid.

Potential Impacts (project will investigate these aspects)

- Reduce the Total Cost of Ownership (including Demand Charges) for XFC site hosts and utilities
- Improve efficiency and reduce losses
- Reduce footprint of equipment
- Provide a single point of grid integration for distributed energy resources
- Provide new capabilities for grid integration (power factor correction, VAR compensation, disturbance isolation, …)
- Optimization of equipment sizing for upstream power supplies that serve XFC equipment
Milestones

Budget Period 1
Oct 1, 2018 – Dec 31, 2019

0.0 Project Management

1.0 XFC Converters and System Design
Converter Design Parameters Finalized
DC Load Center Design Complete

2.0 Medium Voltage AC-to-DC Converter Development
Module Performance Characteristics Documented
Transformer Design Specifications Documented
Module Prototype Tested

3.0 XFC Head Unit DC-to-DC Development
XFC Head Unit Design Complete

4.0 System Testing at NREL
Full Prototype Tested Setup

5.0 Demonstration Site Development
Interconnection Studies Complete
Demonstration Site In-Service
Demonstration Complete

Budget Period 2
Jan 1, 2020 – Dec 31, 2020

Budget Period 3
Jan 1, 2021 – Dec 31, 2021
Approach

Project Teaming Strategy

- **Power Electronics** - System specifications determined collaboratively, while the development of the two major power electronics pieces are designed by suppliers focused on the two different businesses
  - Eaton is leading the work on the Medium Voltage AC to DC converters
  - Tritium is leading the work on the DC to DC converters

- **Testing** - Three levels of testing included in project
  - Component level testing and end-of-line production testing performed by respective manufacturer
  - System testing to occur at NREL laboratory with simulated and actual vehicles
  - Demonstration site testing in collaboration with host utility with actual vehicles

- **Vehicles** - Supporting automakers (Hyundai America Technical Center and Fiat Chrysler Automobiles) are included in project to support testing. If vehicles capable of charging at 350kW and above are unavailable for testing from supporting automakers, EPRI will identify and obtain vehicles from other vehicle manufacturers.

- **Demonstration Site** - EPRI has more than three supporting utilities interested in hosting the demonstration site. The decision on the actual demonstration site will be based on specific site characteristics identified by the utilities, anticipated vehicle charging to occur at site and the site development budget.

Unique Aspects of Work (beyond the barriers described in “Relevance” slide #3)

- **Pathway to Commercialization** - Seeking to develop equipment, standards and techniques that exhibit possible pathways to commercialization
- **Interoperability** – Seeking to develop system that is capable of operating with power conversion equipment and head end units from multiple manufacturers
- **Technology Transfer** – EPRI will be collaborating with industry participants throughout the project process
- **Diverse Project Team** - Project partners from various perspectives (utilities, hardware manufactures, automotive manufacturers, national laboratories,
Technical Design – System Level

* Key system design considerations currently under review

- The number and sizing of the Medium Voltage AC/DC converters to achieve ≥1MW
- The DC Load Center design will be based on vehicle-to-vehicle galvanic isolation requirements (single bus, switchable links, or novel protection system)
- The full project team meets on May 15th through 17th to discuss these system design issues
Technical Design – During Proposal Stage

A system of isolated and non-isolated converters is proposed to reduce size, cost and increase efficiency (Option 1 below)

<table>
<thead>
<tr>
<th>Option</th>
<th>Medium Voltage AC-to-DC Converter</th>
<th>Head End Unit</th>
<th>DC Distribution</th>
<th>Impact on Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>• 1,000 V • Isolated converter</td>
<td>• Non-isolated converters • Voltage regulated for vehicle (200 to 1,000 V)</td>
<td>• Common Bus, if code allows • Switchable links for galvanic isolation • Common Bus with novel protection system for galvanic isolation</td>
<td>• Special controls and/or switches required for interoperability, microgrid and multi-use applications if required for galvanic isolation • Cost, size and efficiency advantages</td>
</tr>
<tr>
<td>Option 2</td>
<td>• 1,000 V • Isolated converter</td>
<td>• Isolated converters • Voltage regulated for vehicle (200 to 1,000 V)</td>
<td>• Common Bus</td>
<td>• Good interoperability, microgrid and multi-use applications • Cost, size and efficiency disadvantages</td>
</tr>
<tr>
<td>Option 3</td>
<td>• Voltage regulated for vehicle (200 to 1,000 V) • Isolated converter</td>
<td>• No converter required</td>
<td>• Switchable links only</td>
<td>• Limited interoperability, microgrid and multi-use applications • Cost, size and efficiency advantages</td>
</tr>
</tbody>
</table>
Responses to Previous Year Reviewers’ Comments

- This is a new project, therefore it was not reviewed last year
Collaboration and Coordination with Other Institutions

**Project Team**
- **Prime** – Leading DC load center design, DC microgrid controls and demonstration site development
- **Subrecipient** – Leading Medium voltage AC to DC converter design and production
- **Subrecipient** – Leading head unit DC to DC converter design and production
- **Subrecipient** – Leading laboratory testing of XFC system
- **Subrecipient** – Leading DC metering activities

**Key Utility Collaborators**
- **DUKE ENERGY**
- **Seattle City Light**
- **nationalgrid**
- **PGE**
- **Southern California Edison**
- **HYUNDAI MOTOR GROUP**
- **FCA**

**Other Collaborators**
Industry Collaboration

EPRI is collaborating with utilities and other organizations to grow industry engagement

Infrastructure Working Council (IWC)

- Industry dissemination of project activities will occur at each of the regular IWC meetings (3 times/year)
- Discussion of related projects and feedback will be sought from participants

Bus and Truck Working Council

- Industry dissemination of project activities will occur at each of the regular IWC meetings (3 times/year)
- Discussion of related projects and feedback will be sought from participants

Project with Supporting Utility Members

- Collaborative process to document technical requirements, utility interconnection requirements and identify recommended standards and gaps
- Study of the economic implications of DC based system
Proposed Future Research

May 15th to 17th project technical kick-off meeting at NREL’s facility, topics include:

- System architecture, focusing on galvanic isolation strategies and other system level considerations
- AC design requirements and utility distribution engineering input
- DC design requirements and DC load center approaches
- Schedule, Risk Management and other coordination processes
- Testing plans

Key Decision Points

Decisions related to galvanic isolation will guide the project’s development pathway. The project team has a workable approach, but will be considering alternatives prior to pursuing additional development activities.

Decisions related to the converter topology, semiconductor choice and medium / high frequency transformer will be evaluated during the simulations. Decisions will be pursued that balance the objectives of the project with the technology readiness of the these components.

Both of these decisions will be documented.

FY 2019 Proposed work

1.0 XFC Converters and System Design
- Finalize system sizing and key component design parameters
- Determine galvanic isolation needs and establish approaches to address
- Document utility requirements for medium voltage connected equipment

2.0 Medium Voltage AC-to-DC Converter Development
- Perform designs and simulations for converter modules
- Study controls and protection for power electronics converters
- Evaluate medium / high frequency transformer alternatives

3.0 XFC Head Unit DC-to-DC Development
- Develop design for DC-to-DC head unit using non-isolated converters
- Evaluate approaches to address galvanic isolation needs
Summary

- Key technical decisions for the project will be made during FY 2019.
- Technology transfer objectives will be a driving objective of the project.
- The application of medium voltage connected DC conversion equipment may also be useful for other electric vehicle DC fast charging power levels and for integration of distributed energy resources.
- The use of distinct power strings may be required for sites that use more than ~3 MW.
Technical Back-Up Slides
## Electrical Requirements For Charging at an Electric Bus Depot

### Pilot Project Experience

<table>
<thead>
<tr>
<th>Charging Characteristics at Sites</th>
<th>50 – 500 kW, less than 10 ports</th>
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<tbody>
<tr>
<td>Site Load</td>
<td>&lt; 2.5 MW</td>
</tr>
<tr>
<td>On-Site Power Distribution</td>
<td>• 480 V 3Ø</td>
</tr>
<tr>
<td></td>
<td>• Single Bus Configuration</td>
</tr>
<tr>
<td>Utility Service</td>
<td>• Secondary metered service</td>
</tr>
<tr>
<td></td>
<td>• Typically able to connect to 11kV and above distribution feeders if circuit is near site</td>
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### Projects Beyond Pilots

<table>
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<th>50 – 500 kW+, 100 ports or more</th>
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<tr>
<td>&gt; 10 MW</td>
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<tr>
<td>• Multiple power strings</td>
</tr>
<tr>
<td>• 480 V 3Ø AC or 1,000 V DC</td>
</tr>
<tr>
<td>• Multiple distribution feeders may be required or a new substation</td>
</tr>
<tr>
<td>• DC as-a-Service potential</td>
</tr>
<tr>
<td>• Opportunity for new system integration strategies (reliability, efficiency, space, cost savings, grid integration, …)</td>
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AC and DC Approaches for DC Fast Charging

AC
- Distribution Feeder(s)
- Medium Voltage Switchgear (if required)
- AC Power Transformer(s)
- Low Voltage Load Center(s)
- AC to DC Conversion
- Charging Ports / Dispensers

DC
- Distribution Feeder(s)
- Medium Voltage Switchgear (if required)
- AC to DC Converter(s)
- Low Voltage Load Center(s)
- DC to DC
- Charging Ports / Dispensers

• Smaller
• More Efficient
• Increased Functionality
• Capable of connecting to storage and other DERs with simple DC to DC converters
• Smaller
• More Efficient
• Less Expensive

Common Point of Utility Demarcation for < 2.5 MW Service

* Point of Utility Demarcation for Primary Service