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

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2021 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: July 2022
- Percent complete: 55%
- Budget Period in Progress: Second 08/01/20 – 07/31/2021

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 2021: $560,898

Partners

- EPRI – Project Lead
- Eaton Corporation
- Tritium
- NREL
- ANL
- North Carolina State University

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.

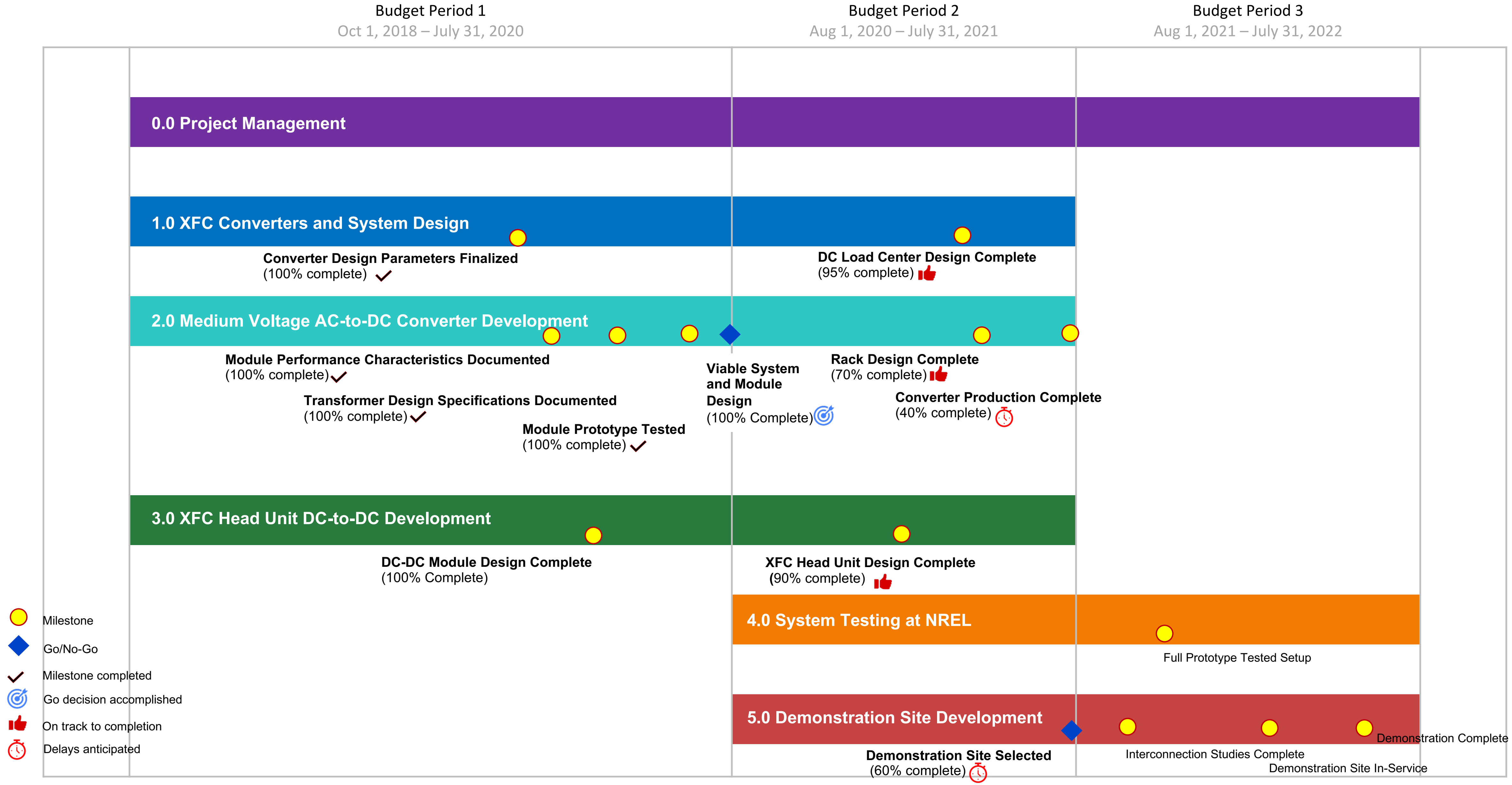
Relevance to DOE's Grid and Charging Infrastructure Program Goals

- 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 & Completion Status



Any proposed future work is subject to change based on funding levels

Approach

<u>Project Teaming Strategy</u>

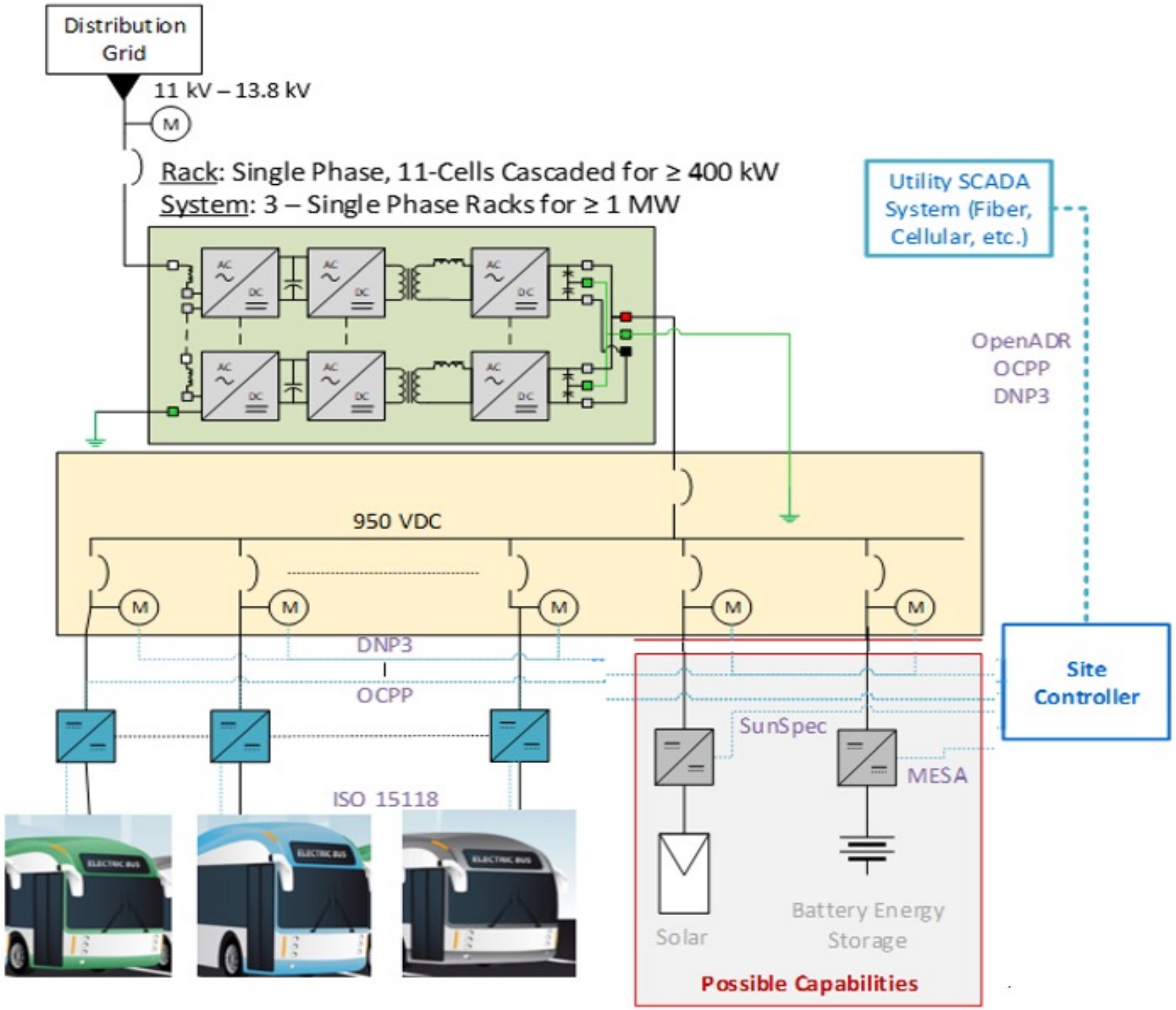
- Power Electronics - System specifications determined collaboratively, while the development of the two major power electronics pieces are designed by suppliers focused on the two different businesses
  - Eaton is leading the work on the Medium Voltage AC to DC converters
  - Tritium is leading the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

Approach
Target Design & System Level Capabilities

Core Components of Project
Utility Interface
Medium Voltage Converter (Solid State Transformer)
DC Load Center (~1000 VDC)
Head-End Units (Isolated 350kW)
Testing with XFC Capable Vehicles (Light-Duty and/or Medium/Heavy Duty)



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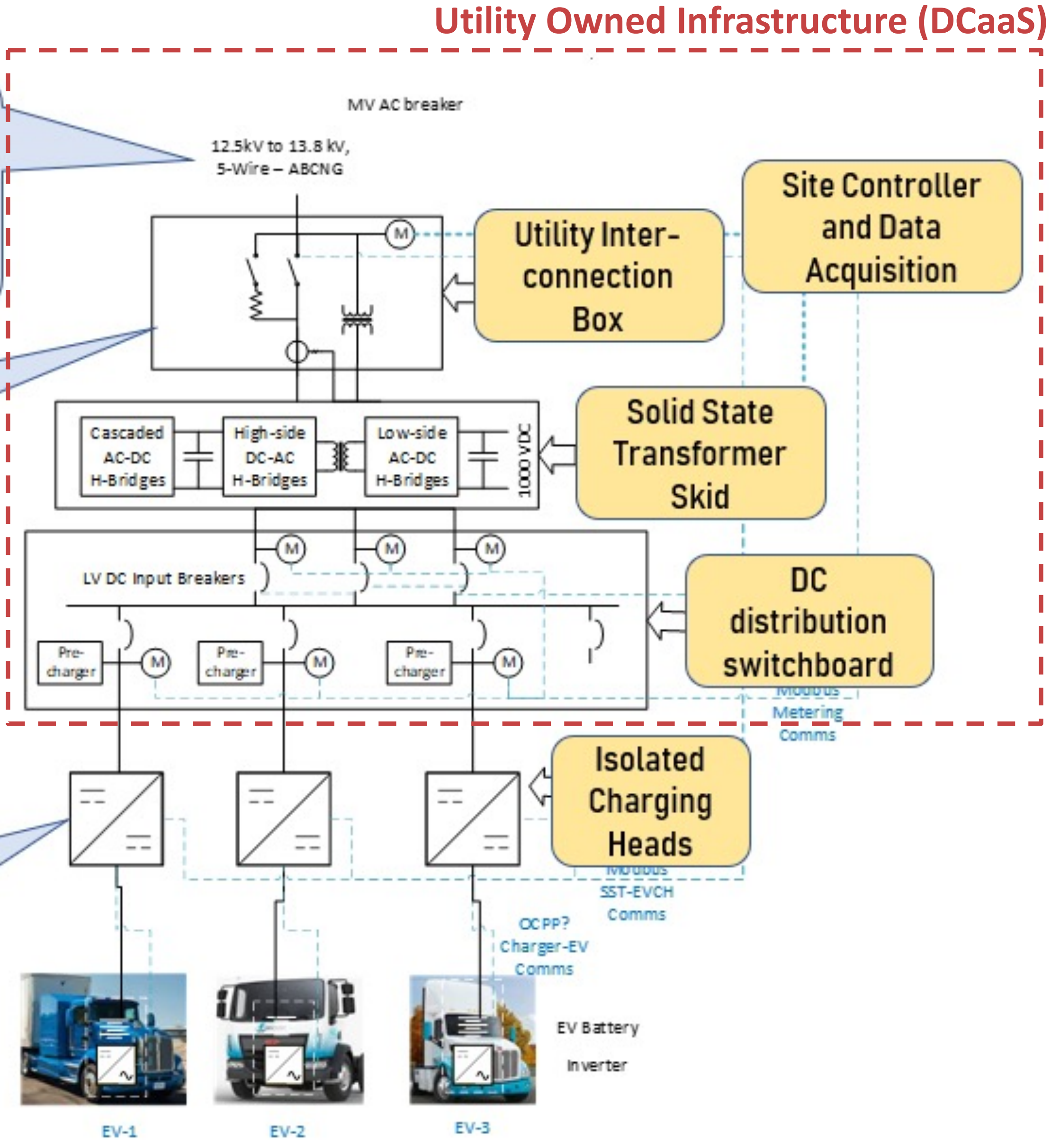
Approach: 1MVA+ System for Onsite Installation

Utility interconnection:
1. Voltage range
2. Upstream breaker size and settings
3. Adjacent loads and variation of voltage
4. ....

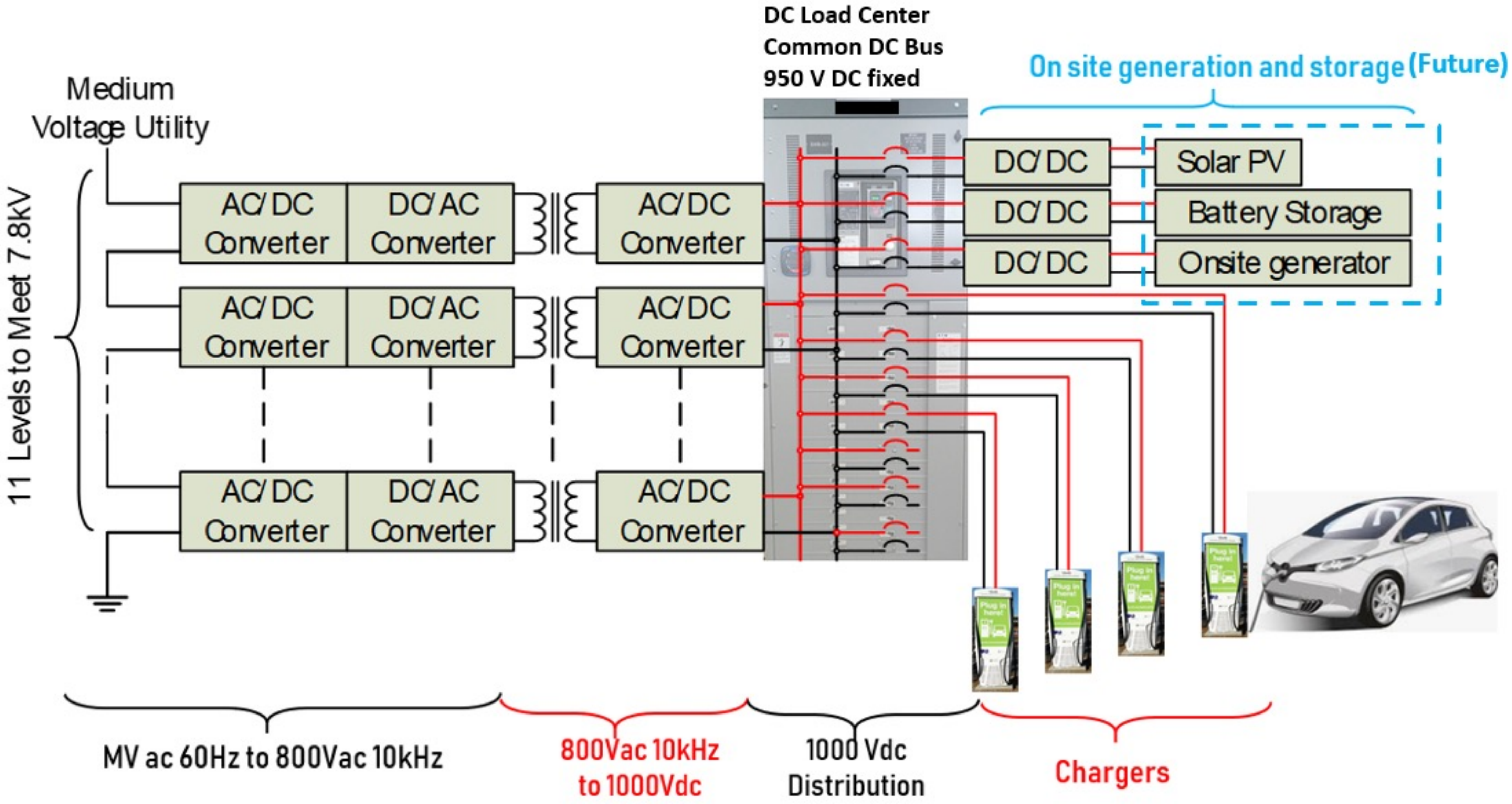
Utility interconnection:
1. Who installs
2. MV line enter from the bottom
3. Elbow type acceptable
4. Any standards to meet
5. Safe operating procedure limitations

DC distribution and charger installation:
1. Breaker panel distance from SST
2. Number of chargers and size
3. ....



Technical Accomplishments & Progress

Novel MV AC to 1000 V XFC Technology

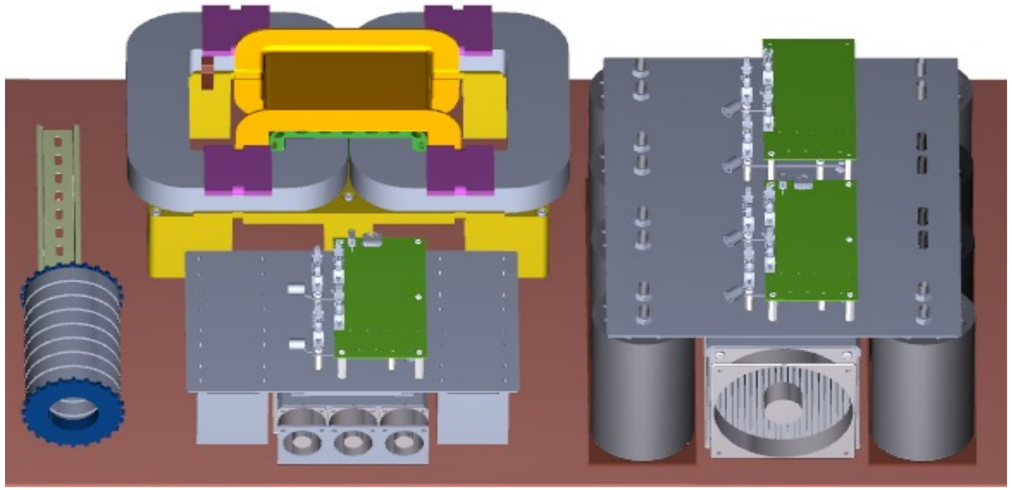


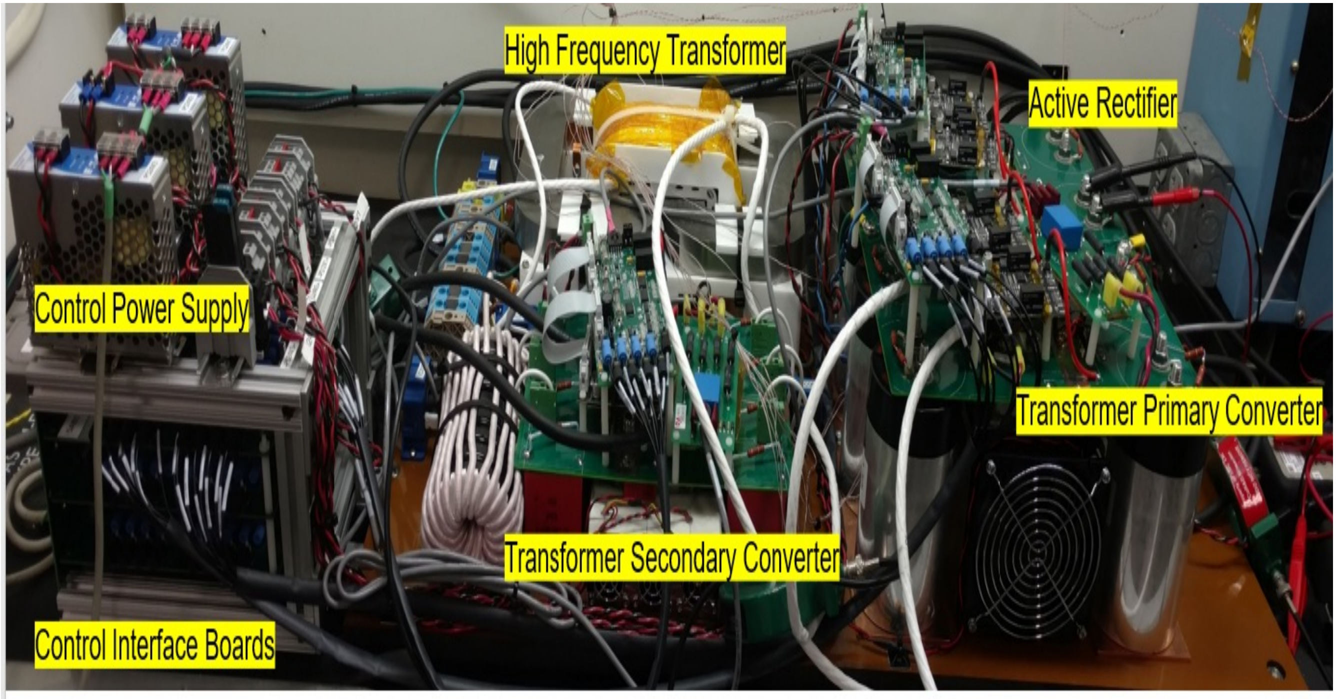
ELECTRIC POWER RESEARCH INSTITUTE

Medium Voltage Converter Topology

- Medium Voltage Converter Rack: will be composed of multiple cells for a power rating ≥400kW
  - Eleven cells will be configured in a single-phase cascade design to bridge the 7.6 / 13.2 kV utility connection
  - Each cell has a power rating of 40kW
  - The cells will be connected in parallel on the DC side of the converter
- Medium Voltage Converter System: composed of three single phase racks for a combined power rating ≥1MW
- Status:
  - Prototype power cells tested
  - Rack design complete
  - Assembly of converter modules in progress

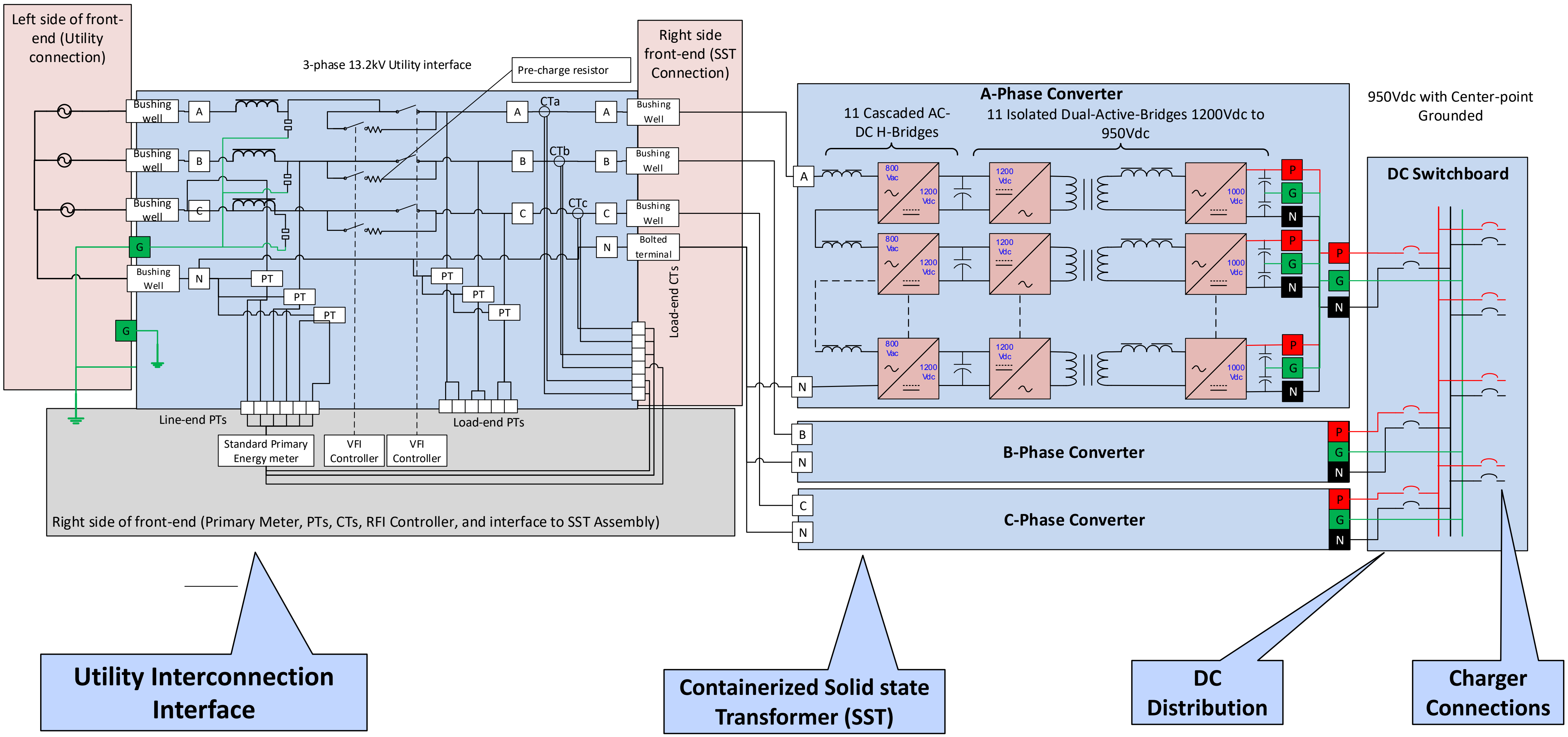
CAD model of a single cell



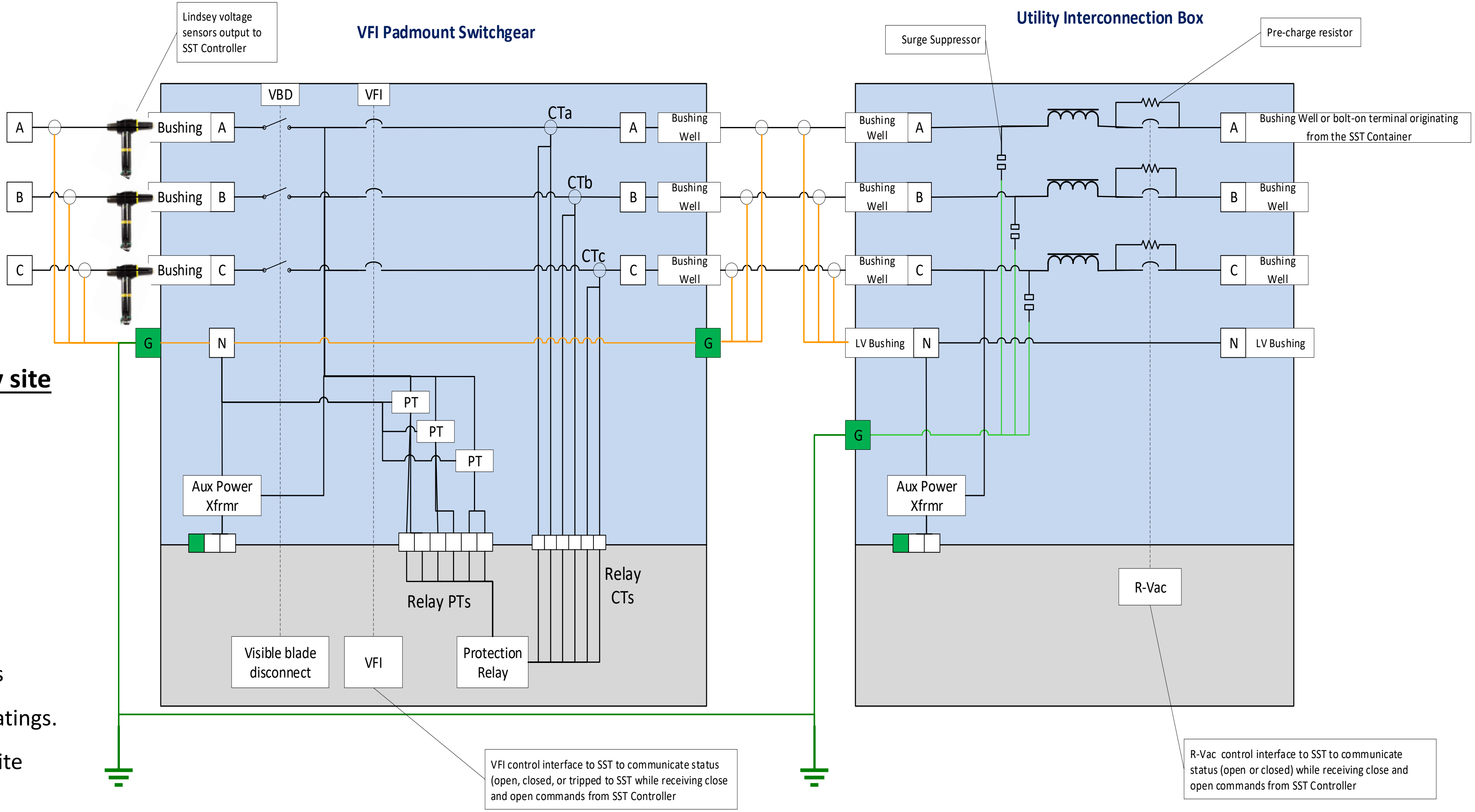


Eaton Single Power Cell Prototype

MV to 1000V DC XFC System: Conversion Stages



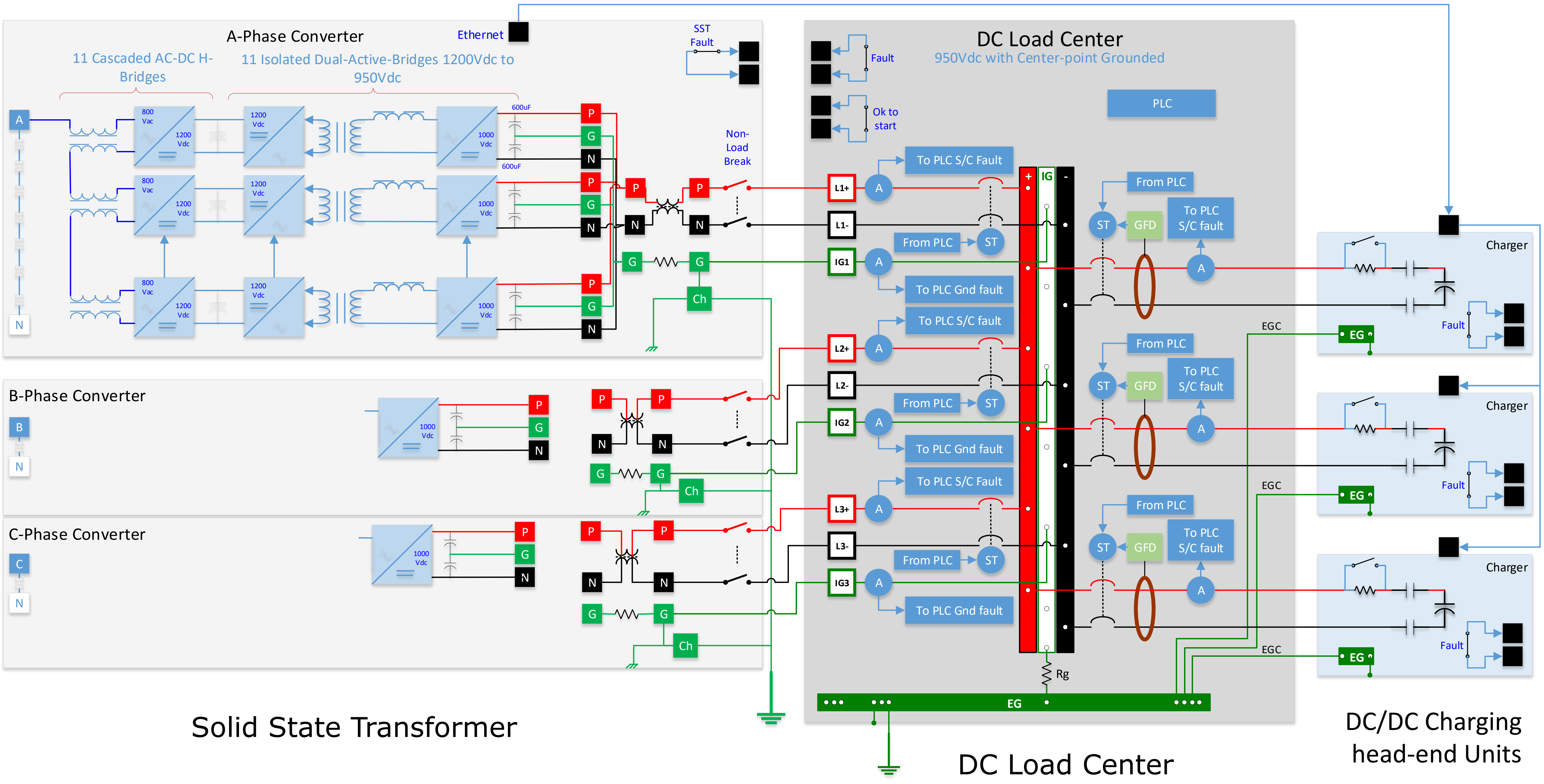
Utility Interconnection Interface



Design requirements driven by site

- Primary-fed electric service requirements (ESR)
- Bushing well details
- Grounding conductor sizing
- Neutral conductor size
- Meter requirements
- Ground and neutral terminal sizes
- Site fault current to address VFI ratings.
- VFI protection requirements for site controls
- Any restrictions on connections to the SST

DC Load Center Design



DC Load Center: Build Spec. and Construction

Performance Specifications

- Nominal 950Vdc, steady-state output within 940Vdc to 960Vdc, 10V/s slew under load
- Center grounded output, ±475V with respect to Earth, for a “950V” DC bus
- Ripple max ±20V for 0 – 400Hz, preferable at ±10V
- Dynamic regulation, overcurrent protection, precharging, discharge, y-capacitance and leakage requirements defined
- PLC-based operation and coordination

Construction Considerations

- Utilize commercially available / commodity wiring with insulation below 600V
- Power electronics with protection settings/configuration leveraged to support protection coordination
- Use commercially available components: fusing/contactors, breakers, DC metering shunts, ground fault, short circuit protection, shunt-signal converters, voltage sensors, relays and PLC.

Technical Accomplishments and Progress

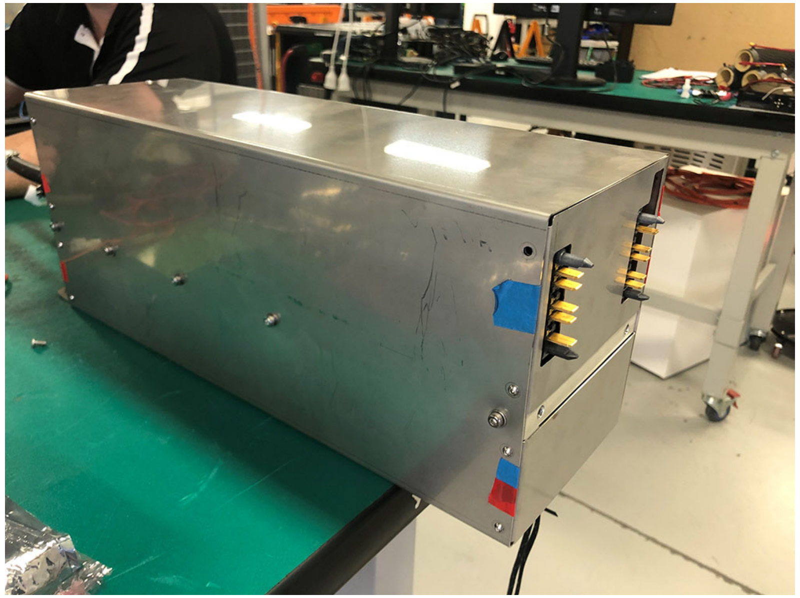
Head-End Unit

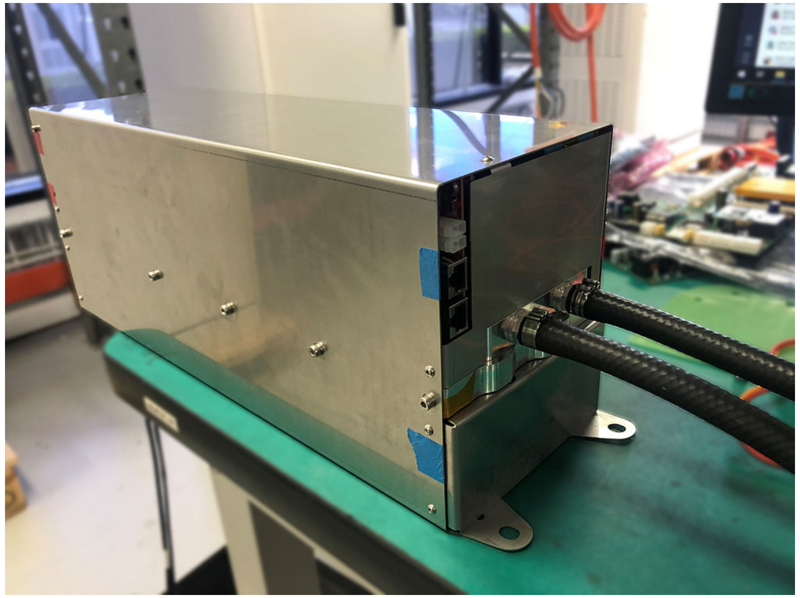
Head-End Unit Will Now Utilize an Isolated Converter

- Project shift to DC distribution requires isolated DC-to-DC Head-End unit to be developed and beyond original project scope
  - Previously, the Head-End unit was to be a modification of Tritium's existing 350kW non-isolated head unit with a switched matrix DC distribution
- Tritium's updated project scope, with new isolated DC-to-DC power electronics modules, not expected to impact project schedule

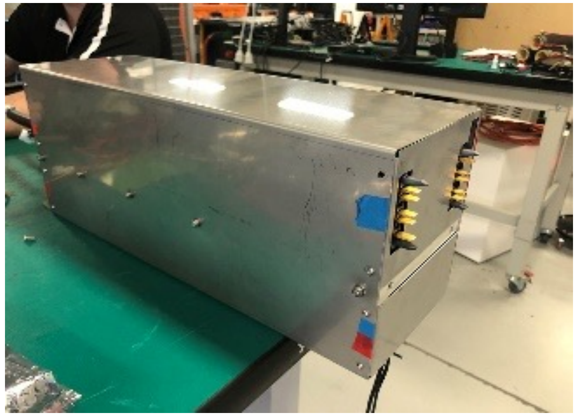
Status of New Isolated Modules for Head-End Converter

- Tritium has now completed development on a 25kW isolated DC-to-DC module, and has validated this design in extensive in-house laboratory testing, including with multiple modules running synchronised and in parallel, eliminating this large technical risk from the overall project
- 14 cells connected in parallel to achieve 350kW
- Prototype liquid-cooled, isolated, 25kW modules, shown below, are approximately 200mm x 150 mm x 400mm

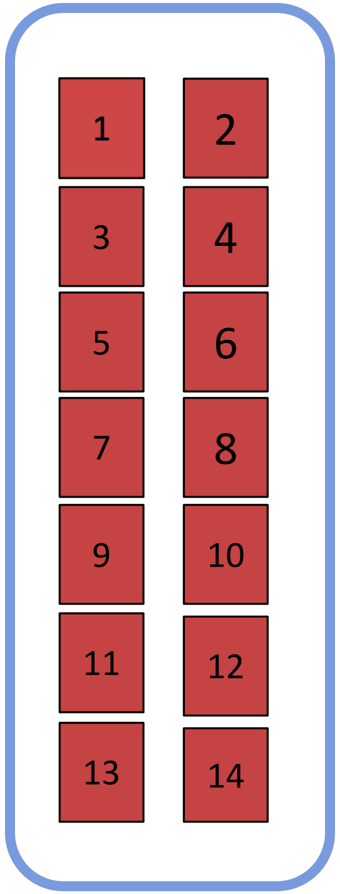




350-kW DC/DC Charger



Single 25 kW module



14, 25 kW modules stacked together

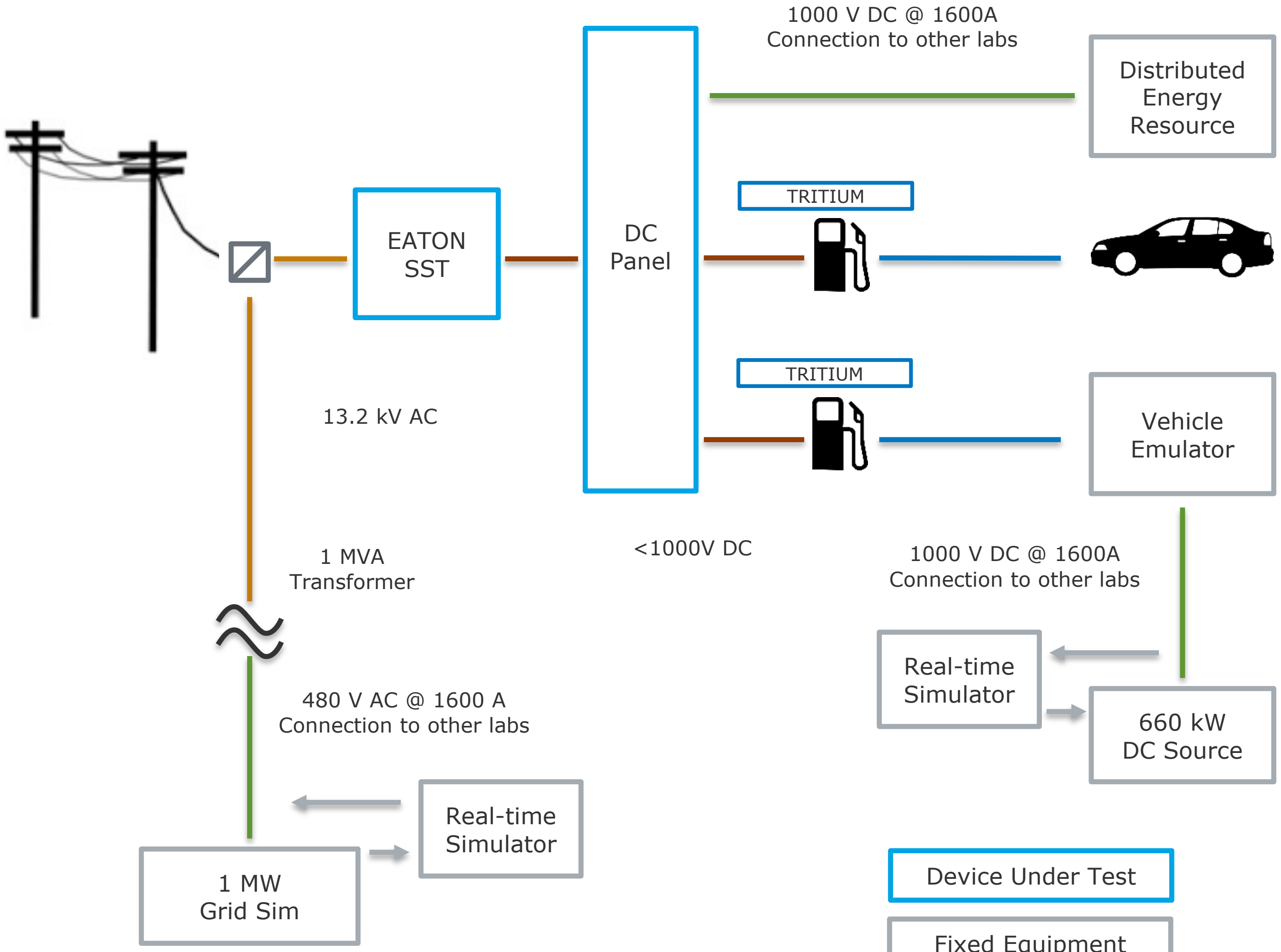
Tritium DC/DC 350 kW Charging Head

Comprehensive System Testing at NREL

Charging system tested with simultaneous electric bus charging each upto 350 kW, total of > 1MW.

Comprehensive testing before deployment at the utility demonstration site.

- System Performance
  - XFC vehicle charging
  - Conversion efficiency
- IEEE 1547 Interconnection
  - Voltage ramps /steps
  - Frequency ramps/ steps
  - Power quality
- IEEE 519 Harmonics
  - Voltage / Current harmonics
- SAE J2894
  - Power Quality
- IEEE 1668-2017
  - Voltage Sag and Short Interruption Ride-Through Testing for End-Use Electrical Equipment Rated Less than 1000 V



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Demonstration Site Selection

Considerations

- Two sites are currently under consideration, from the listed utility collaborators involved in the project
- At one of the potential sites, long lead time construction to accept this equipment is already complete
- Both potential demonstration sites also include vehicle collaborators
- The potential demonstration sites serve different vehicle classes, from light-duty, bus, heavy-duty truck or a combination of vehicle classes

Process

- Project team to complete selection of demonstration site(s) in Budget Period 2
- A variety of factors will go into the final decision of demonstration site(s) including; utility distribution connection considerations, level of utility support, availability of XFC compatible vehicles at the site, construction costs, budget and other factors
- A go / no-go decision will occur at the end of Budget Period 2 based on completion of the demonstration site(s) selection process

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Responses to Previous Year Reviewers' Comments

- *Virtual event, no comments received*

Collaboration and Coordination with Other Institutions

Project Team

EPRI – Electric Power Research Institute	Prime – Leading DC load center design, DC microgrid controls and demonstration site development
EATON – Powering Business Worldwide	Subrecipient – Leading Medium voltage AC to DC converter design and production
TRITIUM	Subrecipient – Leading head unit DC to DC converter design and production
NREL – National Renewable Energy Laboratory	Subrecipient – Leading laboratory testing of XFC system
Argonne National Laboratory	Subrecipient – Leading DC metering activities

Key Utility Collaborators

- Duke Energy
- Southern California Edison – An Edison International® Company
- Portland General Electric
- Southern Company
- Seattle City Light

University Collaborator

- NC State University

Other Collaborative Activities

- EPRI's Infrastructure Working Council
- US DRIVE
- DOE multi-lab Multi-port 1 + MW Charging System for Medium- and Heavy-duty Electric Vehicles effort
- California's Electric Program Investment Charge Program

Remaining Challenges and Barriers

The project team has identified certain challenges going forward that will be closely monitored with mitigation plans for key challenges

Technology

- y-capacitance issues may be problematic for stable operations, protection and safety of system (Low probability, Medium Impact)
- Unexpected problems may be discovered during testing at NREL's laboratory (Medium probability, Medium Impact)

Technology Transfer

- Lack of consensus of interoperability approaches, common understanding of DC topologies, equipment options and communications systems for the DC bus (Medium probability, Low Impact)
- Implementation of communication protocols. Which ones are appropriate, which ones are implemented vs standard being defined (Medium probability, Low Impact)

Other

- COVID-19 related impacts on supply chain, key resources, shipping or organizations (Medium probability, Medium Impact)

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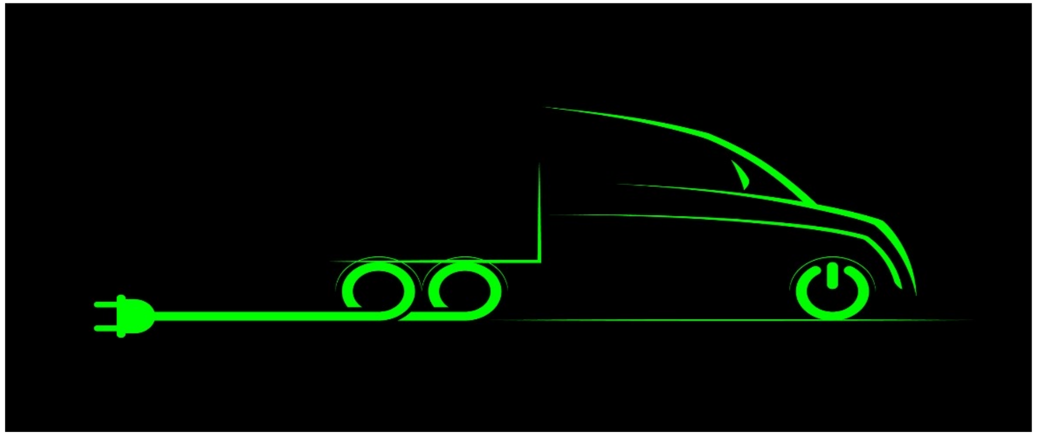
Proposed Future Research

FY 2021 Work

- 1.0 XFC Converters and System Design
  - DC metering
- 2.0 Medium Voltage AC-to-DC Converter Development
  - Procure components and produce converters
- 3.0 XFC Head Unit DC-to-DC Development
  - Procure components and produce converters
- 4.0 System Testing at NREL
  - Conduct system performance and efficiency tests
  - Conduct grid integration tests
  - Conduct testing with XFC capable vehicles
- 5.0 Demonstration Site Development
  - Site planning and interconnection studies
  - Prepare site civil/engineering works



Research Opportunities: Beyond Current Project Objectives

- Additional integration testing of DC microgrid with medium voltage converters
- Testing of hybrid plants within a DC microgrid
- Dynamic response of multi-level converters to unexpected system conditions
- Failure mode analysis, response to blackstart, shut-down, and other low probability / high impact events
- Reliability and resiliency monitoring of the DC infrastructure
- DC distribution for fleet EV charging

Any proposed future work is subject to change based on funding levels

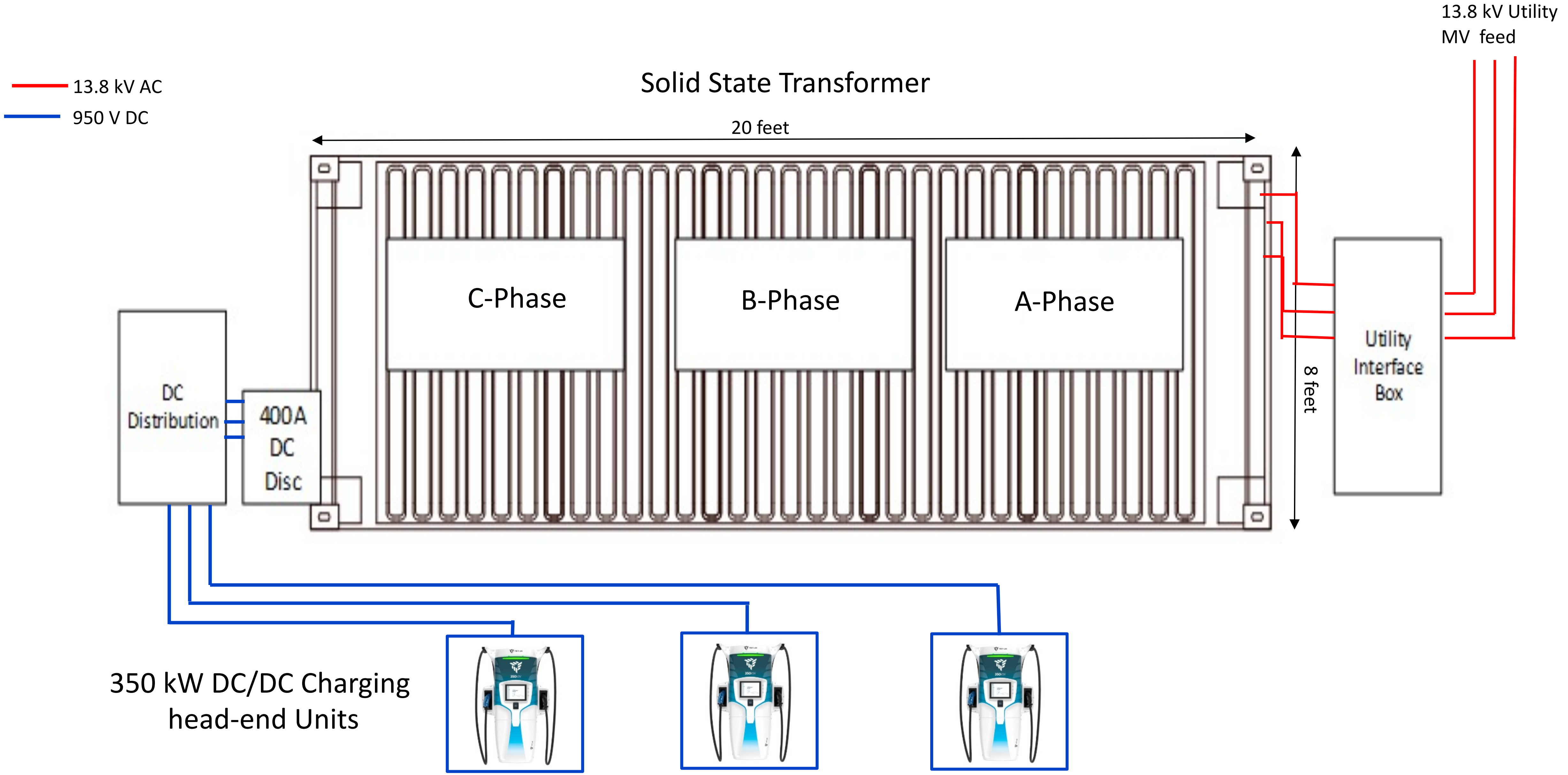
Summary

- Prototypes of the power cells in the Medium Voltage Converter and modules in the Head-End Unit are under testing
- High level interest in DC distribution for DC fast charging exists within the utility industry and with other organizations associated with vehicle electrification
- DC distribution has promising opportunities to support fleet electrification needs
- 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, especially if it’s able to reduce infrastructure space requirements

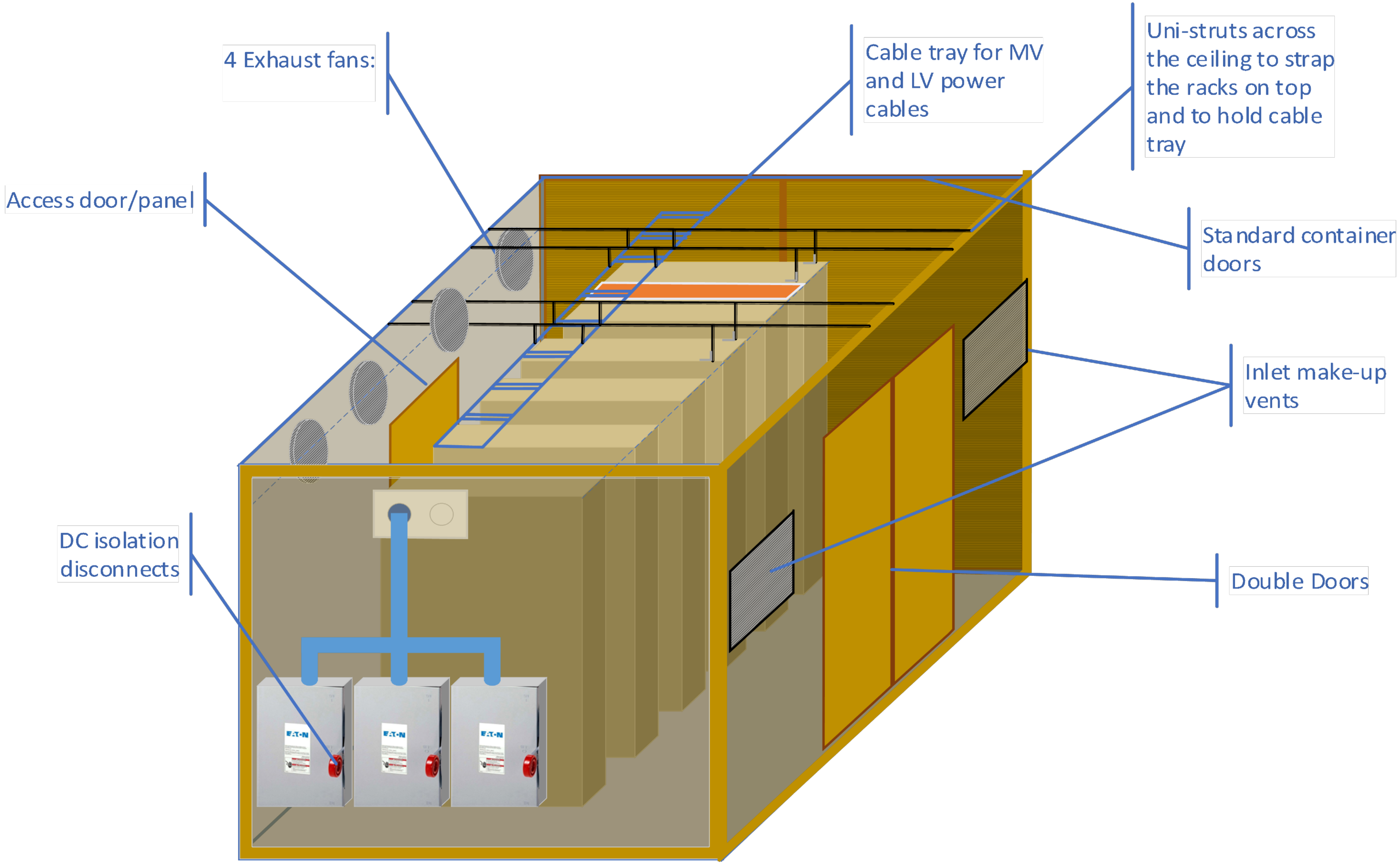
Together…Shaping the Future of Electricity

Technical Back-Up Slides

Containerized Package System Design

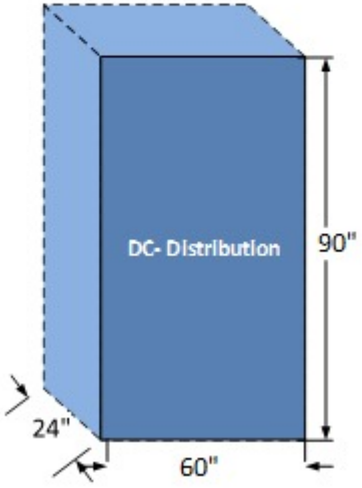


SST Container Design

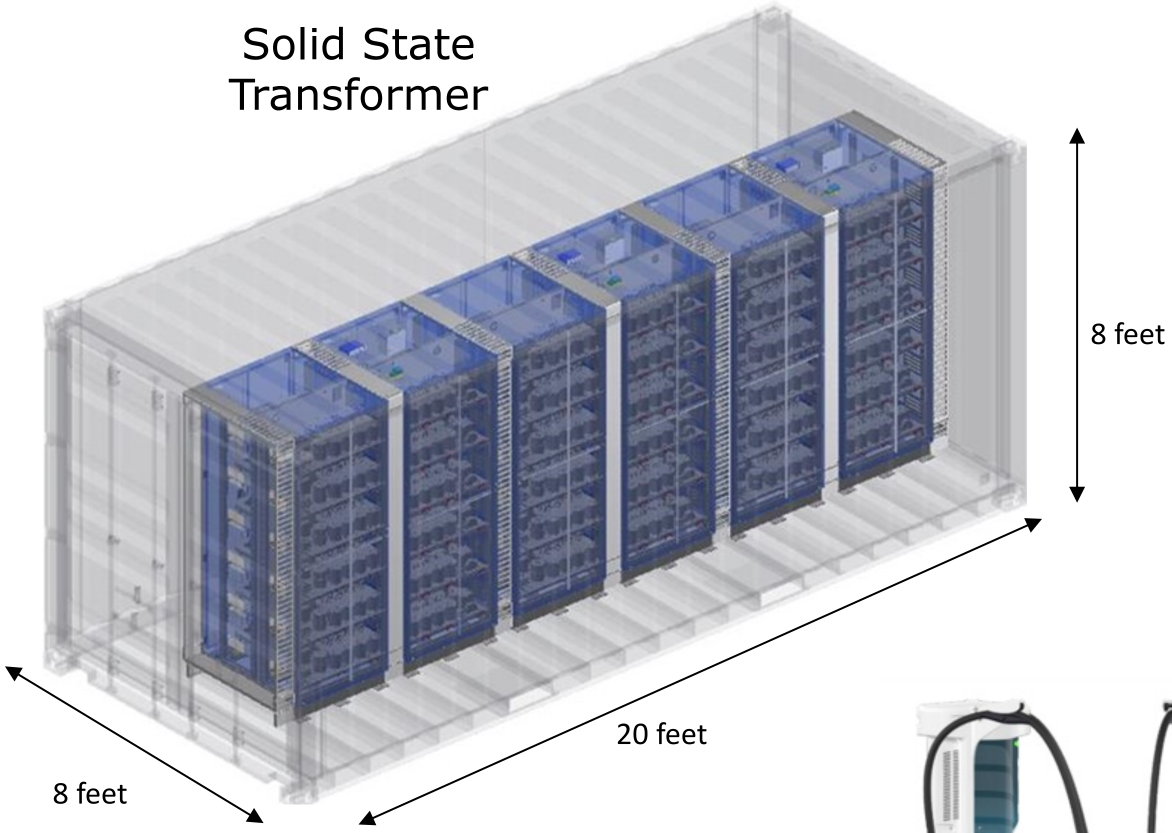


System Components: Physical Footprint

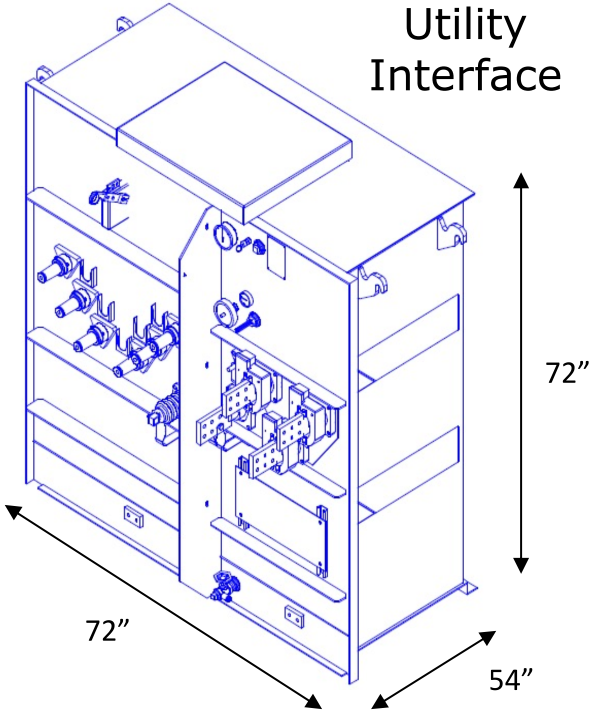
DC Load Center



Solid State Transformer



Utility Interface



DC/DC Charging head-end Units