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Opening Remarks

Andrew Meintz

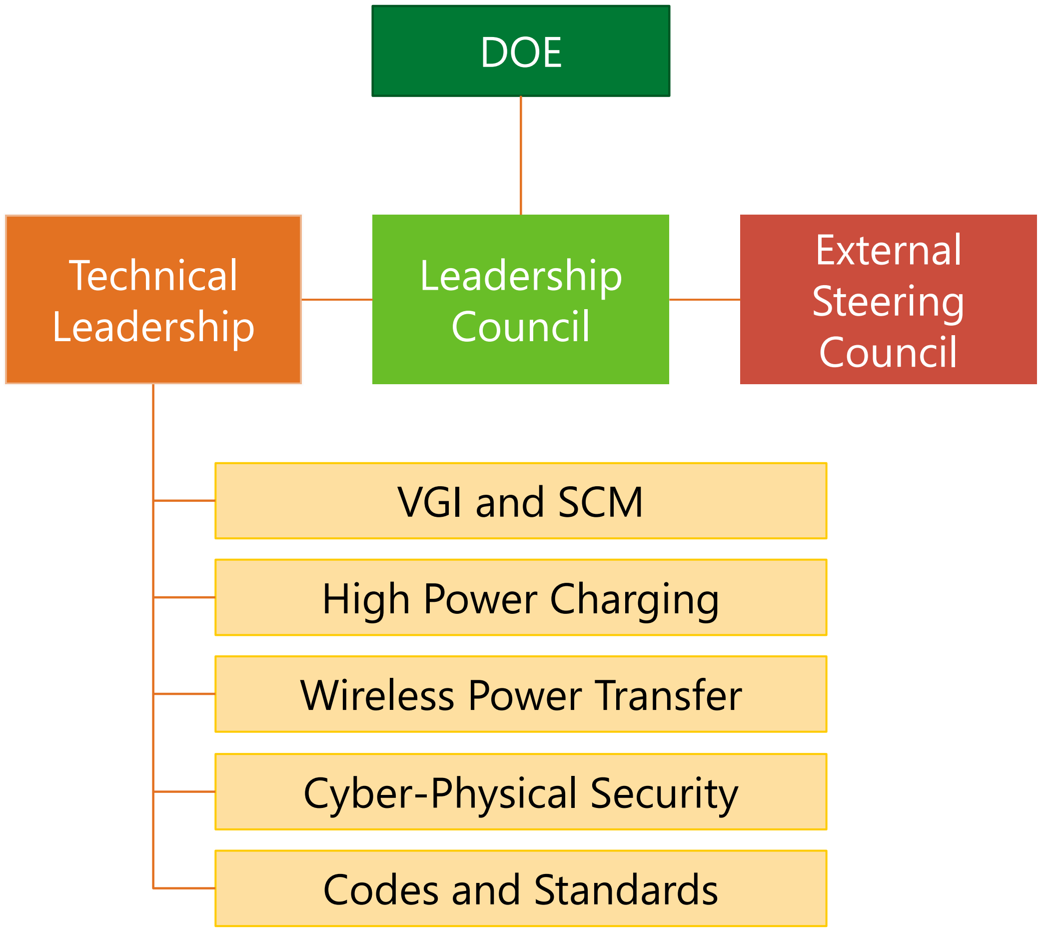
Lee Slezak

Electric Vehicles at Scale (EVs@Scale) Laboratory Consortium Deep-Dive Technical Meetings: High Power Charging (HPC) Summary Report

NREL/PR-5400-84093

Consortium Structure

- Leadership Council
  - Andrew Meintz (NREL, chair), Keith Hardy (ANL, rotating co-chair), David Smith (ORNL), Summer Ferreira (SNL), Rick Pratt (PNNL), Tim Pennington (INL)
- External Steering Council
  - Utilities, EVSE & Vehicle OEMs, CNOs, SDOs, Gov't, Infrastructure
- Consortium Pillars and Technical Leadership
  - Vehicle Grid Integration and Smart Charge Management (VGI/SCM): Jesse Bennett (NREL), Jason Harper (ANL)
  - High Power Charging (HPC): John Kisacikoglu (NREL)
  - Wireless Power Transfer (WPT): Veda Galigekere (ORNL)
  - Cyber-Physical Security (CPS): Richard "Barney" Carlson (INL), Jay Johnson (SNL)
  - Codes and Standards (CS): Ted Bohn (ANL)



EVs@Scale Lab Consortium Stakeholder Engagement and Outreach

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BIANNUAL STAKEHOLDER MEETING

- Open Virtual Forum
- High Level Information Exchange
- Common Understanding / Direction
- Comprehensive Situational Awareness
- Long / Short Term Plans
- Long / Short Term R&D Results
- RFI and Stakeholder Feedback
- FOA Information
- Visibility

DEEP DIVE TECHNICAL MEETINGS

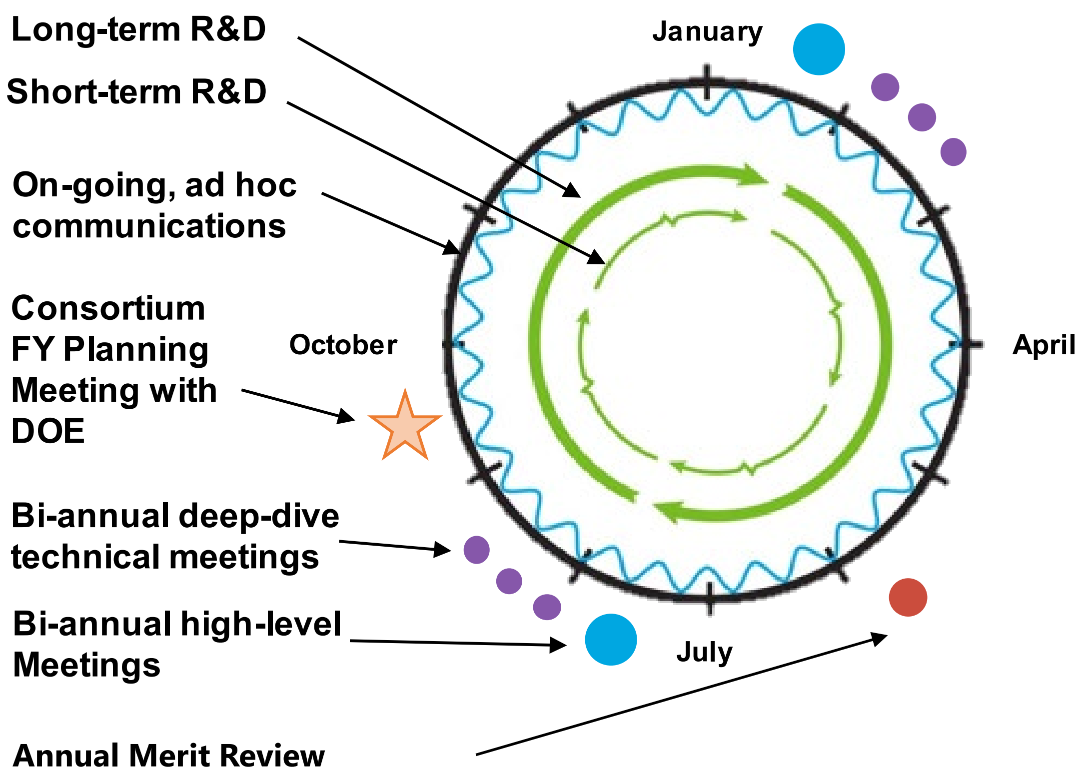
- Detailed Technical Discussions
- Project Plans and Progress
- Stakeholder Feedback
- R&D Agility
- Active Pool of Project Stakeholders
- Short Inception IABs
- Support for RFI Process
- Tech Transfer

DEDICATED ENGAGEMENT WEBSITE

- Continuous Stakeholder Engagement
- Ease of Information Exchange
- Formal and Informal Communications
- Project Updates and Review
- Enable Project Participation
- Record of Information
- Meeting Logistics

Collaboration and Coordination

- **Consortium Laboratories**
  - ANL, INL, NREL, ORNL, PNNL, SNL
- **External Steering Committee**
  - Utilities, EVSE & Vehicle OEMs, CNOs, SDOs, Gov't, Infrastructure
- **Direct interaction for each pillar projects**
  - Utilities, EVSE & Vehicle OEMs, CNOs, SDOs, Gov't, Infrastructure
  - Webinars / Project discussions
- **Bi-annual high-level meetings**
  - Rotation among labs with discussion on all pillars
- **Bi-annual deep-dive technical meetings**
  - VGI/SCM, HPC & WPT, and CPS with C&S incorporated into all meetings



High-Power Charging and Wireless Power Transfer (Week 1)

September 13 | Agenda

- **Power Architectures and Design** – Discussion on the State of the Art of High-Power Charging Station Design and Future Charging Station; The design of Universal Power Electronics Regulator as a Charger Module in eCHIP; and Standards discussion on HPC connectors
- **Modeling, Energy Management, and Power Control in an HPC Station** – Discussion on the Modeling and Analysis of HPC Operations; Site-level energy management: integrating chargers, DERs, and grid; and Standards discussion on grid integration of HPC

September 14 | Agenda

- **High Power and Dynamic Wireless Charging R&D** – Review of High Power and Dynamic Wireless EV Charging ongoing R&D activities with MD/HD use case analysis. Discussion on the integration of WPT system in roadways with our planned R&D activity to develop and validate enabling solutions.

Cyber-Physical Security (Week 2)

September 20 | Agenda

- **Cybersecurity Assessments** – Discussion on cybersecurity assessments of systems, features, and architectures

September 21 | Agenda

- **Cyber Tools, Training, Mitigation Solutions, and Codes & Standards** – Discussion on the Cybersecurity tools and mitigation solutions to improve security and training of the next generation of cybersecurity work force, including relevant codes and standards

Smart Charge Management and Vehicle Grid Integration (Week 3)

September 28 | Agenda

- **Grid and Smart Charging Analysis** – Discussion on the approach to regional modelling activity for light-, medium-, and heavy-duty vehicles utilizing telematics and utility network data to understand the impact of uncontrolled charging and the benefits of smart charge management.

September 29 | Agenda

- **Development/Demonstration** – Discussion on background and applications of charge scheduling, EVrest workplace charge reservation development and demonstration, and OptiQ Smart AC L2 EVSE development and demonstration
- **Codes and Standards –** Discussion on the existing standards of value and the gaps in standards based on analysis and demonstration

Importance of the Deep Dives

These deep-dives are open to industry experts to help us better shape the R&D efforts for EVs@Scale.

We need your input to identify:

- Partners for our R&D efforts to help with insight, data, and other resources.
- Progress in our activities to ensure timely research is available to key stakeholders
- Priorities for R&D that accelerates the transition to EVs at Scale.

Thank you for your participation in this very important activity!

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State of the Art of High-Power Charging Station Design and Future Charging Station

John Kisacikoglu, NREL

September 13, 2022

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Outline

- eCHIP Project Overview
- Introducing Project Team
- State of the Art AC-hub High-Power Charging Technology
- Future DC-hub Charging Station Approach (and how it ties to this project)
- Hardware Development Plan (to reach project goals)
- Conclusion and Next Steps

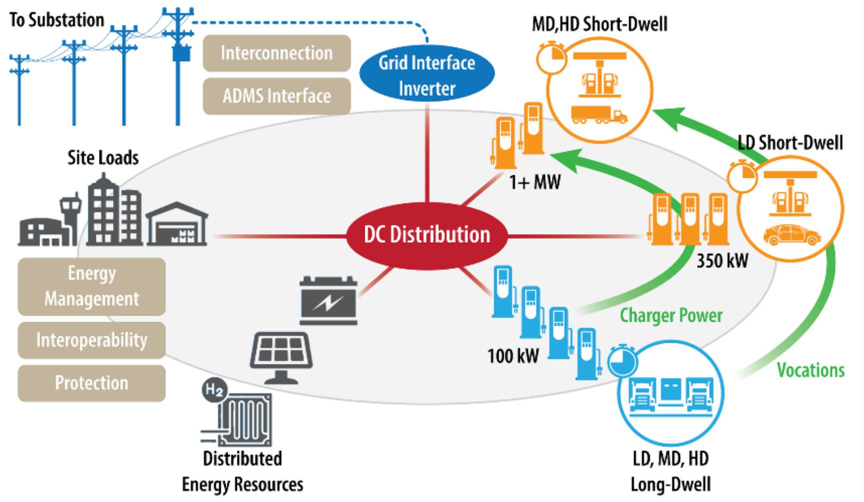
Project Overview

High-Power Electric Vehicle Charging Hub Integration Platform (**eCHIP**)

Objective: Develop plug-and-play solution allowing charging site to organically grow with additional chargers and distributed energy resources through predefined compatibility with standards that will ensure interoperability and reduce upfront engineering expense

Outcomes:

- Develop and demonstrate solutions for efficient, low-cost, and **high-power-density DC/DC** for kW- and MW-scale charging
- **Broadly identify limitations and gaps** in DC distribution and protection systems that allow for modular HPC systems
- Determine interoperable hardware, communication, and control architectures for high-power charging facilities that support **seamless grid integration and resilient operation**



Project Team Roles

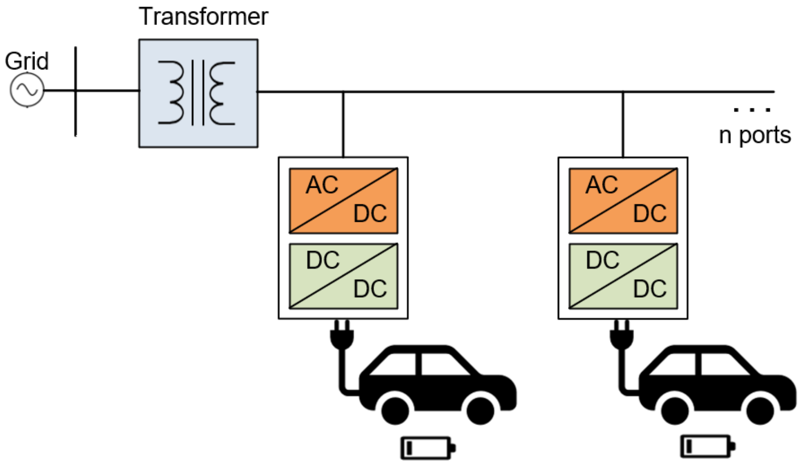
Team Member	Role	Laboratory
John Kisacikoglu	PI, Project management, Power architecture	NREL
Prasad Kandula	Hardware module development, power architecture, controller integration	ORNL
Shafquat Khan	Hardware testbed development, metering	NREL
Rasel Mahmud	Hardware testbed development, DC-bus protection	NREL
Keith Davidson	Hardware testing coordination, lab setup	NREL
Jason Harper	SEM development, controller integration, communication	ANL
Emin Ucer	Modeling, analysis, and SEM development	NREL
Akram Syed Ali	Controller integration and communication system setup	ANL
Ed Watt	System integration and communication, hardware testbed coordination	NREL
Myungsoo Jun	System integration and communication	NREL
Bryan Nystrom	System integration and communication	ANL
Manish Mohanpurkar	Codes and standards coordination, grid integration	NREL
Ted Bohn	Codes and standards coordination, charge connector standardization	ANL

Hardware development

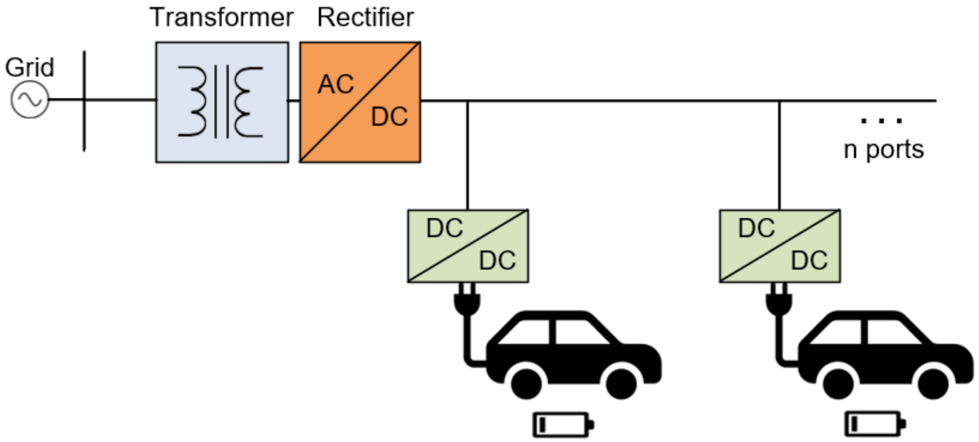
Modeling and controller development; Communication architecture

Grid integration, Standardization

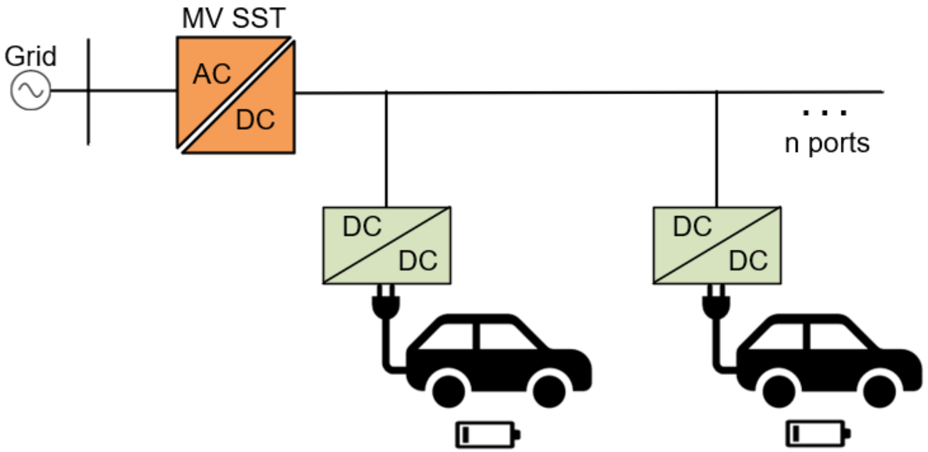
Review of HPC Power Architectures



AC-Hub option

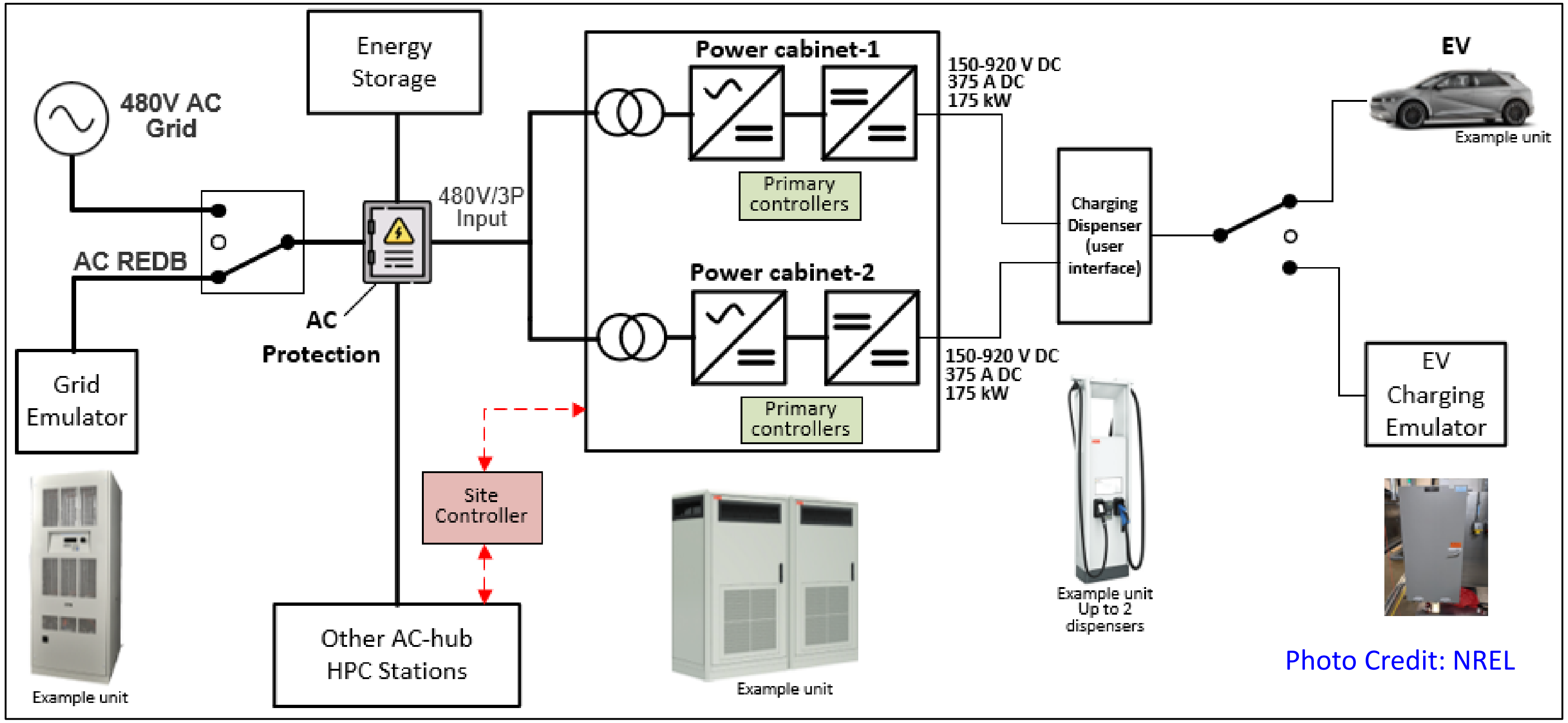


DC-Hub option w/ LF Transformer



DC-Hub option w/ MV SST

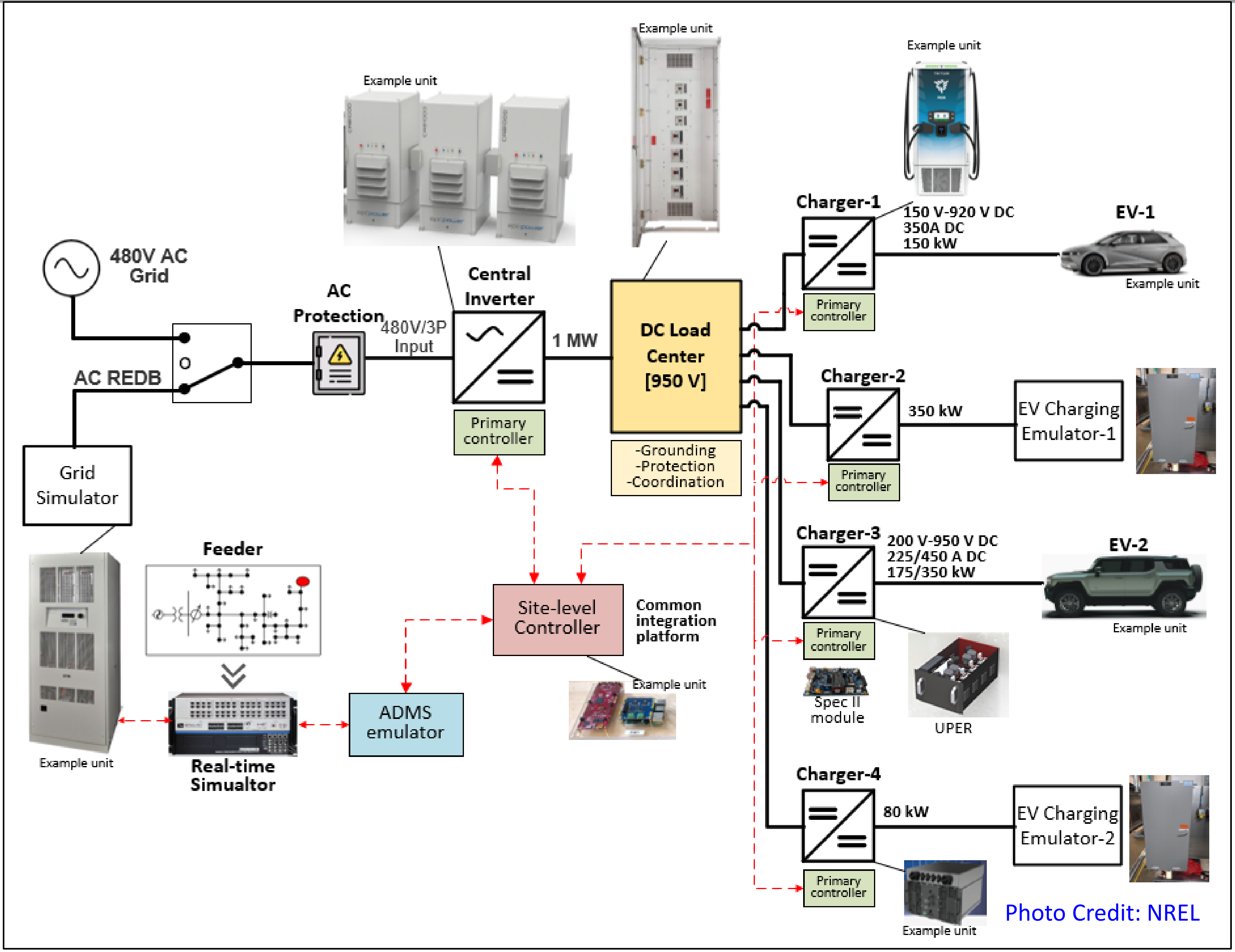
Current State of the Art for AC-hub HPC Station



- Current status of the AC-hub setup that is currently being used for other projects including Next Gen Profiles
- Representative power and communication architecture for COTS AC-hub chargers

Future DC-Hub HPC Station

- **Planned** DC-hub setup under this project
- Representative power and communication architecture for future DC-hub chargers
- Three buckets of research topics will be investigated:
  - Power architecture
  - Site energy management
  - Grid integration and standardization



EV Charging Emulator

EV in a Box: In-house developed vehicle charging simulator that is flexible, mobile, and cost-effective.

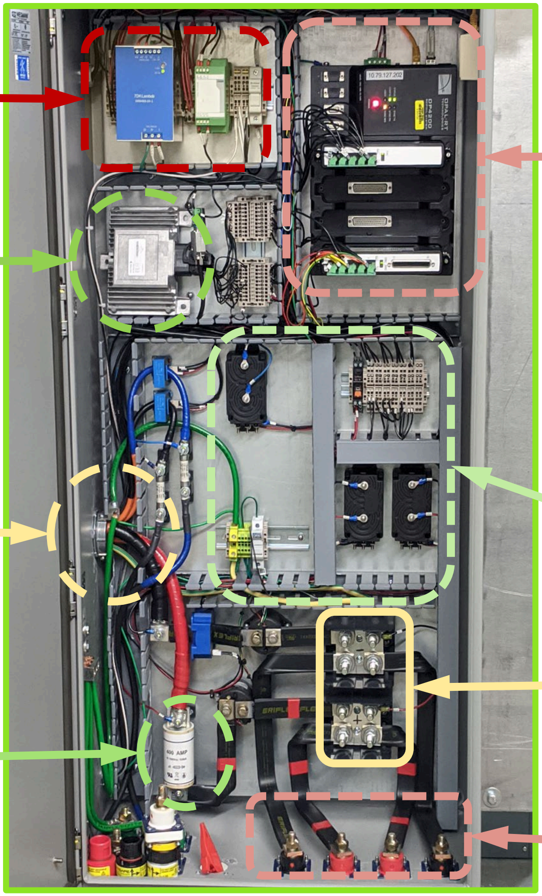
Power Supplies

Vehicle Charge Control Unit (VCCU)

Charge session communications

DC Power Inlet from CCS

Overcurrent Protection



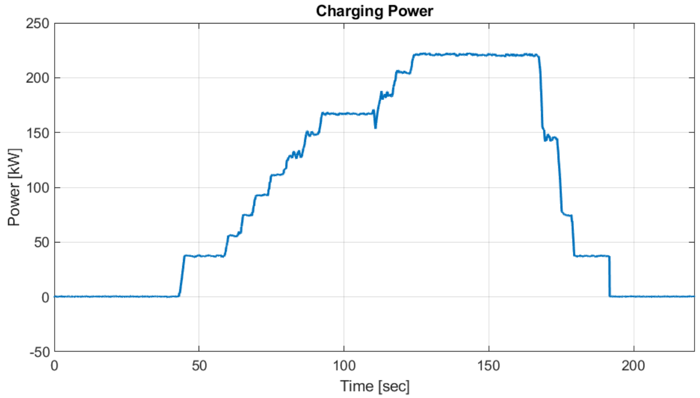
Opal-RT OP4200 FPGA Simulator and Remote IO

Simulation Model of EVs
- To be updated with OPAL 4510 for higher computation capability

Emulated Vehicle Current and Voltage Sensing

Emulated Vehicle Contactors

High Power Connectors to External Energy Sink



Energy Systems Integration Facility

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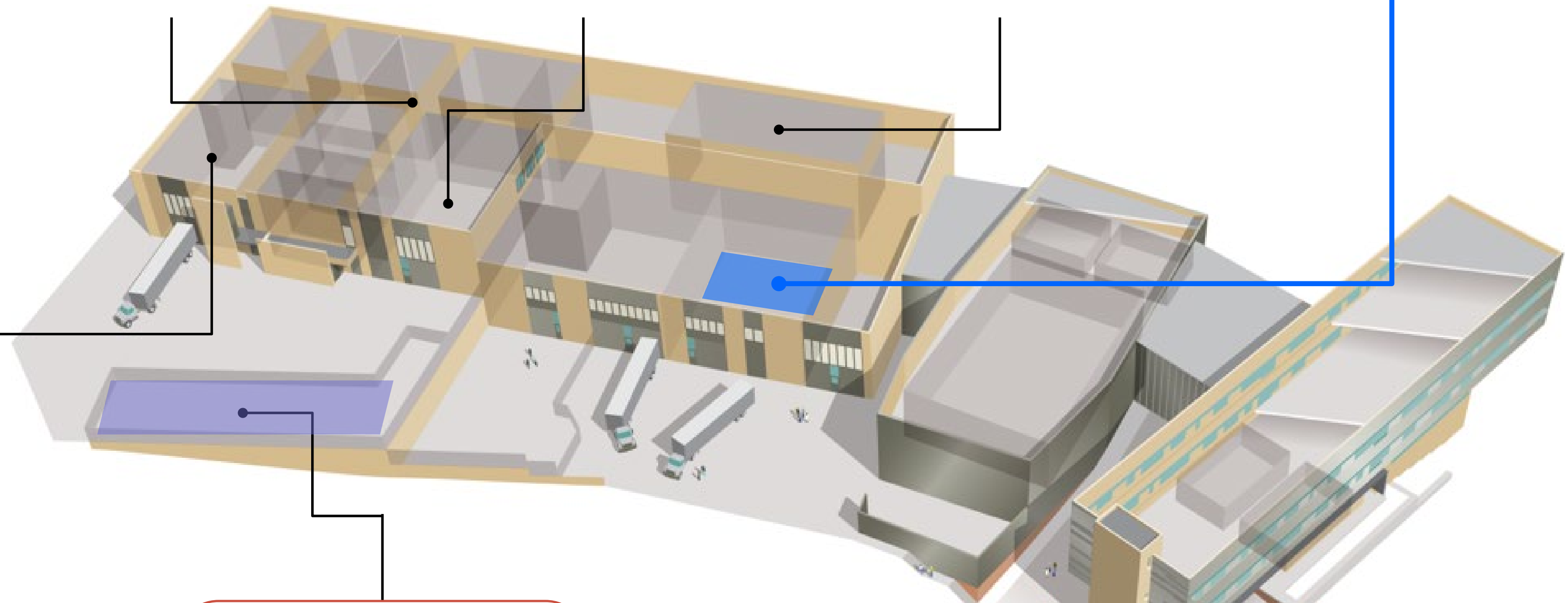
Rooftop Experiment Area
Wind & Solar

Energy Storage Lab (BTMS)
Batteries & Thermal Energy Storage

Systems Performance Lab
Residential Buildings & Loads

EVRI



Hydrogen Systems Integration Lab
Fuel Cells & Electrolyzers

MVOTA
EVs, Power Transformers, Microturbines, & Generators

Hardware Demonstration Plan

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	Phase 1	Phase 2	Phase 3
Objectives	• 100+kW EV charging - COTS • 100+kW EV emulation - COTS • Site Energy Management - Limited	• UPER DC/DC Integration • 1+MW bus capability • Multiple chargers • DC load center integration • Grid side power control • Enhanced SEM controls	• 1+MW level EV charging / emulation • All previous functions w/ multi-MW total power processing * Additional objectives to be finalized after Phase 2
Features	• COTS equipment only • 100-660kW total DC bus power • Initial SEM test capability • 1-2 EV Chargers connected • No grid side controls	• DC distribution test capability • Enhanced SEM test capability • 3+ EV chargers connected • Grid side power control • ADMS integration	• Multi-MW total DC bus power • Full power DC distribution and SEM test • Multiple EV chargers 100kW-1MW
Timeline	**FY23 Q1**	**FY24 Q2**	**FY26 Q4**

Control Hardware-in-the-Loop (C-HIL) Demonstration

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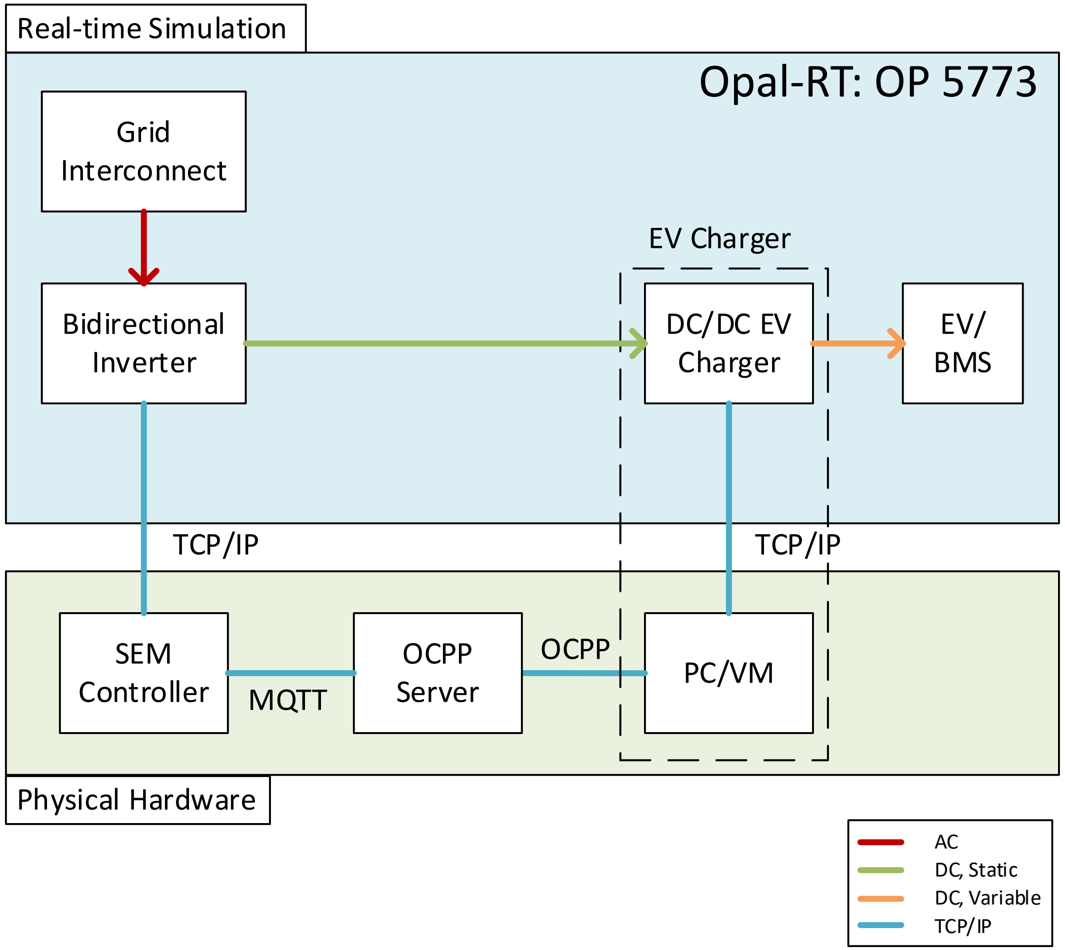
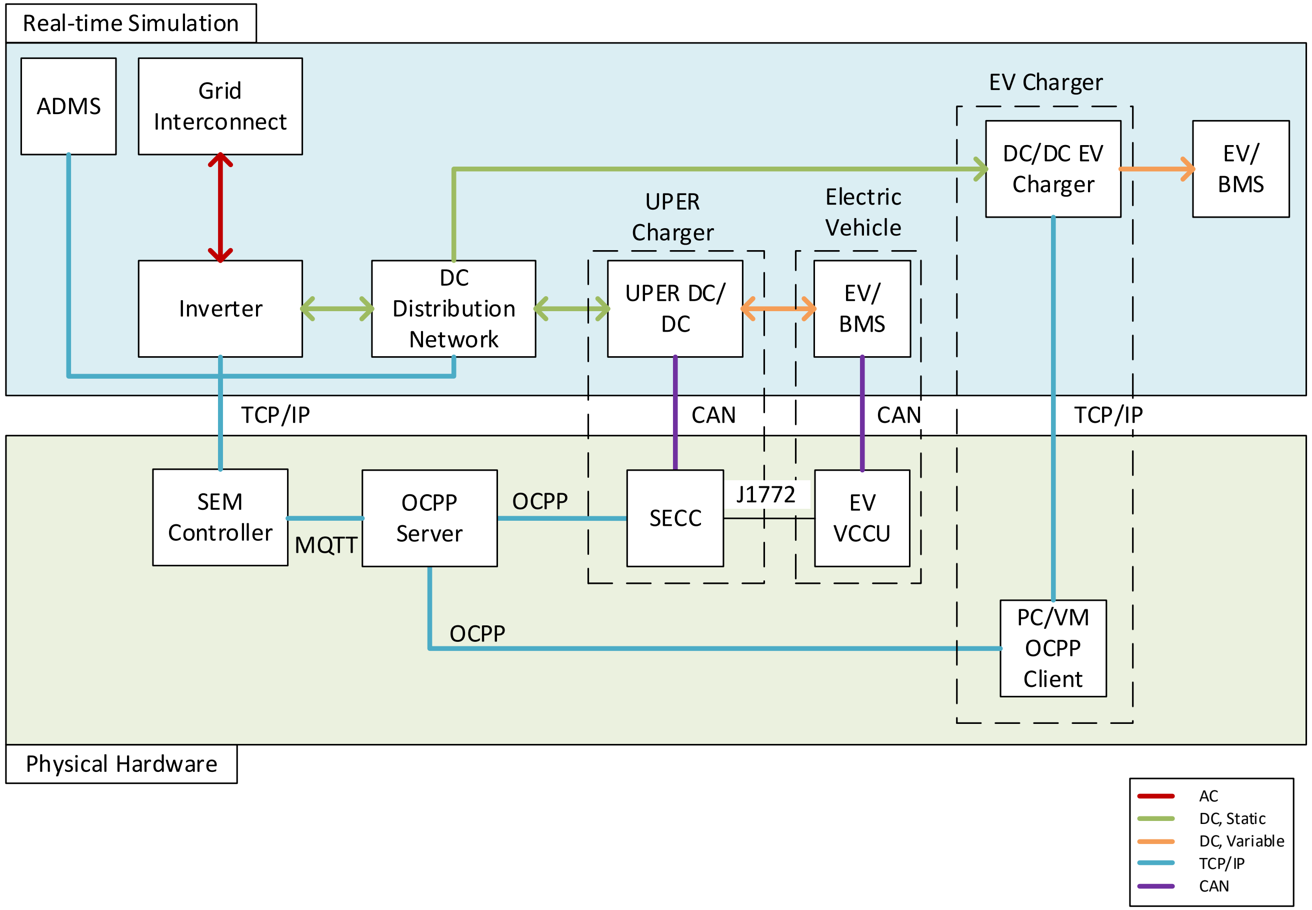
C-HIL Phase 1



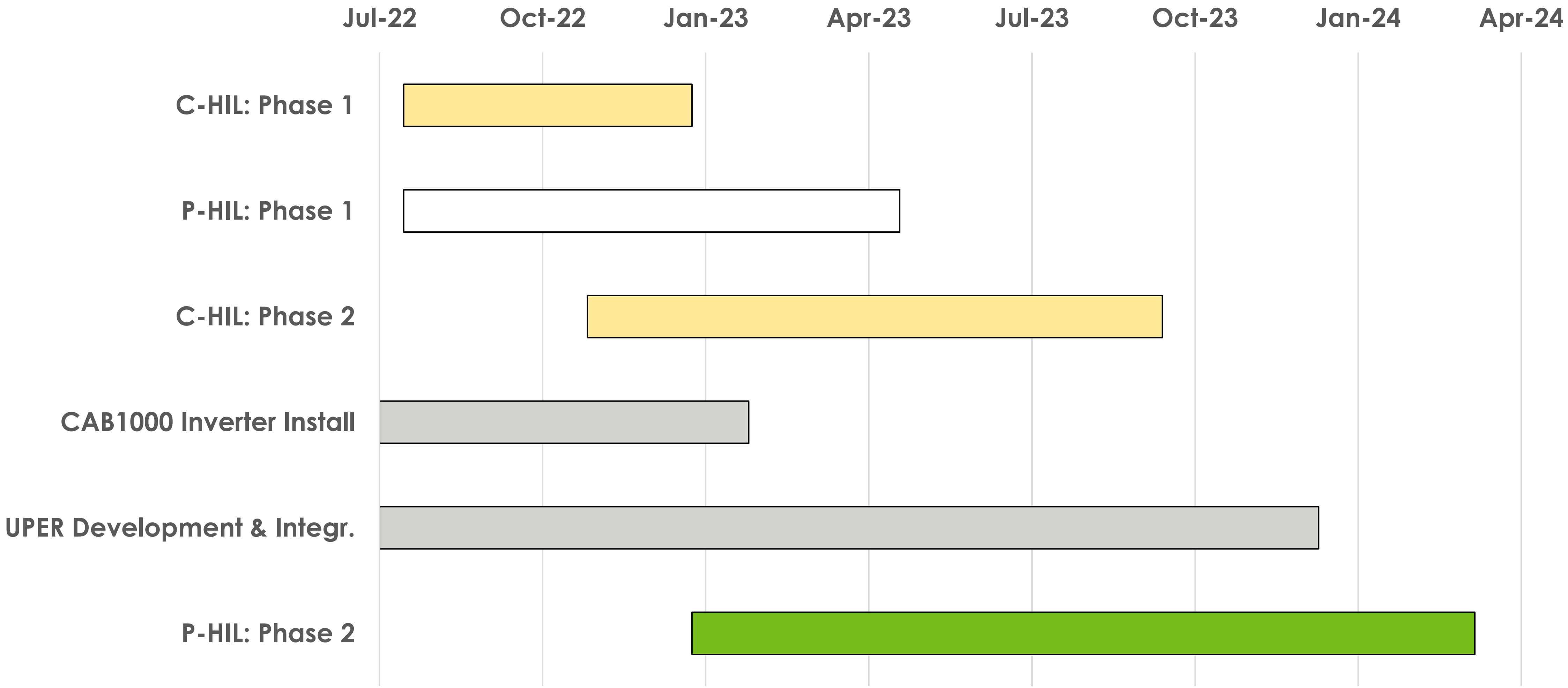
To be completed by FY 2023 Q1

C-HIL Phase 2



To be completed by FY 2023 Q4

Project Timeline



Conclusions and Next Steps

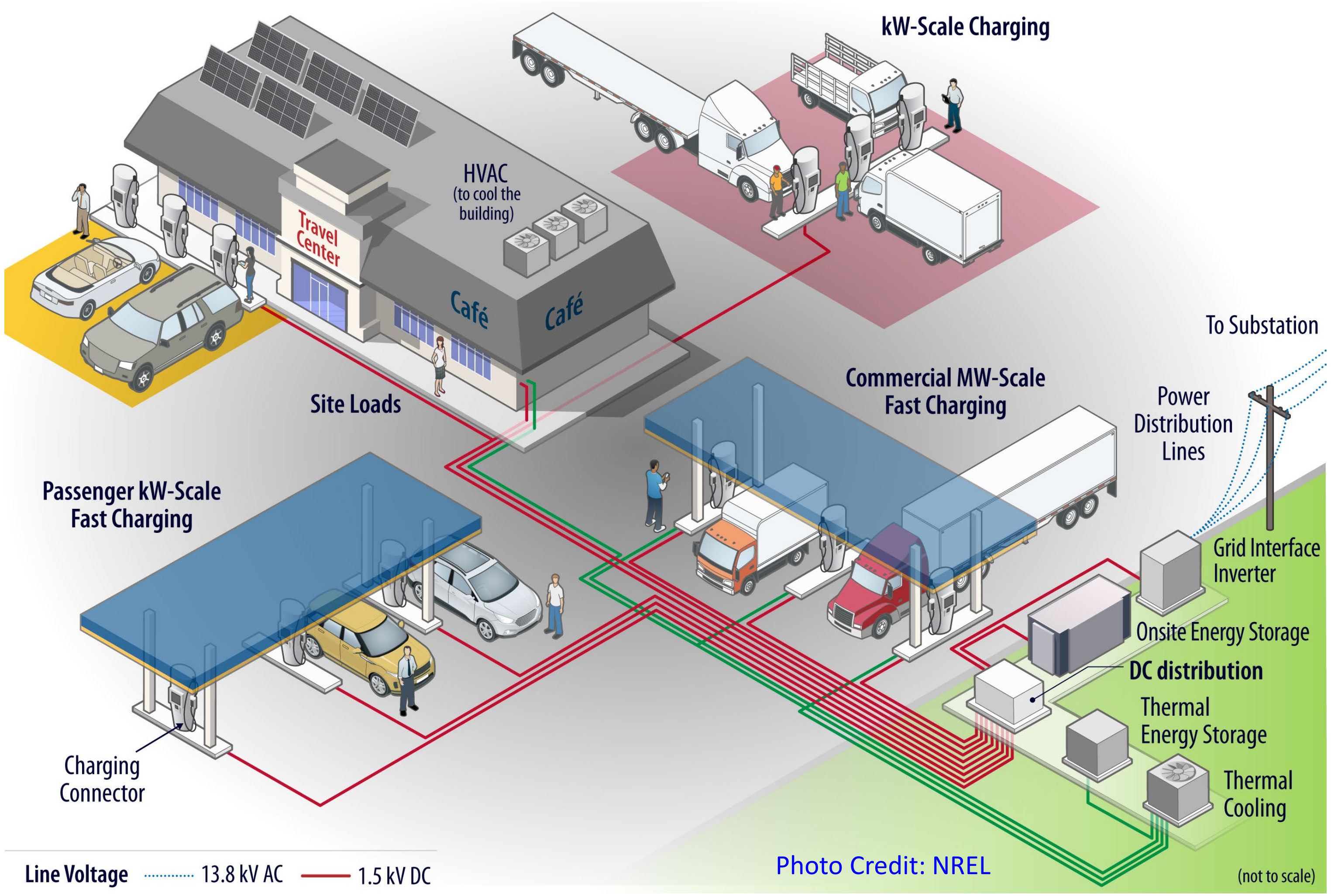
Conclusions

- Development of key components of a DC-hub HPC: **UPER, Spec-II Module, and Site-level controller**
- Charging Hub Demonstration (150 kW – 1 MW) first two years and 1+MW later years
- Controller Hardware-in-the-Loop (C-HIL) Demonstration

Next Steps

- Detailed planning, preparation, and execution for Phase 1 Hardware Demonstration
- Designing and commissioning C-HIL test bed
- Modeling and code development for site-level controller software
- Developing Spec-II module integration requirements with UPER and SEM controller (22 Q4)
- UPER DC/DC development and Spec-II integration

Future High Power Charging Station: A Use Case



Questions are welcome

E-mail: john.kisacikoglu@nrel.gov

Project website: https://www.energy.gov/eere/vehicles/electric-vehicles-scale-consortium-high-power-charging

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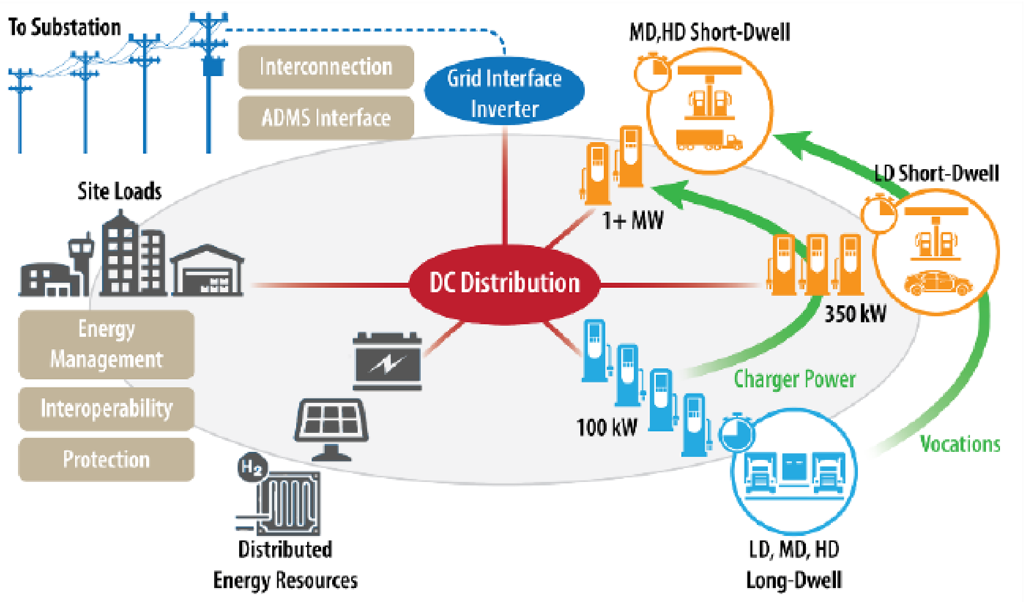
Design of Universal Power Electronics Regulator as a Charger Module in eCHIP

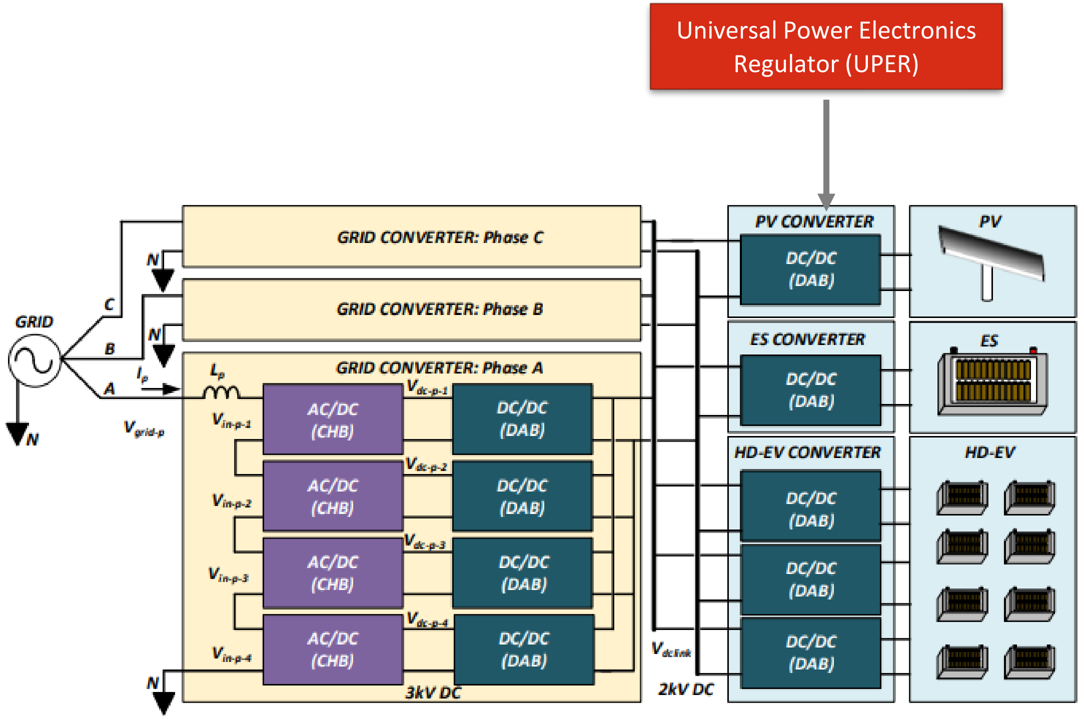
Prasad Kandula, Brian Rowden, Madhu Chinthavali, Rafal Wojda, Michael Starke, Jonathan Harter, Steven Campbell

September 13, 2022

Overall Objective

- **Develop universal converter module for DC distribution to interface**
  - LD/MD/HD charging
  - Renewables
  - Grid interface converter
  - Local loads





M. Starke *et al.*, "A MW scale charging architecture for supporting extreme fast charging of heavy-duty electric vehicles," *2022 IEEE Transportation Electrification Conference & Expo (ITEC)*, Anaheim, CA, USA, 2022, pp. 485-490.

Typical Charging Hub Architecture

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Architecture

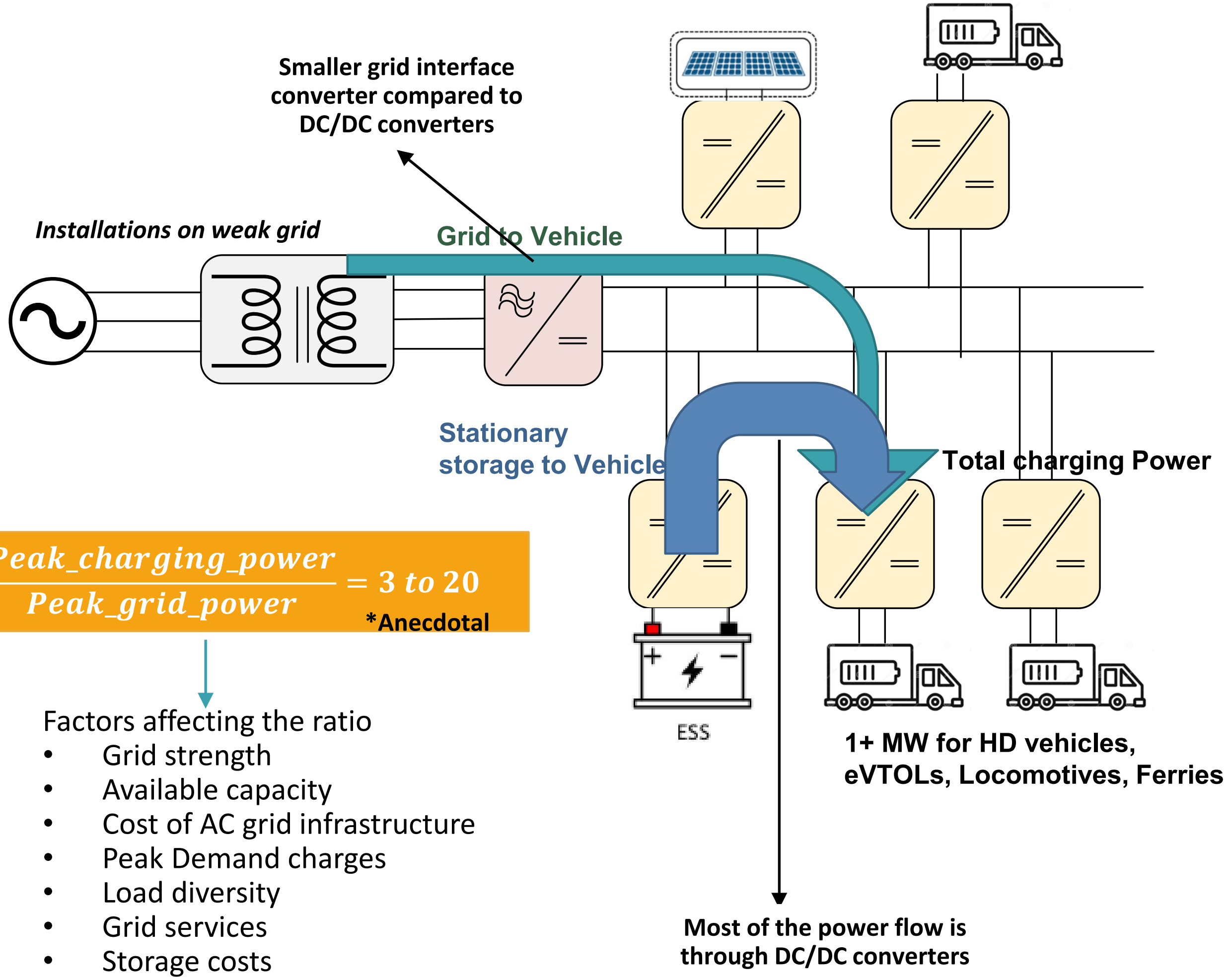
- Stationary storage is typically used to reduce demand charges
- With local storage, bulk of power is transferred between the storage and the vehicle
- Peak charging power compared to peak AC grid power highlights the importance of DC/DC converter

EVSE DC/DC Building Block

- Commercial DC/DC converters are in the range of 50-125 kW
- High-power building block (350 kW) to meet heavy duty (1 MW+) charging requirements is required

Peak Charging Voltage

- Off-road vehicles like the battery-locomotives, eVTOLs (electric Vertical take-off vehicles) may transition to 1500 V
  - Battery locomotives driven by high power
  - eVTOLs driven by need for extreme fast charging



$$\frac{Peak\_charging\_power}{Peak\_grid\_power} = 3\ to\ 20$$

*Anecdotal

Factors affecting the ratio
- Grid strength
- Available capacity
- Cost of AC grid infrastructure
- Peak Demand charges
- Load diversity
- Grid services
- Storage costs

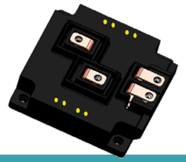
High power, high voltage DC/DC module is a critical enabling component for medium/heavy duty applications

Charger Specifications

A 1500 V class 350 kW charger and an 800 V class 175/350 kW charger is being built

1700 V, 280 A/560 A, SiC

800 V class 175 kW/350 kW charger	
Vin	800-1200 V (TBD)
Vout	200-950 V
Imax	225 A/ 450 A
Eff	>98.5%
Temp	-30°C to 50°C
Comms	CAN
Powerflow	Bidirectional

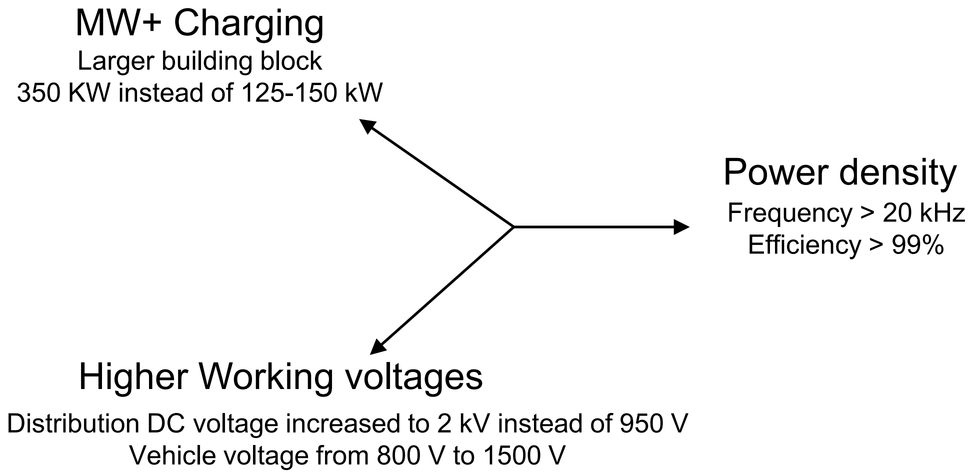


3300 V, 500 A SiC

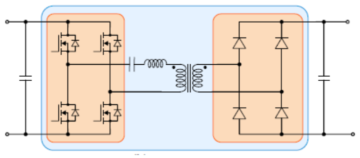
1500 V class 350 kW charger	
Vin	1500-2000 V (TBD)
Vout	500-1500 V
Imax	250 A
Eff	>99%
Temp	-30°C to 50°C
Comms	CAN
Powerflow	Bidirectional

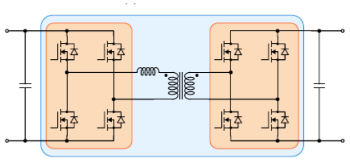
Specifications of charger under development

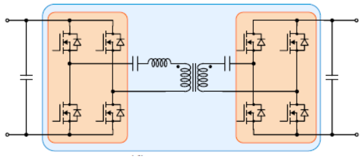
Multi-Dimensional Improvement v/s SOA



EVSE DC/DC Configuration: LLC v/s DAB v/s CLLC







- **Special requirements for EV charging:**
  - Bidirectionality
  - Isolation
  - Wide voltage range
  - Small output current ripple

Selected DAB

	LLC	Dual Active Bridge (DAB)	CLLC
Efficiency: ZVS range	Not good for wide voltage range	Not good for wide voltage range	Not good for wide voltage range
Controllability: Light load power regulation	Medium	High	Medium
DC bias currents- Transformer saturation	Caps block DC	Control based	Caps block DC
Voltage/Current Stress	Resonant cap has high voltage stress		
Bidirectionality	Not well suited		
Output current ripple	Large filter cap required		Large filter cap required
Leakage inductor		Relatively larger: high circulating reactive power	
Medium freq Xmr stress	Sinusoidal voltages	Square voltages	Sinusoidal voltages

Green: Good, Yellow: Manageable, Red: Major constraint

Challenges: Transformer

Medium frequency transformer will be the key component determining size and weight of the charger

Impact of large currents on Transformer design

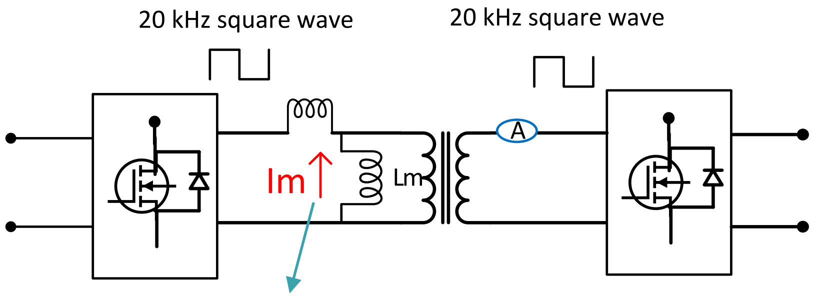
- As power increases, the increase in Litz wire bending radius will impact window utilization, increasing size and weight
- Cooling of such thick windings is also a major challenge
- Optimization of foil-based windings, considering proximity effects (AC resistance) is being considered to increase window utilization.
- Aluminum based windings are also being explored to reduce weight and loss
  - Al has lower AC resistance than Cu

Impact of DC current on transformer size

- DC current in the transformer magnetizing current occurs because of inevitable imperfections in PWM voltage
- High Lm is required to avoid saturation, thereby increasing Xmr size.
- Advanced (predictive) controls are being developed to mitigate DC offsets

800 V, 175 kW, 20 kHz, Transformer, Based on Nano crystalline core and Litz (3/0) Winding

DC Voltage/Current Impact on Transformer Size



Challenges: Protection

Impact of filter capacitors on fault current

- The fault current is primarily driven by the output/input capacitors.
- Converter itself can disconnect within few µS.
- Limiting capacitor size can limit the fault current thereby avoiding costly DC breakers
- Capacitor size can be limited through optimal design of the converter
  - Leakage inductance, switching frequency, current ripple

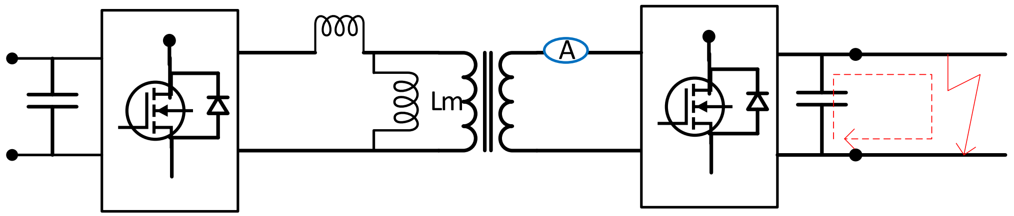
Impact of no. of modules on fault current

- As number of modules increase, the capacitors and hence fault current may increase
- Increasing the power of each module and interleaving concepts can be used to reduce capacitor size.

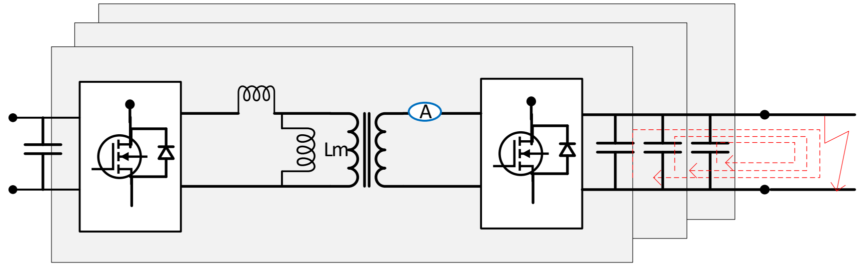
Fault identification enabled through fault current

- Converter may be controlled to provide 0.5-1.5 pu of fault current even under short circuit conditions to enable fault identification and location
- Enables DC Hub resilience

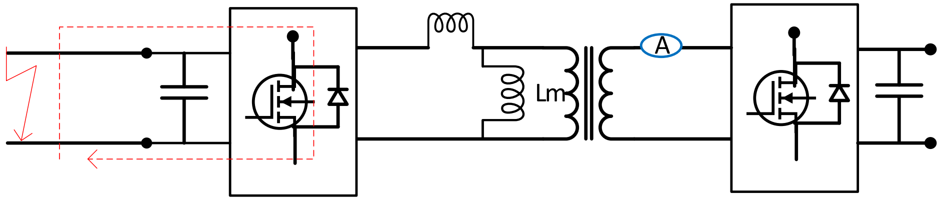
Filter capacitors driving fault current



Impact of no. of modules on fault current



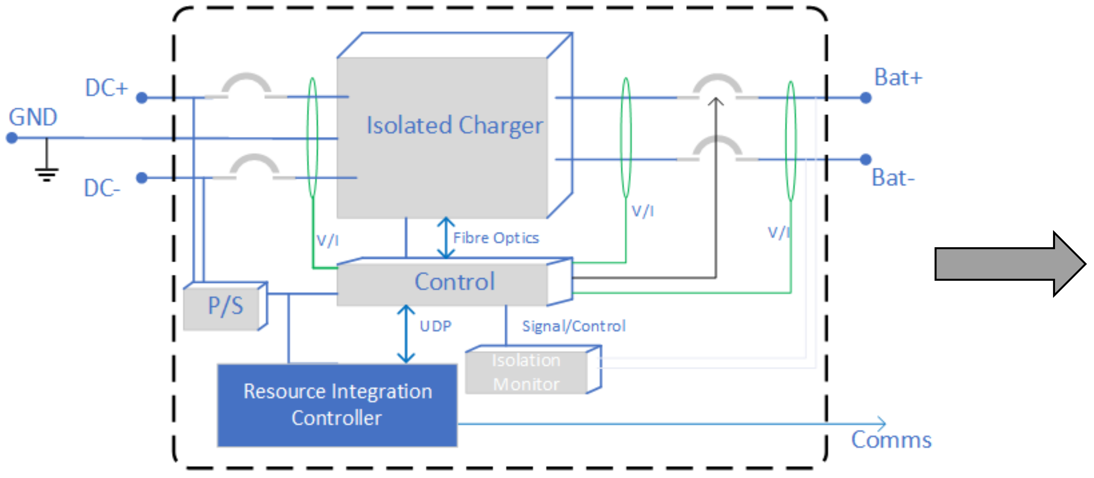
Converter providing fault current (0.5-1.5 pu) even at zero voltage for fault indication and location

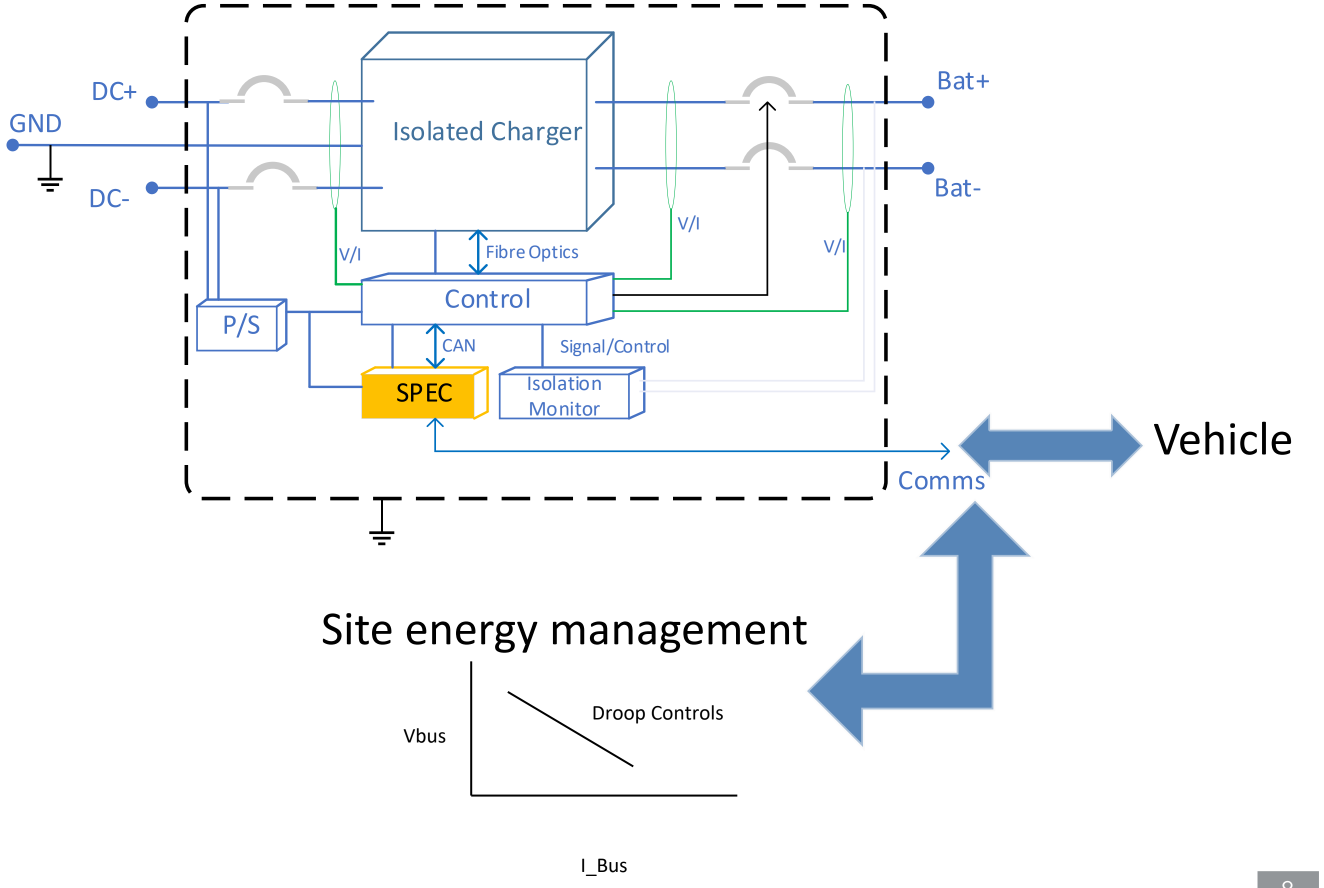


Focus here is to study the impact on converter design and control to enable DC bus protection architecture being developed in coordination with other teams.

Integration and Communication Interface

- The charger will be integrated with ANL SPEC module to enable interface with both the vehicle and site energy management
- The protocol using CAN interface between the charger controller and ANL/SPEC module is being developed.





Leveraging ORNL Existing Architecture

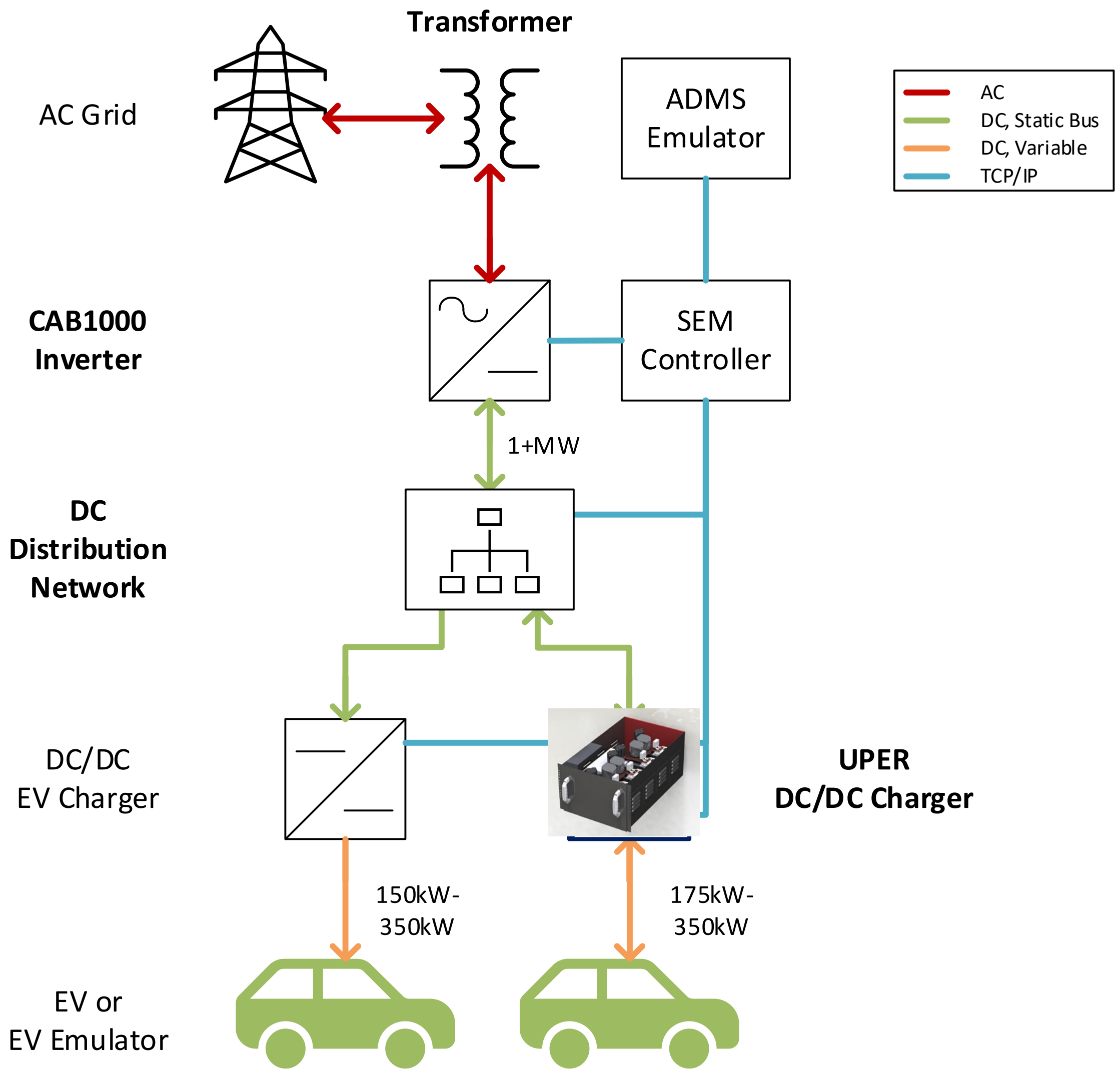
Control communications

New controls

Insertion of SPEC

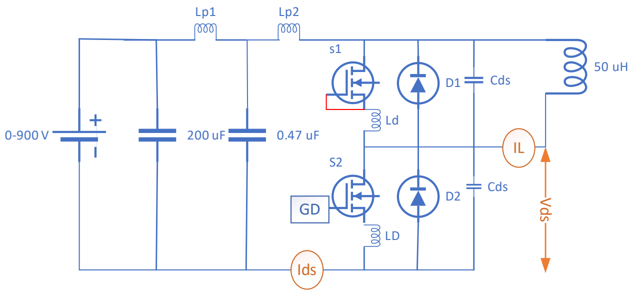
M. Starke et al., "Agent-Based Distributed Energy Resources for Supporting Intelligence at the Grid Edge," in IEEE Journal of Emerging and Selected Topics in Industrial Electronics, vol. 3, no. 1, pp. 69-78, Jan. 2022.

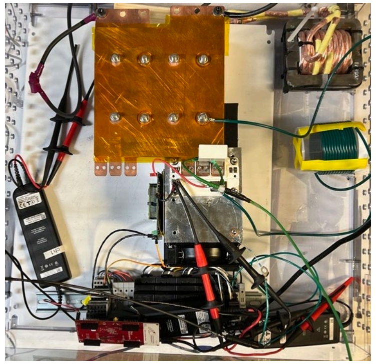
- The developed 800 V class 175/350 kW charger will be tested at the NREL facility



Current Status

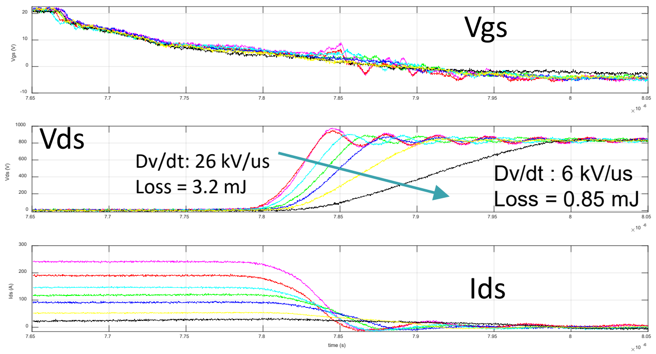
- Devices (1700 V SiC) for 800 V class charger have been characterized
- Custom gate drivers have been developed



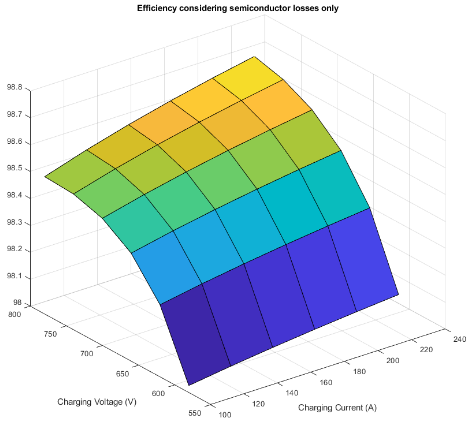


1700 V SiC Device Characterization Test Setup

1700 V SiC Device Turn Off Results



Estimated Converter η based on device losses

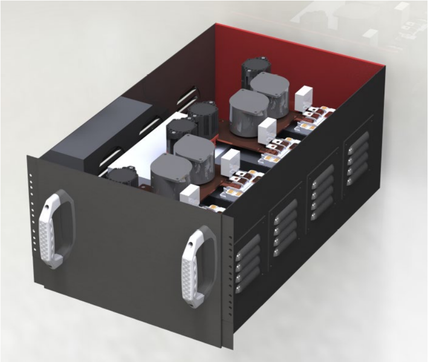


- 800 V class , 20 kHz, 175 kW transformer has been built

11”x 7” x 7”, 175 kW, 20 kHz, Transformer, Based on Nano crystalline core and Litz (3/0) Winding

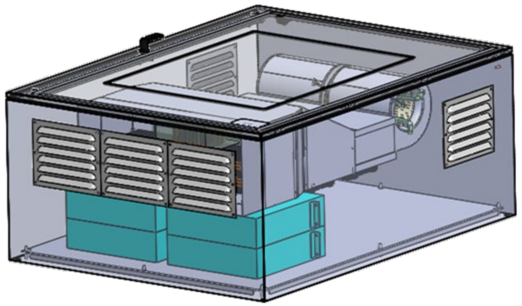
- Complete design (Filters, pre-charging, protection) has been completed for both 800 V class 175 kW/350 kW chargers

800 V, 175 kW Charger



28” x 16” x 12”

1500 V class, 400 kW Charger



Thank You

Prasad Kandula

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EVs@Scale

U.S. Department of Energy

Standards Discussion on HPC Connectors and Interconnection Processes

Theodore Bohn
Argonne National Laboratory

eCHIP Deep Dive, September 13, 2022

Outline

- EVS at Scale Standards Pillar Overview, Prioritization Criteria
- EVSP Standards Roadmap Catalog of Standards/Gaps
- Evolution of High Power Charging (HPC) Coupler Standards
- Measurement System Standards for Commercial EV Charging Transactions
- Implementation of SAE J3271 MCS Charging Solution for Test Data
- Energy Services Interface (ESI) Implementation Pilot Demonstration of IEEE P2030.13
- Conclusion and Next Steps

Codes and Standards Support Initiative Overview

Objective: Codes & standards support priorities focus on development of the most critical standards for EVs at Scale, i.e., high power DC charging, storage (microgrid, DERMS) integrated with DC charging, vehicle-grid integration, high power scalable/interoperable wireless charging, vehicle-oriented system standards and energy services to support transparent optimized costs/delivery.

Outcomes:

- Establish and complete draft of SAE J3271 Megawatt Charging System (MCS), AIR7357 TIRs
- Create work group to develop EV Standards Roadmap based on 2012 ANSI EVSP roadmap
- Develop and demonstrate a reference DC as a Service (IEEE P2030.13) implementation with off-the-shelf hardware and Open API Energy Services Interface (ESI) implementation
- Complete a study w/summary reports in support of identified high importance standards
- Active participation in SDO standards meetings/committees to close gaps in EVs@S standards

Argonne National Laboratory

- Theodore Bohn
- Mike Duoba
- Keith Hardy
- Jason Harper
- Dan Dobrzynski

Idaho National Laboratory

- Richard Carlson
- Anudeep Medam
- Tim Pennington
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- Vivek Singh
- Isaac Tolbert
- Ed Watt

Oak Ridge National Laboratory

- Veda Galigekere
- Omer Onar
- David Smith

Pacific Northwest National Laboratory

- Brian Dindlebeck
- Lori O'Neil
- Richard Pratt

Identifying Codes and Standards Activity Priorities Enabling EVs at Scale

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U.S. Department of Energy

Filter Criteria: The group of lab team members proposed areas **most** relevant to EVs at Scale

Priority Areas:

- EVs at Scale standards support focus is mostly on scaling charging capabilities. I.e. how to serve more vehicles in more locations without exceeding resource limits, for a spectrum of vehicle sizes/classes (from light to medium to heavy duty; commercial and passenger cars) Charging rates from 30A to 3000A for conductive/wireless methods, AC or DC, µGrid, etc

- Electric power delivery oriented standards areas; V2G, local DER, integrated storage, system controls including the Energy Services Interface method of bi-directional information exchange leading to contract based optimization of resources, DC as a Service, communication protocols

- Vehicle Oriented **System Standards** (including non-road, electric aircraft) that include on-vehicle systems (power take-off, refrigeration units, battery management, battery safety, etc.),

- High Power Scalable/Interoperable Wireless Charging (SAE, SWIFTCharge) (up to 1MW)

ANSI EVSP EV Charging Roadmap Process/Overview

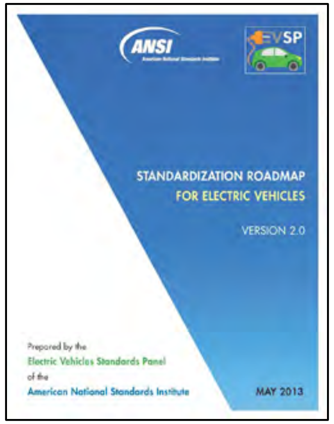
Roadmap Overview

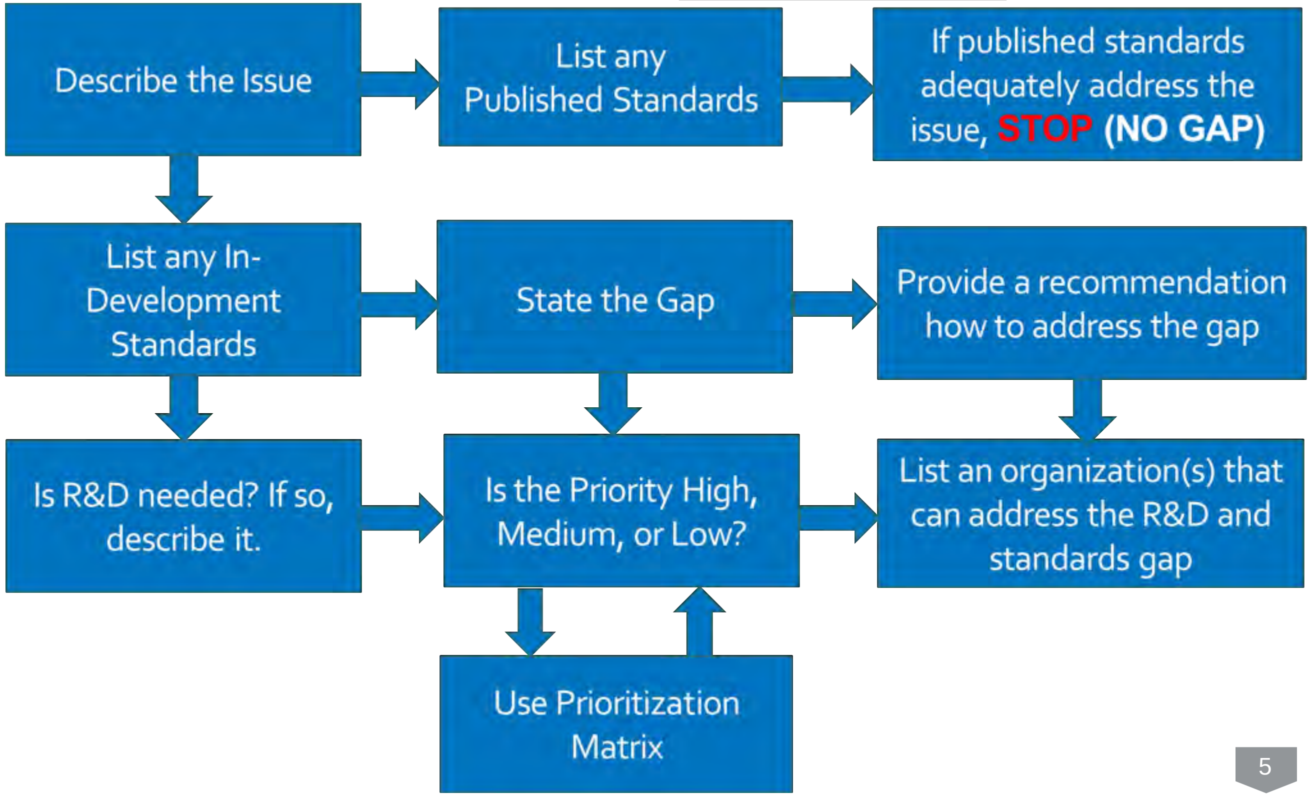
- Identifies issues as well as standards, codes, and regulations that exist or are in development to address those issues

- Identifies “gaps” & recommends development of new or revised standards, conformance and training programs, where needed

- A “gap” means no published standard, code, regulation, or conformance program exists
- Suggests prioritized timeframes for standards development and organizations that may be able to perform the work

- Focus is U.S. market with international harmonization issues emphasized in key areas





Alphabet Soup-TLA Overload; SAE Battery Standards List/Diagram (50+)

Thermal Management & Adhesives: J3073, J3178

Battery Labeling: J2936

Battery Life Assessment Testing: J240, J2185, J2288, J2801

Truck & Bus Batteries: J3004, J3125,

Battery Safety: J2929, J2464, J3009

Battery Size, Identification & Packaging: J1797, J3124, J2981, J3004

Battery Testing Methodologies: J2758, J2380

Electric Drive Battery Systems Functional Guidelines: J2289

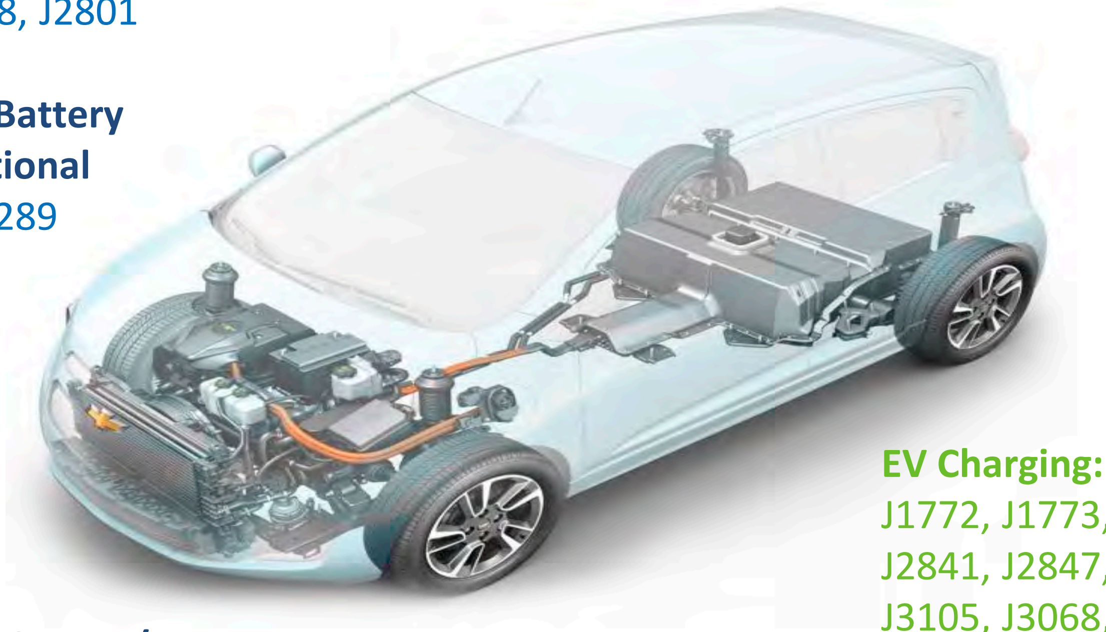
EV / Battery Fuel Economy & Range: J1634, J1711, J2711

Battery Materials Testing: J2983, J3021, J3042, J3159

Battery Vibration: J2380, J3060

Battery Secondary Use: J2997

Battery Transport: J2950



EV Charging: J1772, J1773, J2293, J2836, J2841, J2847, J2894, J2931, J3105, J3068, J3271, AIR7357

Capacitive Energy & Start/Stop: J3012, J3051

EV Battery Safety: J1766, J2344, J2910, J2990

Battery Recycling: J3071, J2974, J2984

EV Charging Safety: J1718, J2953/1, J2953/2, J2953/3, J2953/4, J2953/5 (CSRP)

Starter & Storage Batteries: J1495, J2185, J240, J2801, J2981, J3060,J537, J930

Battery Terminology: J1715/2

Battery Performance & Power Rating: J1798, J2758

Battery Electronic Fuel Gauging & Range: J2946, J2991

Global Summary of High Power Charging (HPC) Coupler Standards

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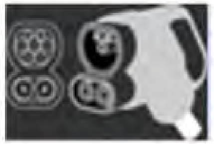
SAE J1772 first published ~30 years ago w/32A AC, 400A DC rating; now 500A->800A,

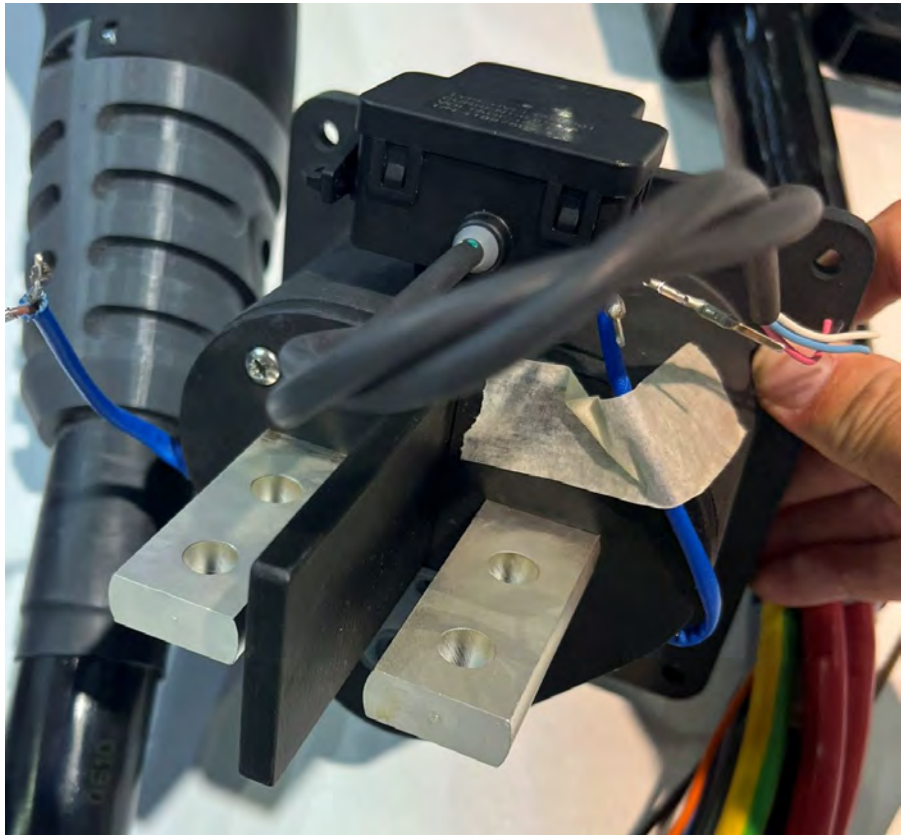
- SAE-IEC Combination Charging System (CCS) DC couplers (w/liquid cooled cables) can deliver up to 1000v/500A (.5MW) today; pushing to 800A in J1772-v9 standard (next revision/release)
- The SAE J3271 Coupler is compared in the table below to Tesla and ChaoJi(GB/T-CHAdeMO)
- Mechanized couplers, J3105 and robotic actuated coupler systems increase safety, moving parts

	GB/T	New GB/T	CHAdeMO	CCS1	CCS2	Tesla	MCS
							
Max Power	950V x 250A = **237.5 kW**	1500V x 600A = **900 kW**	1000V x 400A = **400 kW**	1000V x 500A = **500 kW**	1000V x 500A = **500 kW**	410V x 610A = **250 kW**	1500V x 2000A = **3 MW??**
Range add /minute charge	1.5 miles	5.8 miles	2.6 miles	3.2 miles	3.2 miles	1.6 miles	19.2 miles
Communication Protocol	CAN (SAE J1939)	CAN (SAE J1939)	CAN (ISO 11898)	PLC (ISO 15118)	PLC (ISO 15118)	CAN (SAE J2411)	CAN or Ethernet (ISO 15118)
Location Used	China, India	China	Global	US	EU, South Korea, Australia	Global	US?, EU?
Related Standards	IEC 61851	IEC 61851	IEC 61851 IEEE 2030.1	IEC 61851 SAE J1772	IEC 61851	none	none
Notes	none	Liquid Cooled under development	Liquid Cooled under development	Liquid Cooled	Liquid Cooled	Liquid Cooled	Liquid Cooled

in development

J3271 MCS Couplers- Rema, Amphenol Examples at EVS35

20mm contacts with fingerproof deadfront covers, Level 1=350A, Level 2=1000A, Level 3=3000A



Gradient of Power Levels/Vehicles for EV Charging Coupler Standards

Right coupler for the right application; High power is relative to battery pack size (C-Rate)

- **Light duty vehicles**, some school buses use AC SAE J1772 Level 2 (208/240vac-80A) chargers; 30A/7kW nominal; 80A/19.2kW max.
- **Medium Duty (commercial) Vehicles** can use SAE J3068 AC; 3-phase; 63A/480v(53kW)
  Advanced versions on J3068 can handle 120A/480v(99kW), or Tesla at 160A(120kW dc)
  Higher voltage **SAE J3068-DC6** can push 320A(2x160A) up to 1000vdc (600vdc today)
- **Light-Medium Duty vehicles**; can use **J1772-CCS** 1000vdc/350A-500A (up to 500kW)
- **Medium/Heavy Duty vehicles-Buses** (port/drayage trucks) can use **SAE J3105** (/1, 2, 3) <600kW
- **Medium/Heavy Duty trucks** can use J3271 MCS; under 1000vdc/1000A (1MW) today, 1250v, 3000A (3.75MW) in the future higher voltage battery pack vehicles; parallel inlets for mining/rail


J1772->19.2kW


J3068->53kW-99kW(ac)
120kW-320kW (DC6)

J1772-CCS
350-500kW(DC)


J3105->600kW


J3271 MCS 350kW-
3.75MW

ANSI C12.32 DC Meter Standard; Examples for DC as a Service

High power charging requires meters w/ 1% net accuracy (w/cable errors), 350A, 500A, 3000A

DC distribution/utility regulated markets require certified DC meters, C12.32 now published

https://webstore.ansi.org/Standards/NEMA/ANSIC12322021 ($147) {no known ANSI C12.32 certified meters available today}

ANL Benchmark DC meter examples

	Manufacturer	Model
1	AccuEnergy	AcuDC 243
2	EVoke	EUMD6m
3	Isabellenhuette	IEM-DCC
4	LEM	DCMB
5	Lumel	PH30
6	MeasurLogic	DTS DC
7	Porsche Engineering Services	DCEM 100
8	Rish	Alpha EM DC
9	Satec	PM130-PLUS-DC
10	Tritium	integrated DC

NIST Handbook 44-3.40 Commercial Transaction Code (National/State level)

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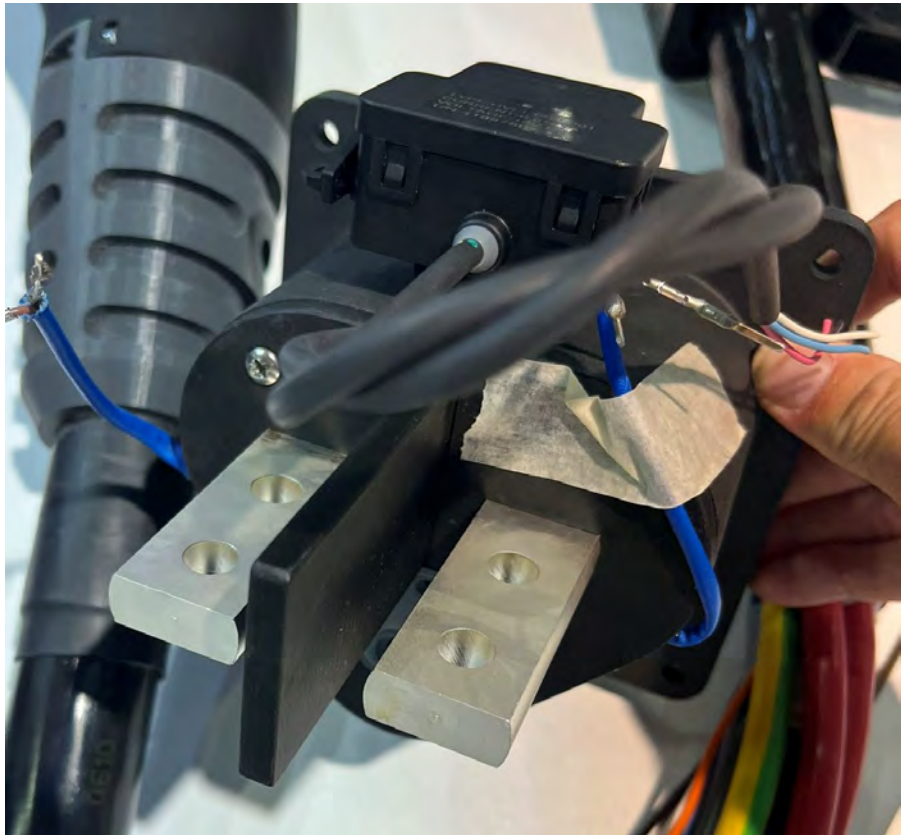
High power, high accuracy sensor and meters for 350A, 500A, 3000A HPC Testing Solutions

- HB44 for commercial DC EV charging will be adopted as permanent code nationwide January 2023
- Simple, affordable accurate test solutions developed under EV@S, based on 6ppm sensors 20ppm meters
- Pass through measurement cable (CCS now, MCS soon), have been field test w/ Labview GUI

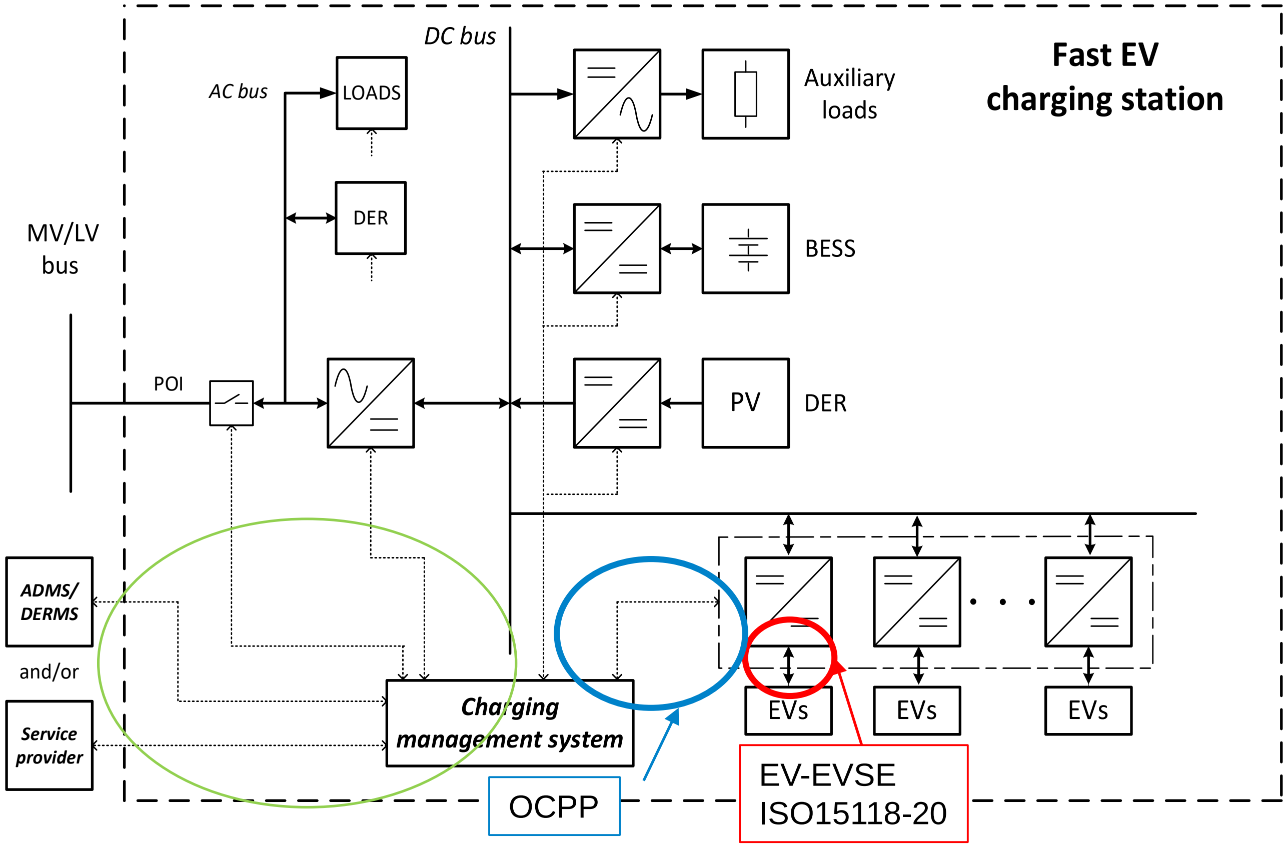
500A, 1000A, 3000A Sensors

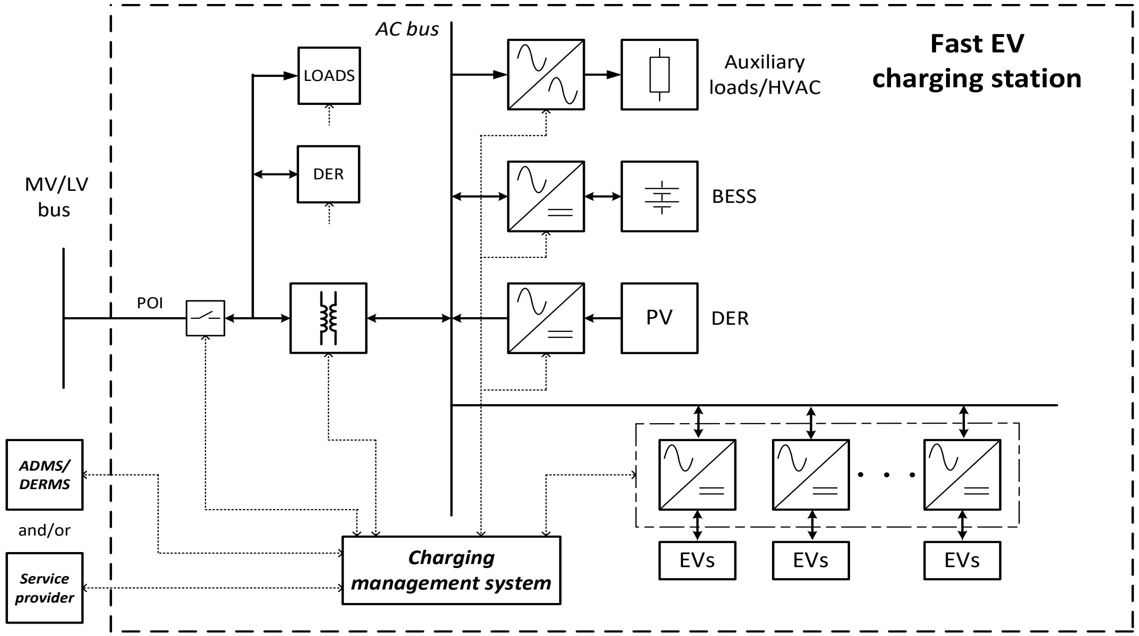
20mm contacts with fingerproof deadfront covers, Level 1=350A, Level 2=1000A, Level 3=3000A



IEEE P2030.13- Charging System Components; Energy Service Interface

- ***"Guide for Electric Transportation Fast Charging Station Management System Functional Specification"***
- DC and AC bus system diagrams in P2030.13, Dotted lines represent protocols between components/subsystems and for the most part, the charging management system 'block'.





Balance of System Standards as Subset of J3271- interconnected parts
Implementation of a J3271 MCS Charging installation

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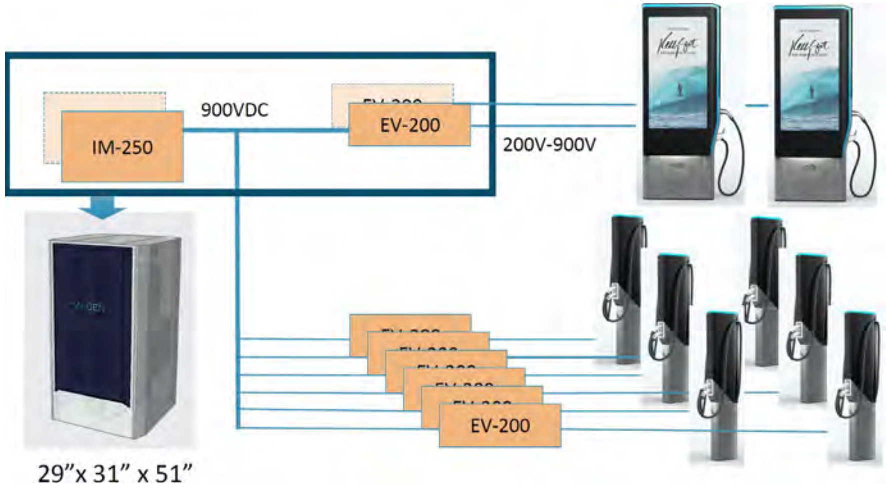
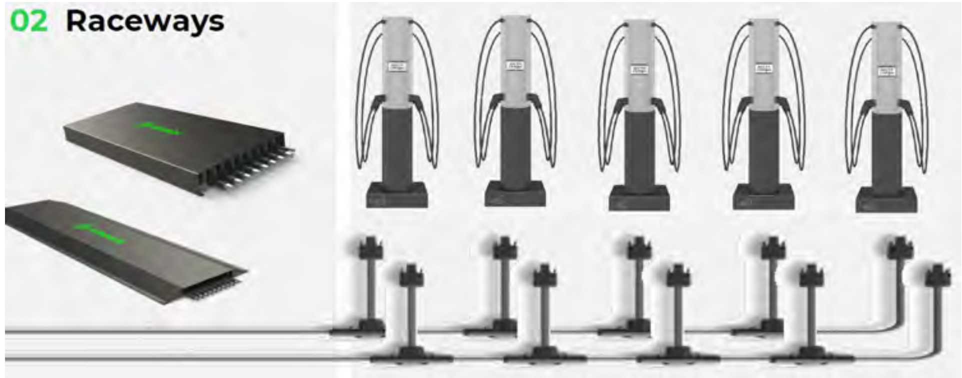
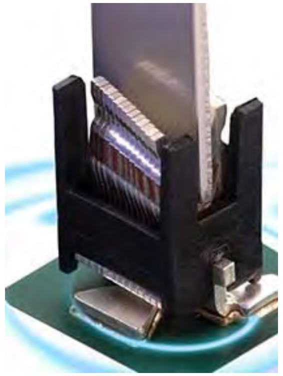
C&S Support Activity Collaborators- developing standards for connecting subsystems:





Imagen/Shoals DCaaS, 250kW blocks, MCS Ready



Tesla MCS Charging power electronics interconnected systems

Energy Service Interface Implementation- Connecting Components (Stds)

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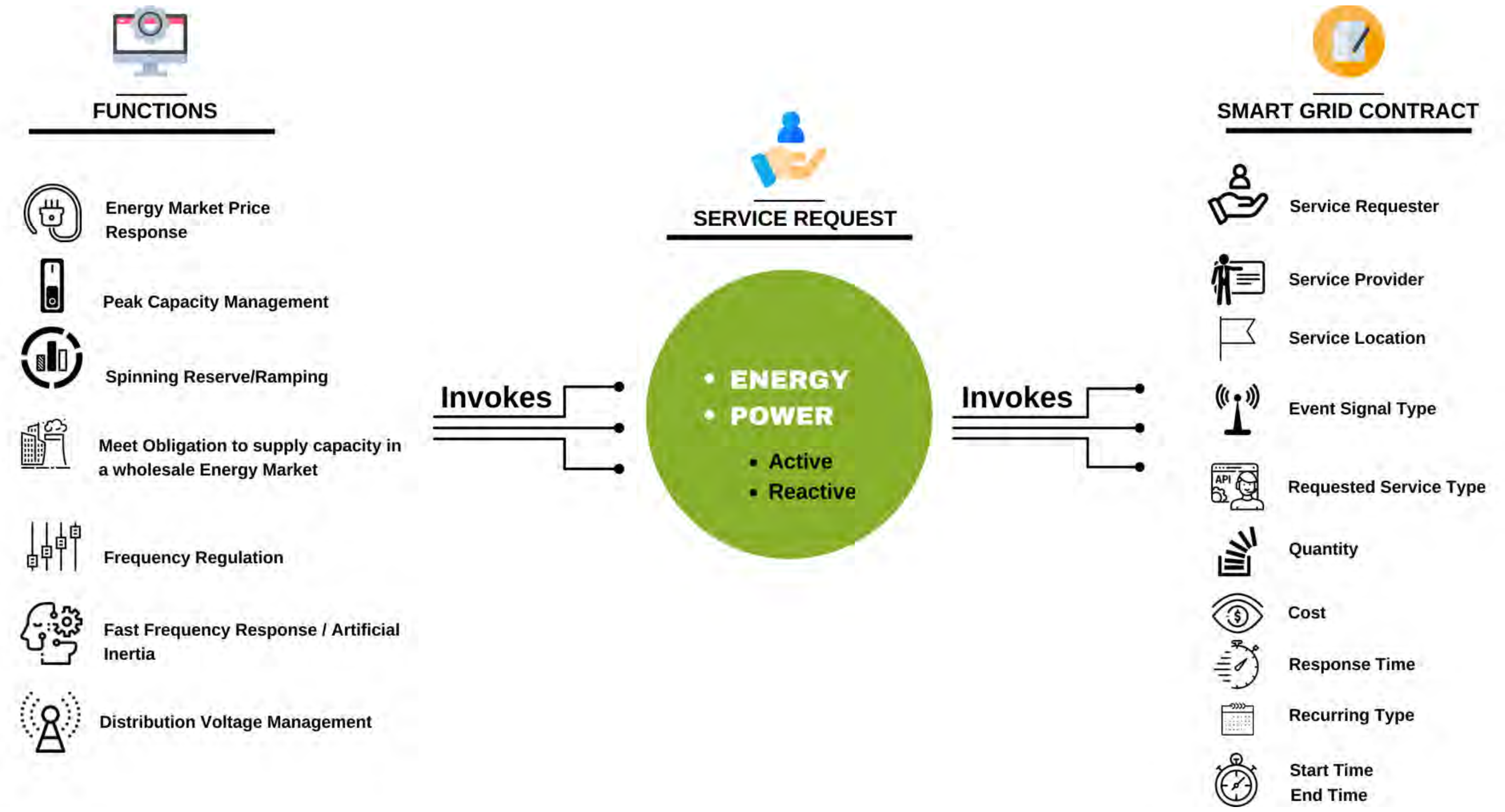
Ability to Communicate with all the ‘pieces’ of an HPC installation, sell Energy Services, Implementation with industry/utility partners



Conclusion and Next Steps

Review

- Initiative Overview
- Standards Support Priority Selection Methodology
- Significant areas of standards development activities
- Implementation/validation of technology-requirements as part of standards

Next steps

- Continued monthly MW+ Charging Industry Engagement interactions/feedback
- Continued weekly SAE J3271(AIR7357) meeting to TIR goal in October 2022
- Continued monthly standards work group participation; drafting standards, etc
- Progress to milestones are studies support WPT and P2030.13 standards
- Engagement in tentative Interoperability (Testival) events in 2022

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eCHIP
Modeling and Analysis of HPC Operation

Emin Ucer, NREL

September 13, 2022

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DC Hub Overview

EVs@Scale U.S. Department of Energy

Why a DC hub?

- Higher efficiency
- More natural interface with
  - EV
  - PV
  - ESS
- No issues in DC with
  - Reactive power flow
  - Frequency synchronization
  - Angle synchronization
- Less issues with harmonics

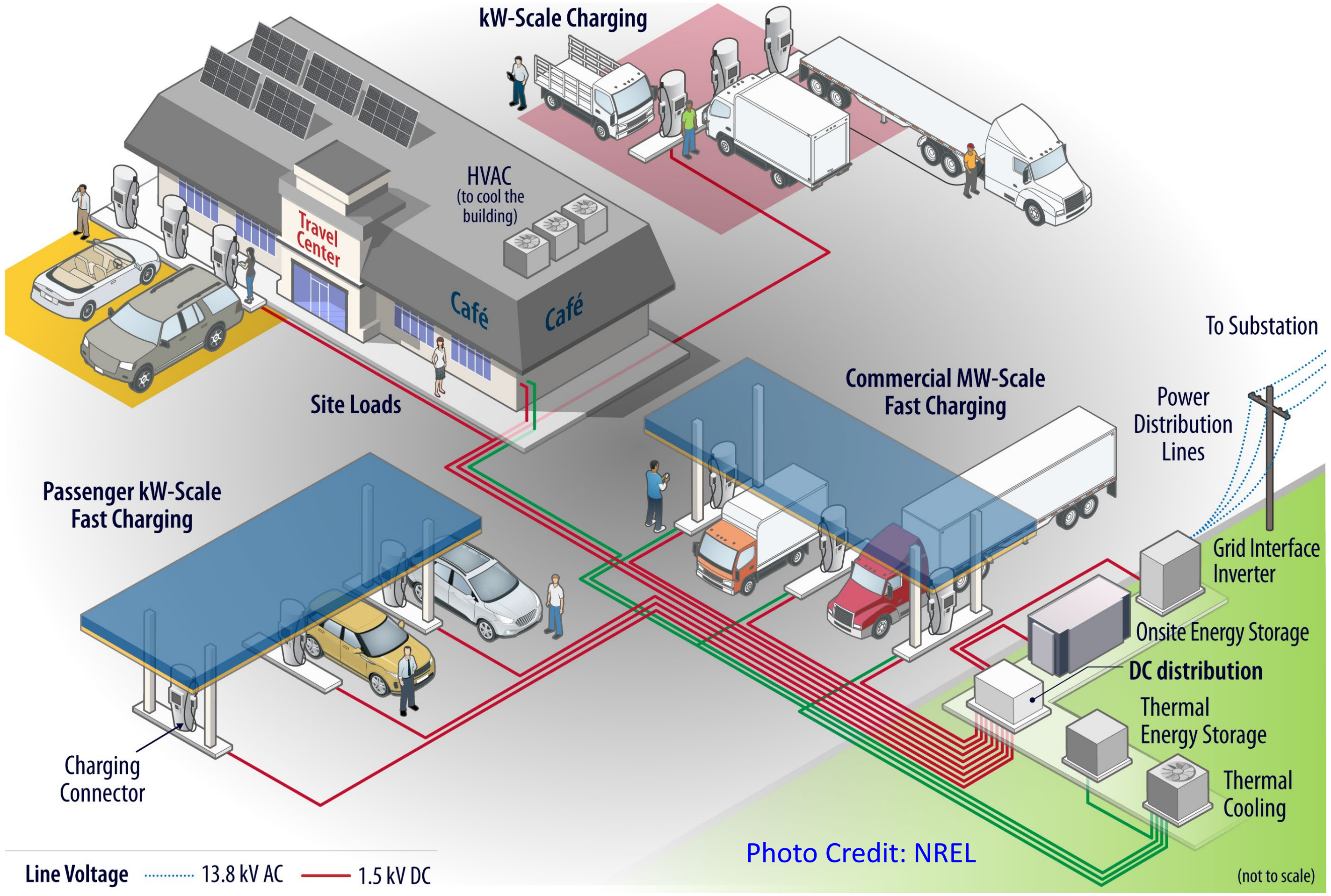


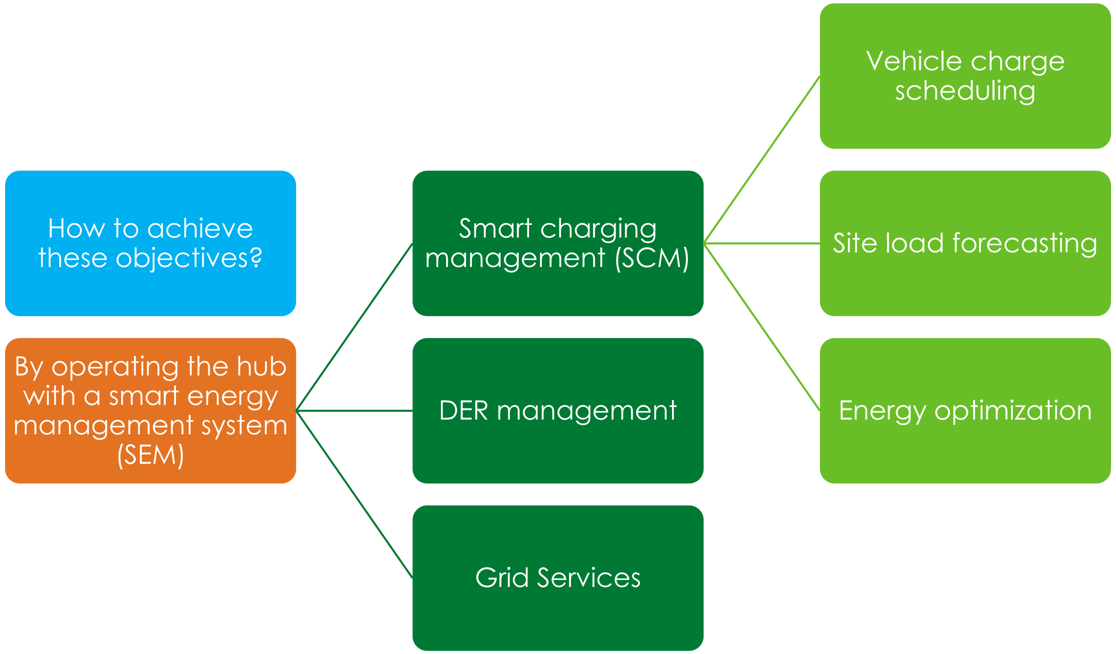
Photo Credit: NREL

Problem Definition

What are the main objectives of DC hub operation?

Reducing grid impact while still providing high power (MW level) fast charging service for several vehicles of different types, sizes and vocations by

- Minimizing peak loading
- Minimizing charging time and cost while meeting vehicle and grid requirements
- Providing grid services
  - Providing grid voltage support
  - Providing reactive power support
- Enabling DER integration
- Improving system resiliency and stability
- Providing islanded operation



Why modeling matters?

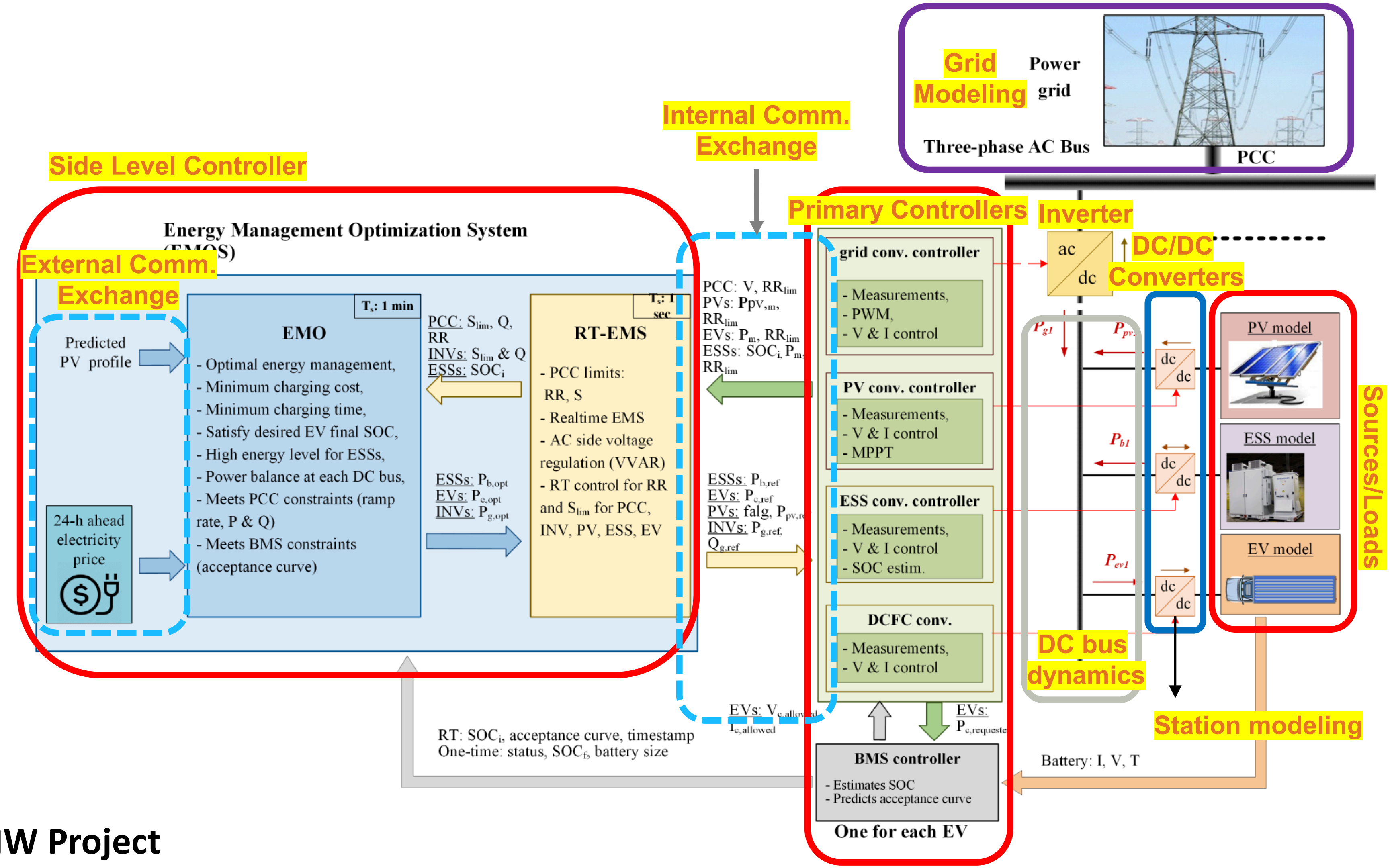
What are some main challenges in achieving these objectives?

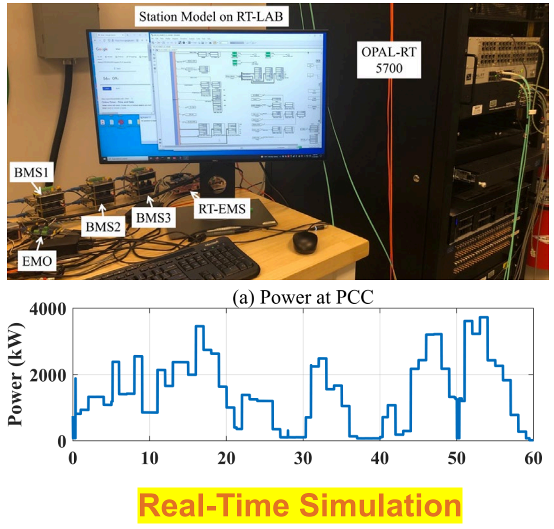
- Integration of PE interfaced constant power loads (chargers)
- Stability
- Interoperability
- Protection
- Operational and performance evaluation

These topics require extensive offline and real-time simulation analysis

These simulations require high-fidelity modeling of the system components and development of simulation environments

System Modeling and Components

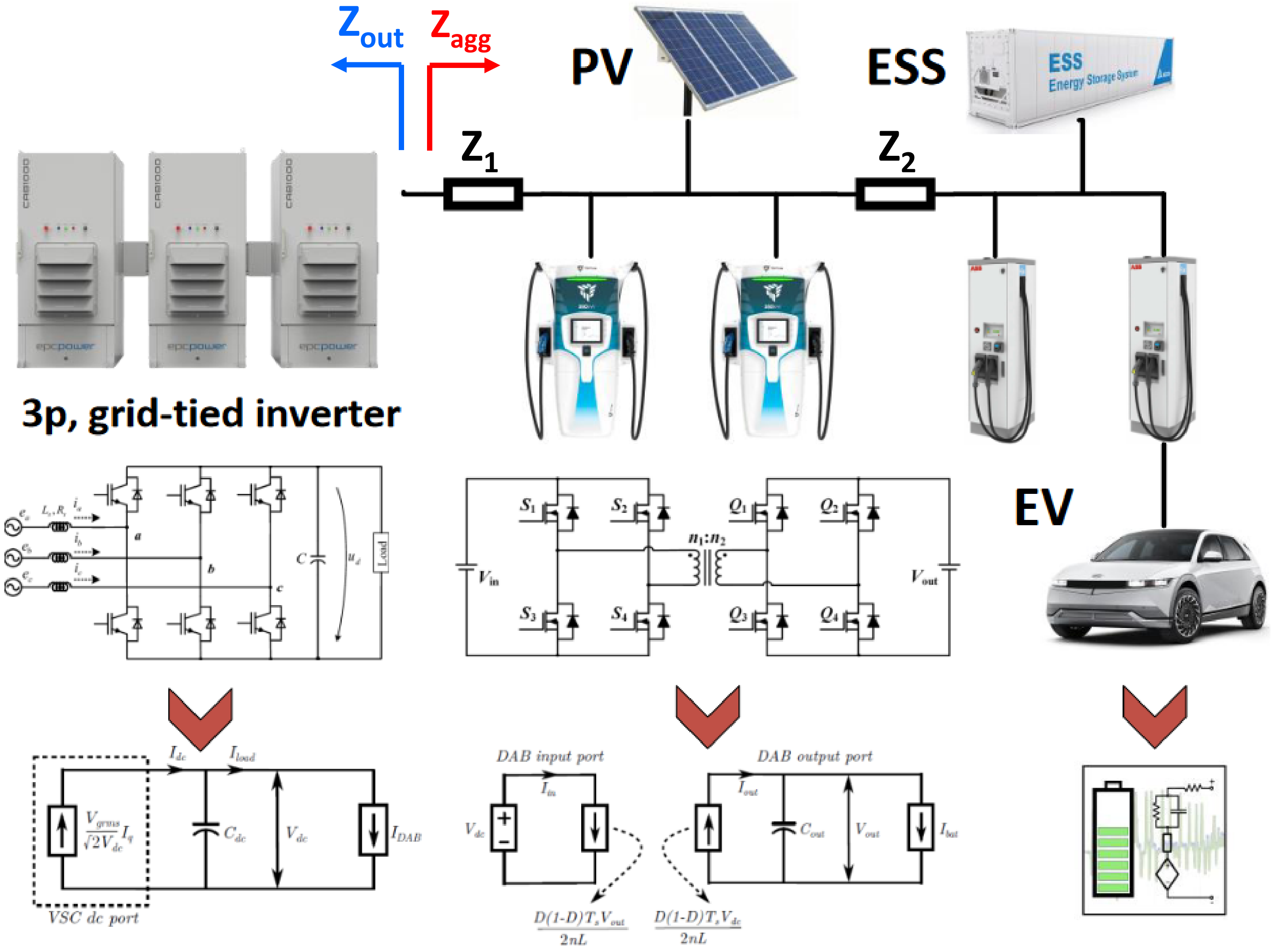


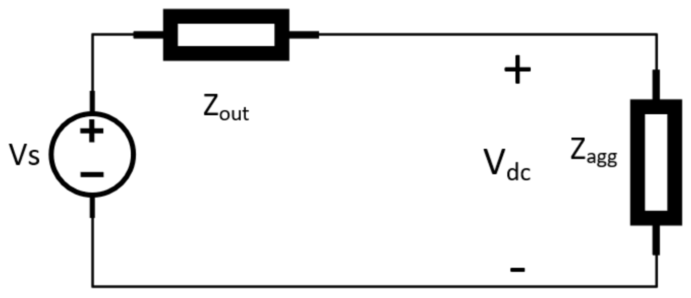


1+MW Project

A. A. S. Mohamed et al., "Hierarchical Control of Megawatt-Scale Charging Stations for Electric Trucks with Distributed Energy Resources," in IEEE Transactions on Transportation Electrification, doi: 10.1109/TTE.2022.3167647.

Converter, Inverter and DC Bus Modeling





DC bus dynamics stability will be determined by the impedance ratio of inverter output (Z_{out}) and aggregate load input (Z_{agg})

Highly regulated loads pose a threat to system stability and affect control decisions/actions

Therefore, accurate modeling of system under test is crucial

Side Energy Management Tools

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EV Charging Technical Assistance Landscape

Does energy storage lower charging costs?

EVI-EDGES

Accounts for rate structure, battery life, and cost

How should the stations be designed?

EVI-EnSite

Station performance, load profile, charge management, and quality-of-service metrics

What is the station cost?

EVI-FAST

Investor payback period, net present value, and break-even first-year charging cost considering both site and grid infrastructure upgrades

Where should the charging stations be located?

How many chargers and ports are needed?

EVI-RoadTrip

Based on conventional long-distance travel patterns

Does on-site solar reduce charging costs?

EVI-EDGES

Accounts for annual solar insolation, building loads, weather, and electricity rates

What are the equity implications of station location?

EVI-Equity

Charging infrastructure accessibility from environmental-justice perspective

What power levels are needed?

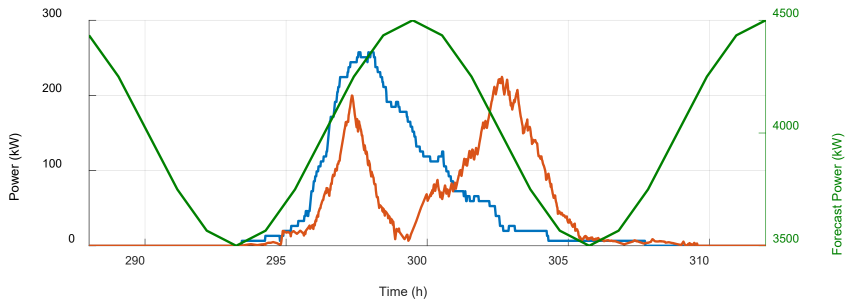
EVI-EnSite

Queueing model to identify wait times based on vehicle/power levels

EVI-EnSite Capabilities

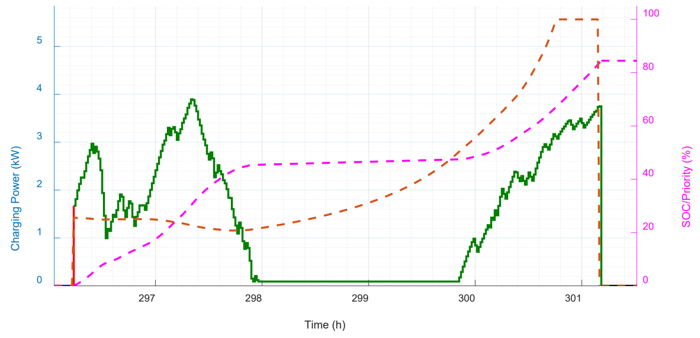
EVI-EnSite capabilities

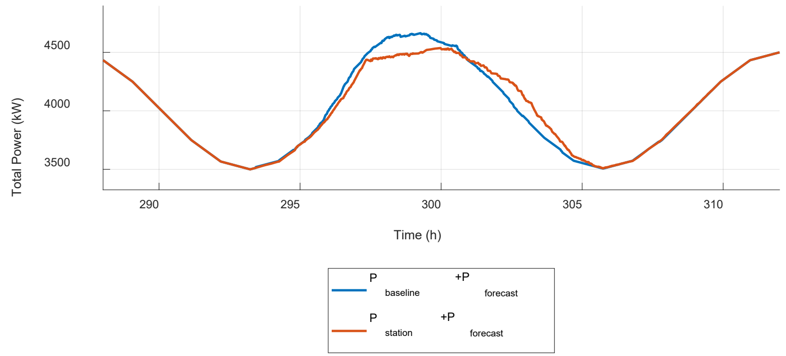
- Simulate a charging station with different port power levels
- SEM capabilities
  - Peak shaving
  - Cost optimization
- Power cap policies
- XFC charging profiles for EV
  - Future proofing for high power, short dwell time charging, short dwell time charging



Future SEM Capability development

- Energy optimization management system (EOMS) adoption and formulation
- Modify energy storage and PV coupling to reflect charging hub topology
- More controller options

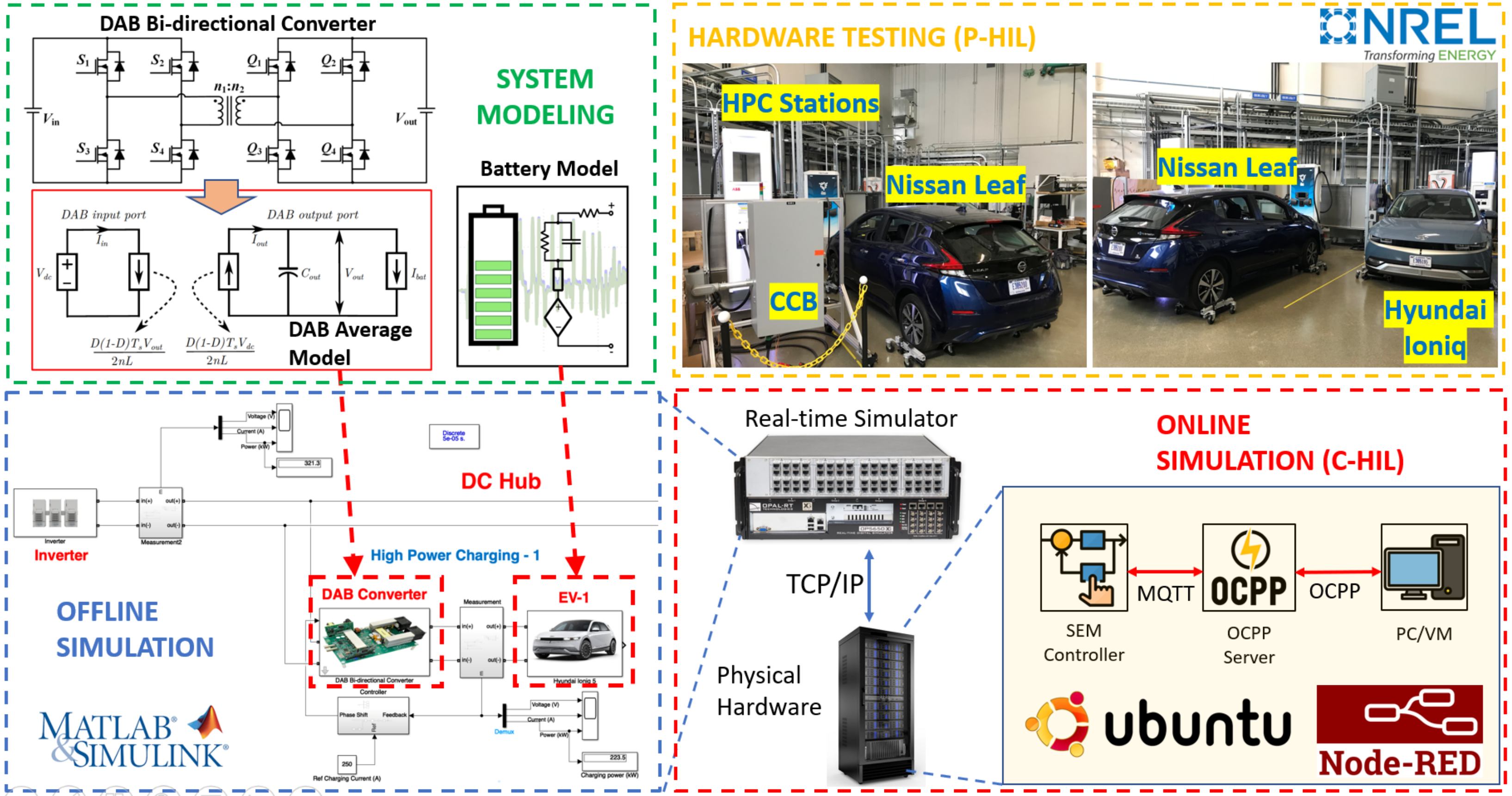




Controller Hardware-In-The-Loop (C-HIL)

C-HIL platform will investigate the methods and issues with practical charging hub development and operation

- Communication standards
- Scalability
- Multiple vendor assets
- SEM real time operation
- Power electronics modeling



C-HIL will serve as a digital twin of the physical DC hub, and help us test, analyze and evaluate all possible use cases and scenarios in a non-destructive environment before final hardware implementation.

THANK YOU

- **Questions?**

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U.S. Department of Energy

Jason D. Harper

ANL EV-Smart Grid Interoperability Center

Advanced Mobility and Grid Integration Technology

September 13, 2022

High-Power Charging Pillar: eCHIP

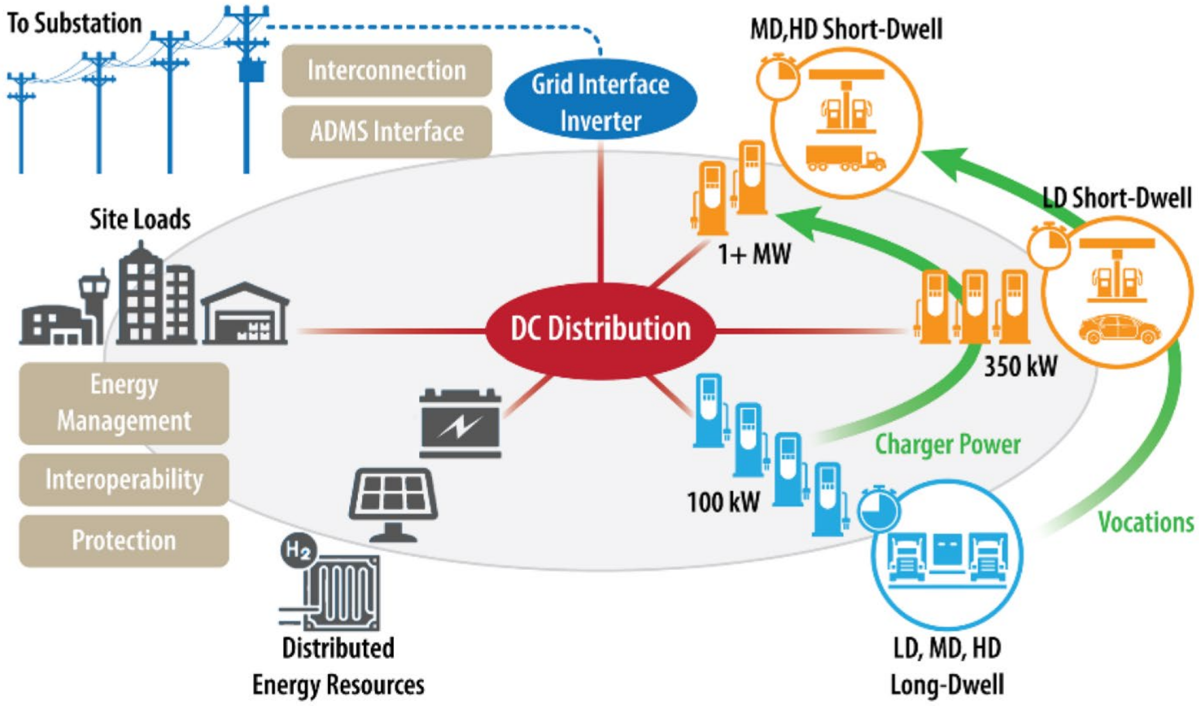
Site-Level Energy Management:

Integrating Chargers, DERs and the Grid

High-power Electric Vehicle Charging Hub Integration Platform

eCHIP System Block Diagram

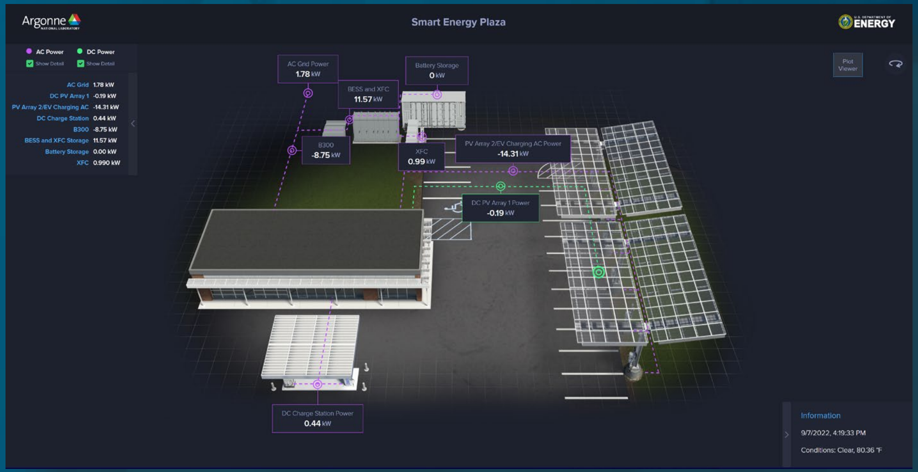
- **Design and develop a high-power, interoperable charging experimental platform to research, develop, and demonstrate integration approaches and technology solutions**
- **Focused on DC Distribution and V2X capabilities**



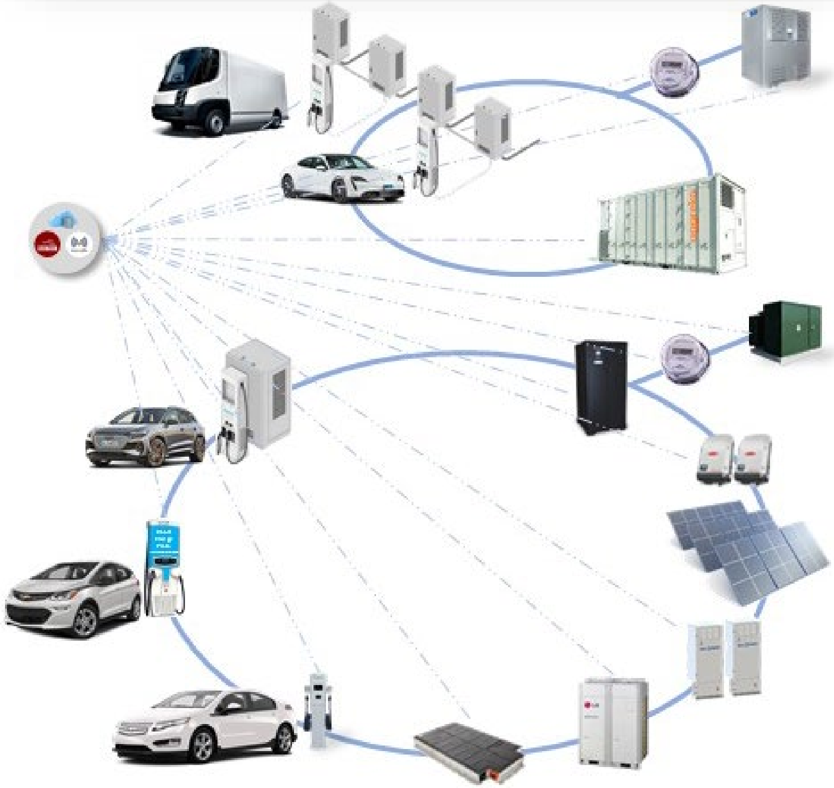
Argonne Smart Energy Plaza

Background

- 80 kW PV Solar Canopies
- 12 AC L2 EV Charging Ports
- Second-use BMW i3 battery
- Grid isolation switch
- 200 kW DC xFC
- 2x350 kW DC xFC
- 660 kWh Li-ion battery

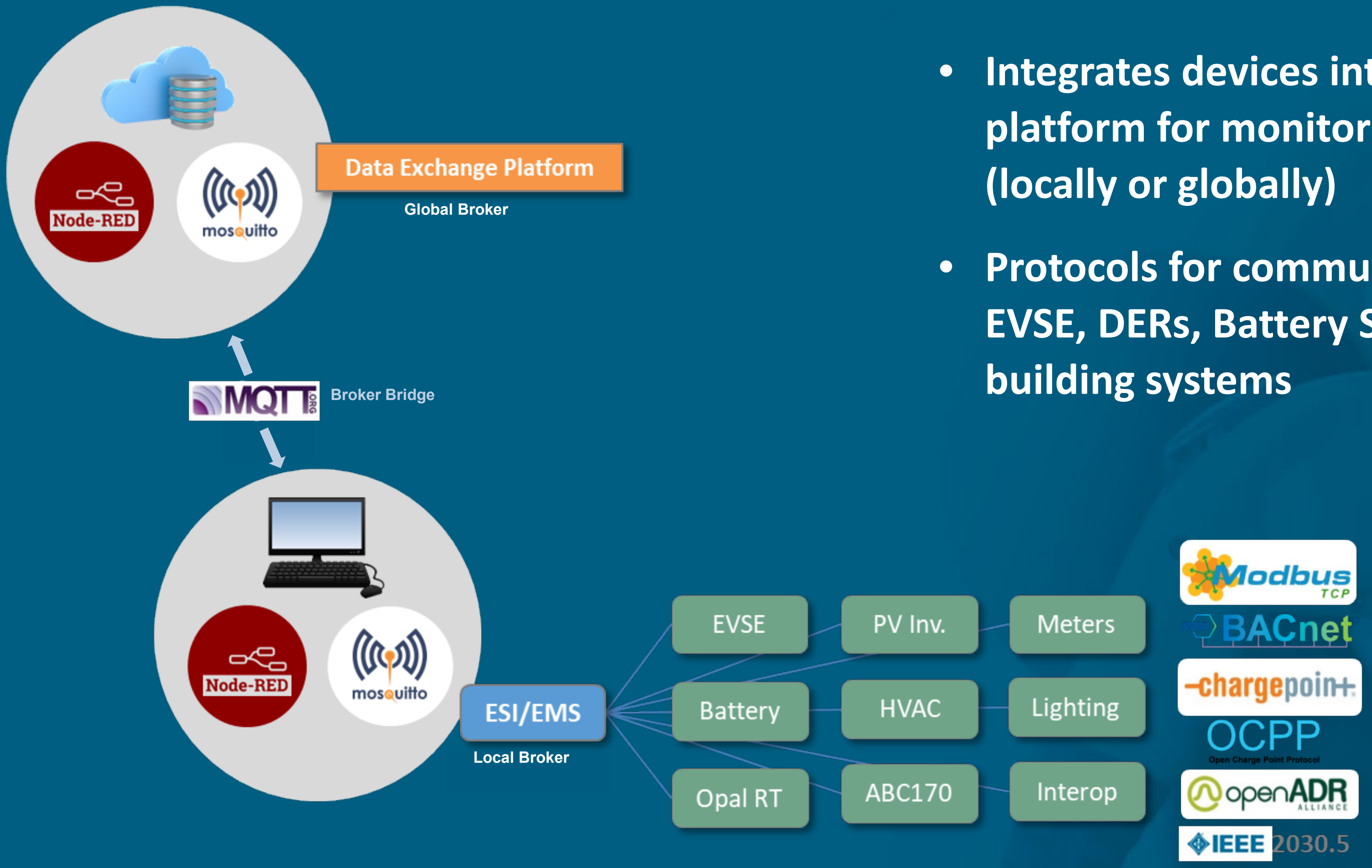


https://iot.ioc.anl.gov/



Common Integration Platform

CIP.io

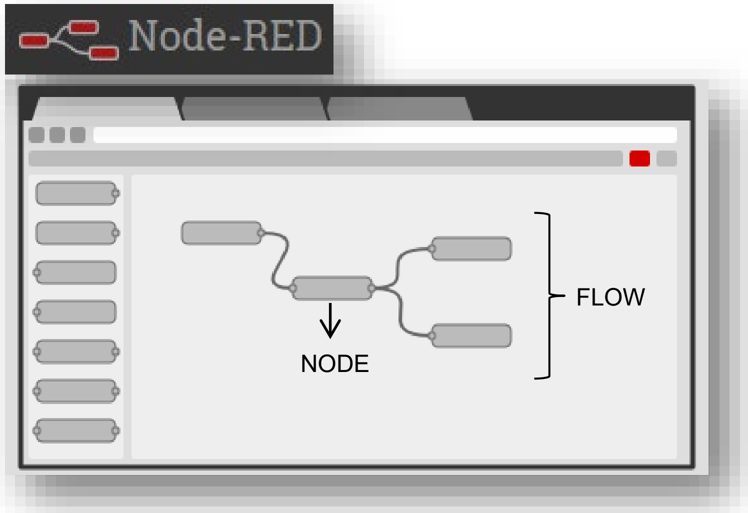


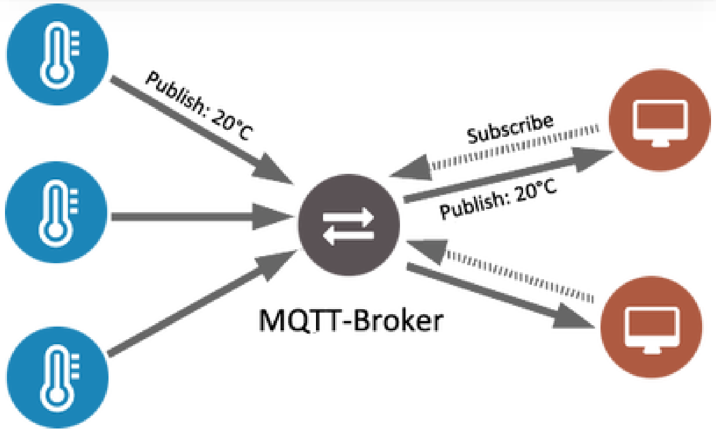
- Integrates devices into a common platform for monitoring and control (locally or globally)
- Protocols for communication with EVSE, DERs, Battery Storage and building systems

Common Integration Platform

Containerized for Deployment

- **Site Energy Management controller with built-in capabilities**
  - Node-Red (logic)
  - Mosquitto (MQTT)
  - Influxdb (time-series database)
  - Grafana (plotting and dashboards)
  - MongoDB (database)
- **Common language distributed over MQTT Broker(s)**
- **Open-source; runs on single board computer**
- **Customizable via Node-Red flows; example flows provided**
- **Auto-loads Argonne custom nodes**
  - OCPP
  - OpenADR
  - Modbus





Node-RED

mosquitto

influxdb

Grafana

mongoDB

Site Energy Management Requirements

Development

Outcome: Determine interoperable hardware, communication, and control architectures for high-power charging facilities that support seamless grid integration and resilient operation

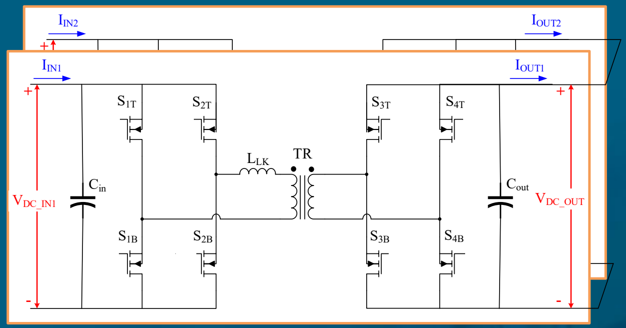
	Challenges	Requirements	Approach
Site Controller Architecture (Centralized/ decentralized)	• Lack of systematic methodology for controller structure design	• Scalability • Flexibility	• Hierarchical • Modular
Communication Interface	• Different standards • Proprietary	• Open standard • IP based • Interoperability	• Plug and play configuration
Data Storage	• No universal data structure for storing all types of data	• Data lifespan • Determine the types of data for public release • Time resolution	• Data categorization

Other technical requirements to consider

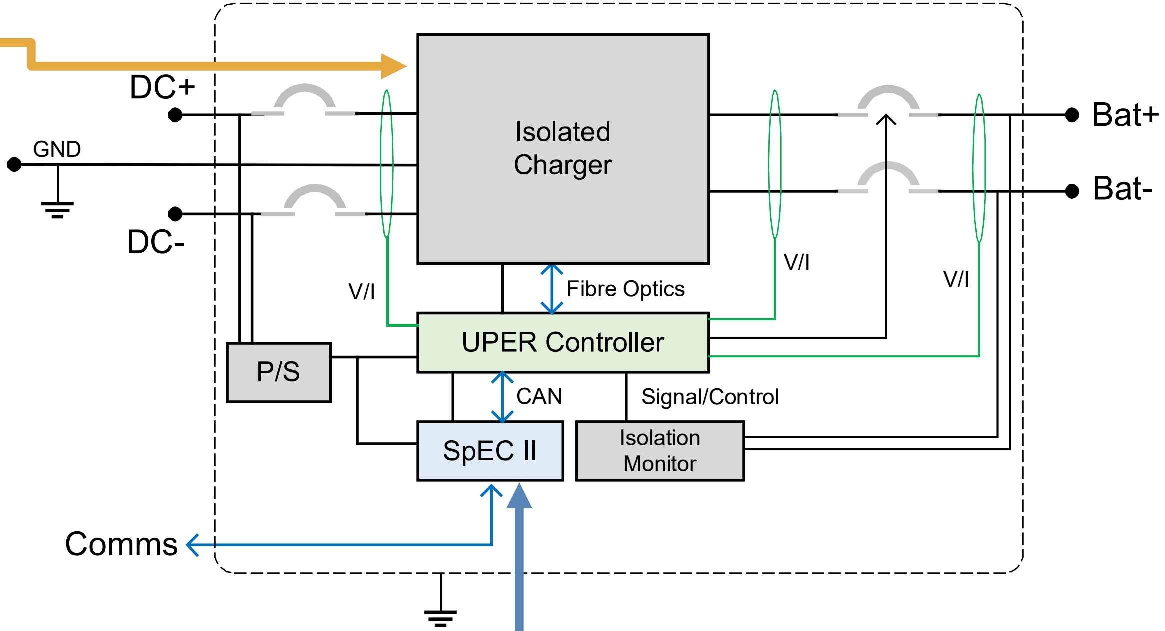
- Use Case/Control objective requirements
  - Requirements may vary for different locations such as public charging station, depot, airports etc.
  - Vehicle to edge capabilities, islanding operation
- Cyber security requirements
  - encryption (TLS), authentication, authorization, attack vectors, detection, and mitigation
- Measurement requirements
  - Measurements from different DER assets, protocol, latency

Bi-Directional High Power DC Coupled Charger

Development



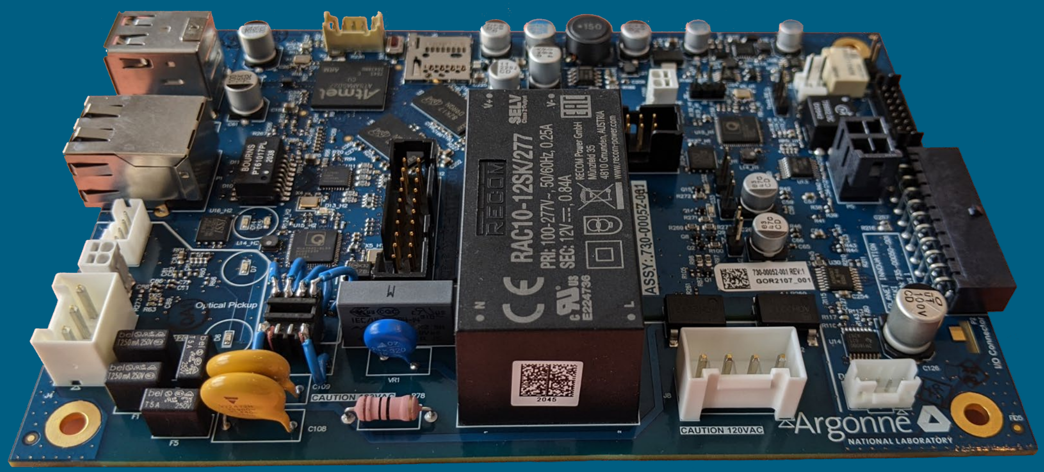
Isolated bi-directional DC-DC Module
2000V/1500V 350 kW

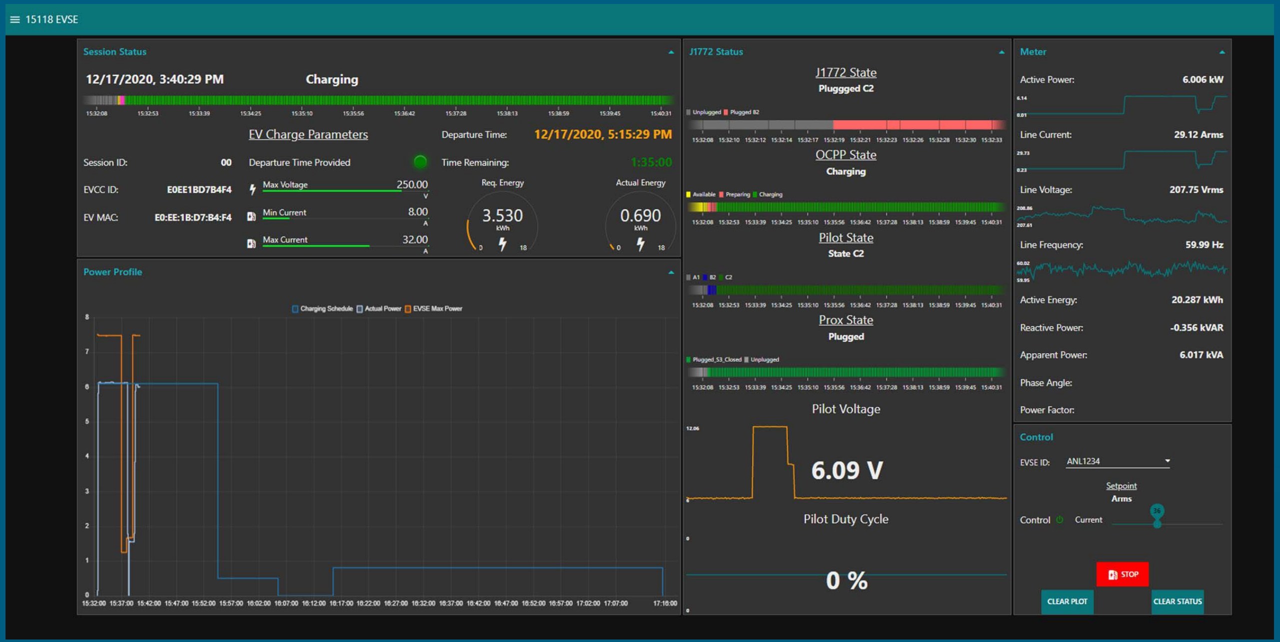


- ANL SpEC II module enables HLC between charger and EV
- ORNL UPER DC-DC module with analog instrumentation
- Implementation provides full control over communication and power electronics for R&D

SpEC Module

Gen II





Linux Kernel: 5.4.81

Custom Device Tree Overlay

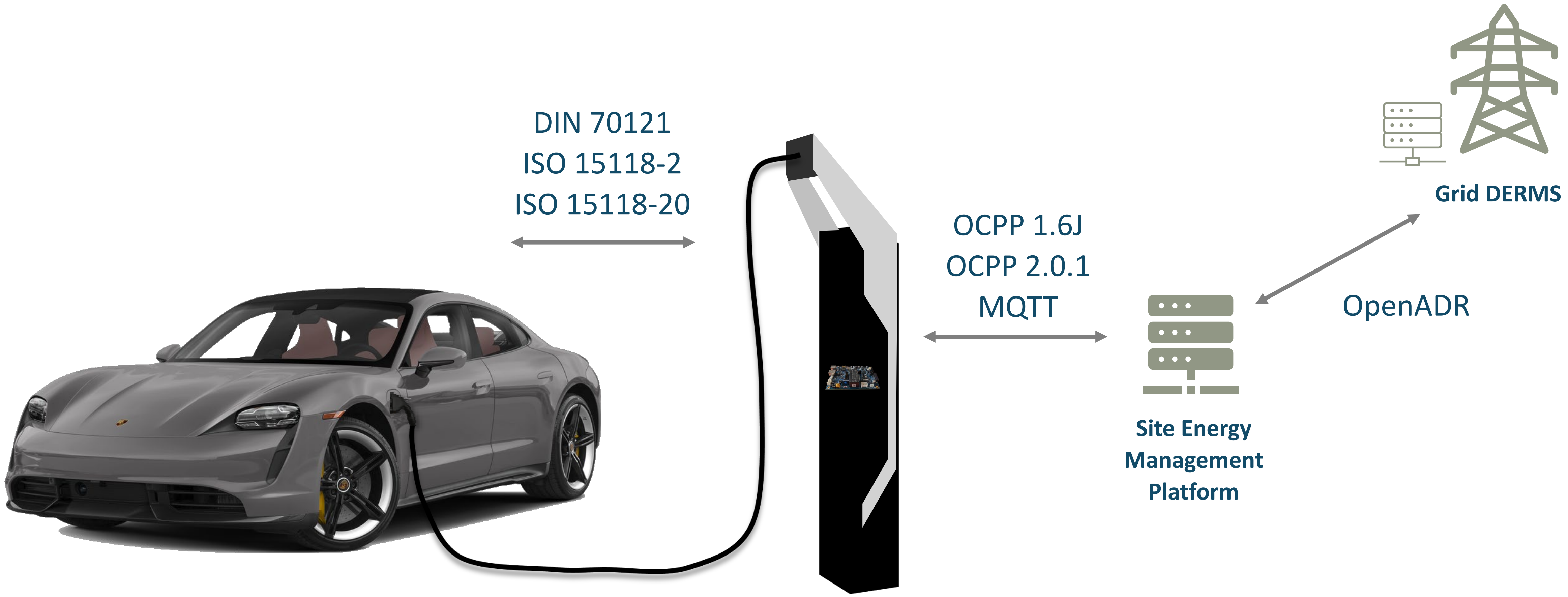
OCPP 1.6J Client

Custom C/C++ Applications

- DIN 70121
- ISO-15118-2
- ISO-15118-20

Site Energy Management Integration

Initial Protocols



Site Energy Management: Site level controls informed by site objectives and grid level insight/control
Grid Integration: coordination with utility grid, standardization, grid services and power quality

Development Milestones

DC Coupled Bi-Directional Charger

Note: Milestones reflected are subject to change

Q4 2022
- Finalize Hardware integration requirements
- Develop and test SpEC firmware for CAN comms with UPER
- Begin implementing V2X using DIN 70121 / SAE J2847-2

Q1 2023
- Run simulated BPT session at ANL using DIN 70121 / SAE J2847-2
- Run a charge session with SpEC + UPER (DIN 70121)

Q2 2023
- Demonstrate BPT with SpEC + UPER (DIN 70121 / SAE J2847-2)
- Finalize development of ISO 15118-20 EXI codec
- Run simulated BPT session at ANL (ISO 15118-20)

Q3 2023
- Run actual BPT session at ORNL (ISO 15118-20)
- CIP.io integration with NREL
- Final demo of BPT session (ISO 15118-20)

Q4 2023
- Continue testing and maintaining

Credit: **Akram S. Ali**

Thank You

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Summary of Codes and Standards Engagement for High Power Charging

September 13th, 2022

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

EV Grid Integration Standards Gap

- At-scale adoption of emerging technologies needs standards, best practices, and guides
  - IEEE 1547 (device level): technical specifications for, and testing of, the interconnection of DERs
  - IEEE 2030.7 and 2030.8 (systems level) specifies microgrid energy management system functions and testing
  - IEEE 2800 (device/systems level) deals with interconnection and interoperability of IBRs at transmission level
- For fast charging stations, guidance/standards are needed to address:
  - Interconnection and interoperability issues between chargers, DERs, and higher-level management systems
  - Lack of generalized control functions/guidance to manage stations (distribution or transmission levels)
  - EV charger and station level settings for ride through and reconnection
  - Barriers in enabling and measuring grid services provided by stations for diverse EV vocations
  - Lack of standardized control functions/interfaces for grid capacity management, demand charge mitigation, flickers, PQ issues

EVs@Scale Codes & Standards

- **Objective:** Address challenges and barriers for high-power EV charging standards by identifying and filling gaps in charging equipment as well as grid impacts, interoperability, and safety topics.
- **Outcomes:**
  - Facilitate creation and improvement of codes and standards enabling ‘Evs@Scale’ charging
  - Engage with industry stakeholders to create a consensus-based EV standards roadmap
  - Create interoperability guidelines and criteria to evaluate standards compliance/implementation
  - Supply validation test data with industry partners to support standards refinement
- **Team and Collaboration:**
  - ANL, INL, NREL, ORNL, PNNL
  - Industry charging stakeholders
  - Subcontractor subject matter experts (ANSI, University of Delaware, Rema, BTCPower)
  - Standards organizations (SAE, IEC, ISO, IEEE, ANSI), Code panels (NCWM, UL, NFPA)

IEEE P2030.13 and SAE J3271

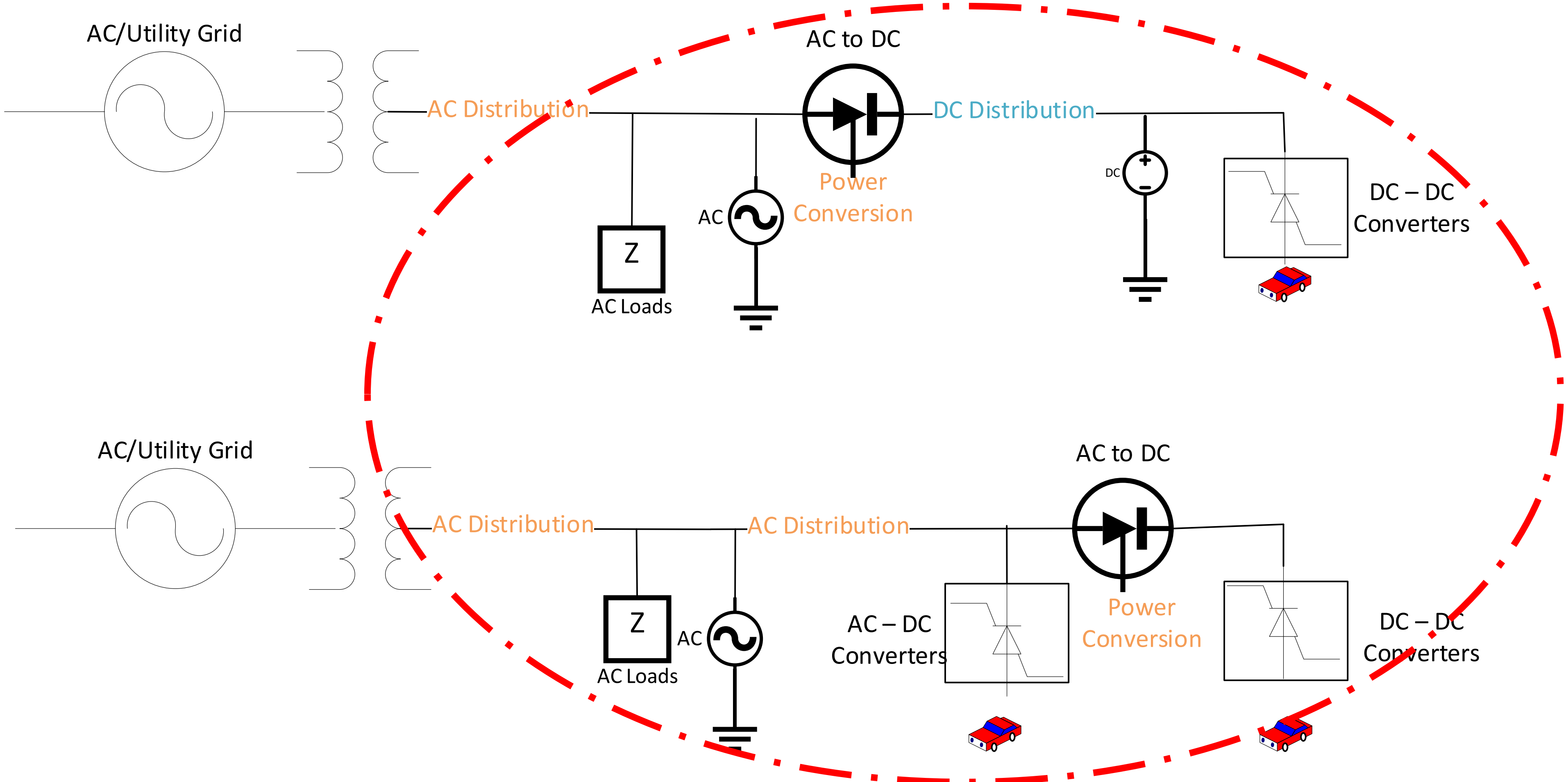
- **IEEE P2030.13:** Draft Guide for Electric Transportation Fast Charging Station Management System Functional Specification
- **SAE J3271:** Megawatt-level DC charging system requirements for couplers/inlets, cables, cooling, communication and interoperability
- SAE J3271 (specifically grid integration) and IEEE 2030.13 – **harmonized!**
- SAE J3271 will evolve: TIR (Fall 2022) -> RP -> IS

P2030.13 Introduction & Scope

- FCS may have any number of chargers, DERs, etc. based on need and power/energy availability
- Functional specs for EV fast charging station management and controls
- Incorporate solar photovoltaic (PV) & battery energy storage systems
- Set of core functions for FCS control systems:
  - Energy storage discovery and evaluation of charging; monitoring and control of charging profiles;
  - Charging station energy estimation,
  - Energy scheduling and management,
  - Charging station grid interaction and interaction,
  - Grid power exchange management, and
  - Grid code requirements and ancillary services provision

Architectures for Fast Charging Stations

- AC/DC architectures for FCS design to enable rapid adoption
- Guide covers both architectures, and control functionalities are agnostic



Typical Control Functions

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- Levels of control functions needed:
  - L1 lower functions (Typical DER functions)
  - L2 core functions (EMS and CSMS)
  - L3 higher level functions (ADMS, markets, etc.)
- Hierarchical or distributed controls can be implemented
- Microgrid functionalities such as dispatch and islanding/reconnection
- EV charging and other key loads can be treated as critical
- Utility grid conditions and DERs optimized to provide EV charging loads and non-critical loads

Summary

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- Actively working on the development of IEEE P2030.13 and SAE 3271
- Addressing functional specifications, control functions, and integration requirements for high power chargers and DERs
- Leverage existing standards IEEE 1547 for behind-the-meter DER integration
- Microgrid functionalities to be leveraged from IEEE 2030.7 and 2030.8 for enhancing resilience of charging infrastructure
- Higher level grid integration of grid management systems and FCS control systems will ensure seamless integration
- **Are we missing anything?**
  - Similar to IEEE 2030.8, an annex for 2030.13 on control systems testing?
  - How to ensure voltage/frequency ride through and re-synchronization on EVSEs?

Thank you!

Questions?

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No	Topic Discussed	Feedback / Takeaways
1	Converter cooling	1. Cooling of high voltage/high frequency passive components could be an issue. Specially for the case where the converter weight needs to be low. 2. For example, 175kW transformer used in the converter – using a thick cable to minimize loss. It becomes challenging to bend the thick cable. Also, cooling of the transformer is not easy. Liquid cooling of the transformer will increase the weight. 3. One industry partner is working on liquid cooling of converter and has shown interest in further discussions.
2	Location of the converter (Outdoor or indoor set-up)	1. For outdoor placement – the converter has to withstand environmental conditions (i.e., temperature, cosmic radiation). 2. Third party vendors could potentially provide solution for the enclosures.
3	Power level and voltage level	1. 950V DC-hub voltage in the 1st phase of the eCHIP hardware demonstration seems reasonable as one industry member comments. The same industry member commented that when the central inverter (e.g., EPC Power CAB 1000) is available, it will be interesting to see how it works for a DC voltage of 1500V. However, it should be noted that the DC output voltage range for the CAB 1000 inverter is 720VDC-1250VDC. 2. Phase 1 stage of the hardware demo will be dedicated to unidirectional operation while Phase 2 will investigate bidirectional operation with the grid.
4	Grid event	1. If there is any grid disturbance event, the converter needs to identify (or be acknowledged by) and respond to the grid event.

No	Topic Discussed	Feedback / Takeaways
1	Protection, Transients and Stability	1. Critical to model and characterize bus transients induced by high power charging events. This needs to include normal operation, fault conditions and protection trip offs events. 2. There will likely be challenges in accurately modeling the fault condition and protection trip offs cases.
2	Use Cases - V2G, V2B, V2X. etc	1. Topic is worth pursuing. 2. Industry investment / priority for this technology is still unclear.
3	Commercial Site Energy Management (SEM) solutions	1. Commercial products exist which perform SEM for just building loads or just charging. Many are locked into working with only certain company's products. 2. It is still unclear if there are industry SEM solutions that we might incorporate or test within this project.
4	Open-Source SEM - Project Output	1. There is interest in making an open-source SEM controller available at the end of this project. 2. Given the configuration / customization needed for a real-world charging hub, it makes sense to limit this controller to a proof-of-concept which will demonstrate some of the core features developed on this project.

No.	Topic Discussed	Feedback/Takeaways
1	General Regulatory Comments	1. There have been difficulties getting a DC utility tariff put in place. Various concerns over metering, pricing, etc. are hampering progress. Also, most of tariffs are specific to electrification and do not apply directly to all behind-the-meter assets, i.e., not uniformly applicable to the charging site. 2. Currently, some areas within the general codes and standards topic are growing apart in some ways – either a proposed topic fits into the standard and changes are sought, or it doesn't fit in and there are conflicting goals from different organizations. Efforts in this area are very important in order to harmonize the various topics within Codes & Standards.
2	MCS/J3271	1. Talked about cord handling approaches as discussed in MCS/J3271 meetings. 2. Important to consider requirements for different use cases (such as a train in a railyard experiencing some movement while charging). Should take into account differences between human vs. machine/robot-operated charging solutions when developing standards.
3	NEC/ADA/Canadian Electrical Code	1. NEC, Canadian Electrical Code (CE Code), and ADA should be referenced for the Codes & Standards area. 2. Some codes, such as CE Code, are primarily electrical safety-focused, and may not have many EV-specific, charging station configuration-focused regulations. 3. Regulations and guidance for first responders should be considered for situations such as battery fires.

4	State Utility Commissions	1. State Utility Commissions would like codes and standards to address:
		    1. Safety issues – handling of charging cords and overall site electrical safety
		    2. Interoperability issues – should make sure what's installed will work with any utility, EVs, customer, etc.
		    3. Useability standards – EV chargers should be as easy to use as a gas station. Anyone should be able to use them easily, no matter what vehicle they drive.

5	Electrical Ratings with Smart Charge Control	1. With smart charge control, some high-power-rated sites could want to use smart controllers to ensure that current never exceeds operating limits of lower-rated equipment (i.e., a 10 MW site with smart charge software to ensure that a particular cable never exceeds 500 kW). Codes and Standards work should address how use cases like this fit into regulatory framework. 2. Should provide guidance on how to perform testing on fast-charging systems. (e.g., specifying a certain testbed/test process to quantify a fast charger's performance in different areas.)