OAK RIDGE National Laboratory

Resilient High Power Charging Facility

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U.S. DEPARTMENT OF ENERGY

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Overview

Timeline

- Start – FY21
- End – FY23
- Three budget periods

Budget

- Total project funding
  - DOE share – $4.5M
  - Cost share from partners – $ 0M
- Project spending BP1: $650 K

Barriers

- Availability of charging profiles for extreme fast chargers
- Charger topologies for MD and HD vehicles
- Charging station architecture for extreme fast chargers

Partners

- Oakridge National Lab (ORNL) (Project lead):Madhu Chinthavali, Michael Starke, Suman Debnath
- Pacific Northwest National Laboratory (PNNL): Rick Pratt, Thomas Carroll, Lori Ross O'Neil, Frank Tuffner
- Idaho National Laboratory (INL) : Tim Pennington, Craig Rieger, Kenneth Rhode, Richard "Barney" Carlson
- Company: ABB
- Virginia Commonwealth University (VCU)

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

Project Objectives and Relevance

Overall Objectives:

- Develop control and anomaly detection techniques to improve the resiliency of the electric grid and charging stations:
  - Potential challenges: poor charge management, malfunctioning equipment, cyber-physical security
  - Reduce grid impact of high-power charging stations (125 kW, 350kW+ and 1MW +)

FY 2021 Objectives:

- Develop use cases for charging station anomalies and the station architecture
- Development of analytical approaches to anomaly detection
- Develop system level control techniques to mitigate impacts.

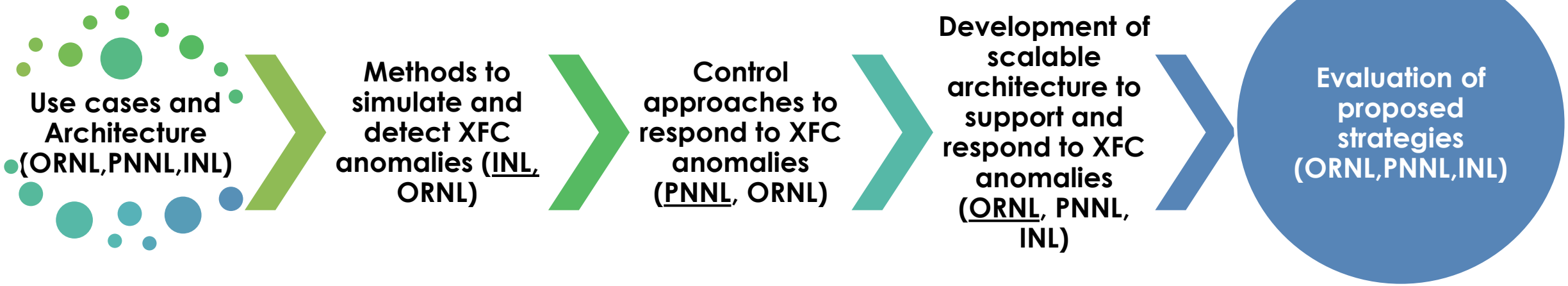
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Project Milestones

Date	Milestones and Go/No-Go Decisions	Status
BP1 (FY21) 10/2020-09/2021	Complete the development of use cases, detection methods for anomalies, and the control techniques to mitigate station impacts.	On track
BP2 (FY22) 10/2021-09/2022	Complete the control hardware in the loop evaluation charging station platform with distributed controller architecture	Not started
BP3 (FY23) 10/2022-09/2023	Integrate anomaly and control mitigation techniques into emulated charging station platform and validate the use cases	Not started

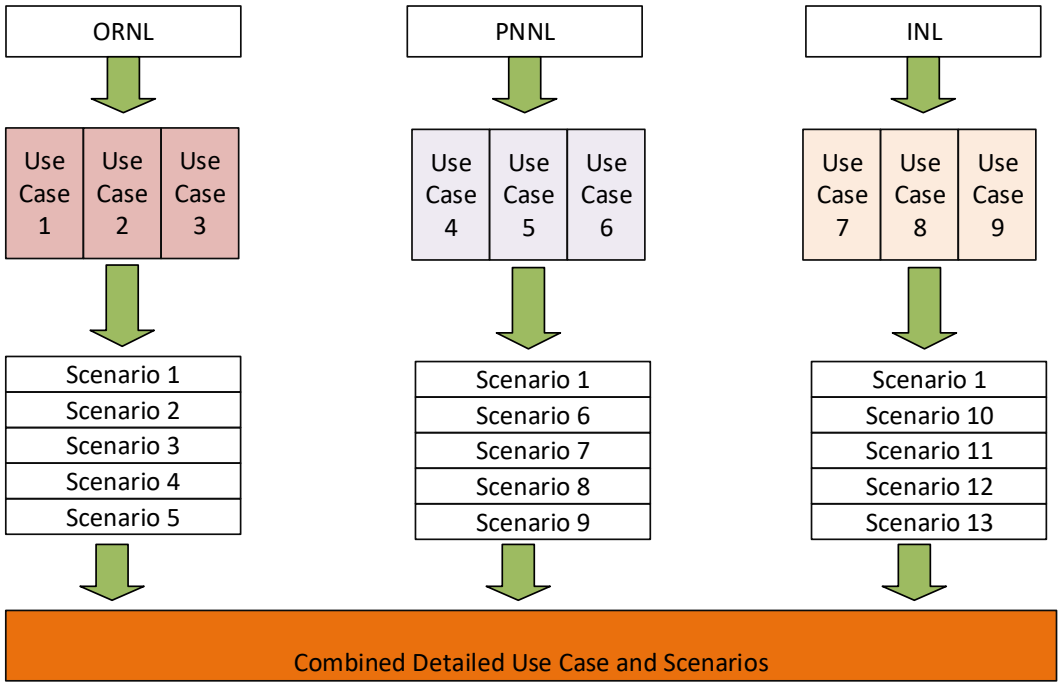
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Approach / Strategy



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Technical Approach



Use Case: Defines a mechanism that could lead to potential failure of the charging station. This could be a piece of equipment, communication network, or line outage as examples.

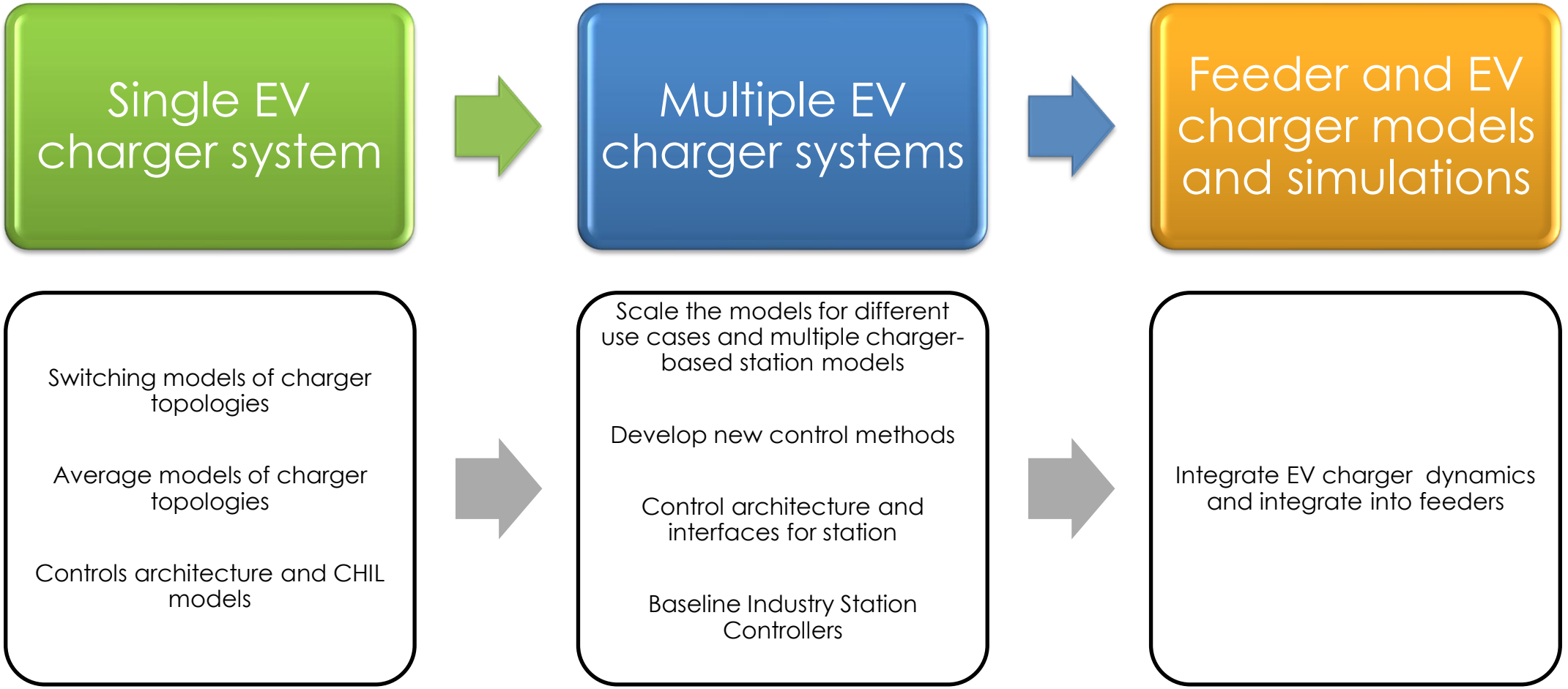
Scenario: A condition in which the system is operating. This could be high loading or charging conditions, low renewable generation, or low battery energy as examples.

Detailed Use Case: Defines a use case as applied to a real-world example. This could be a UPS facility that has an equipment failure.

Example: Detailed Use case populated with scenarios:

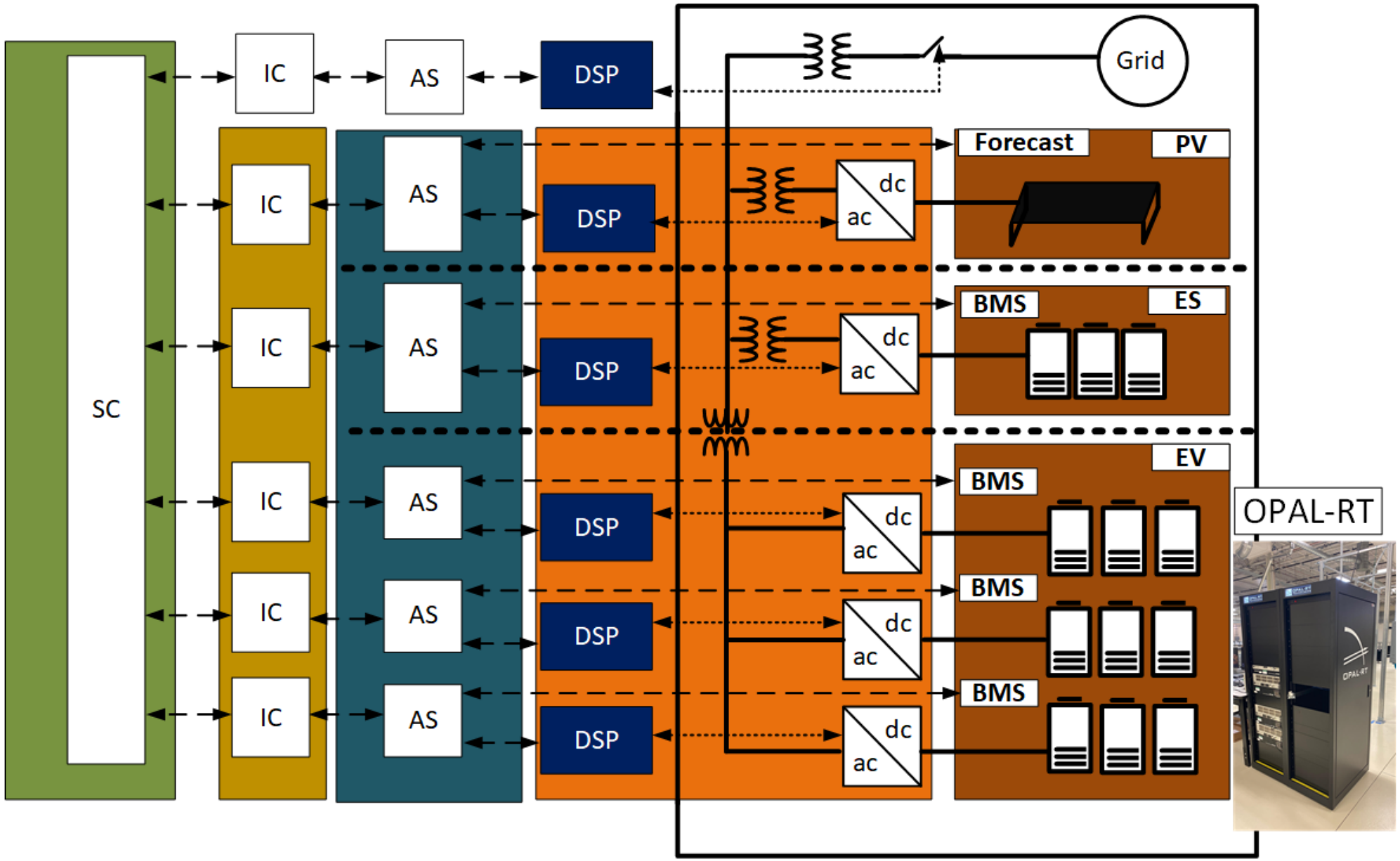
Fleet operating facility is connected to a system in which the electric grid has gone out. This occurs during a high loading period before truck rolls and in the evening with low solar output.

Technical Approach: Power Electronics and Controls for Charging Station Models



Technical Approach : Example Integration into HIL systems

- SC- Station Controller
- IC – Interface Controller
- AS – Agent System
- DSP – Converter Controller



Technical Approach: Charging Station Metrics

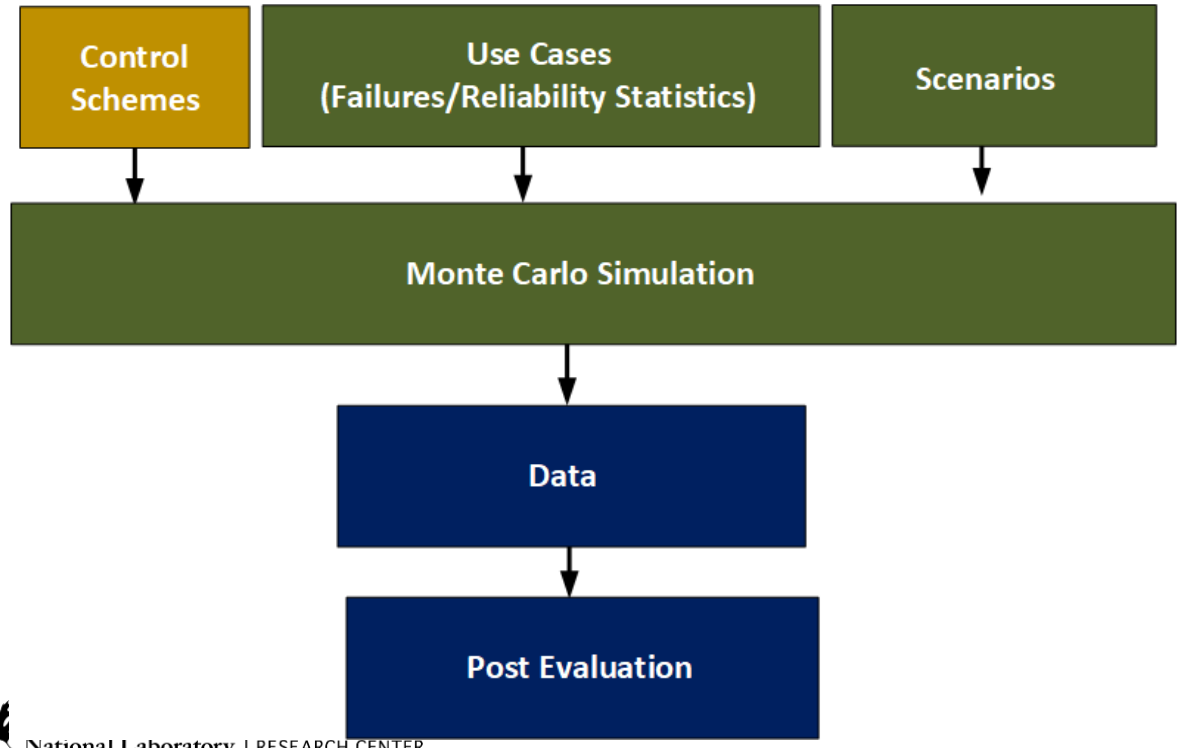
- Resiliency for charging station is focused on customer (electric vehicle charging) outages (frequency and duration used in metric)

- Resilient mechanisms will simultaneously consider minimizing customer experience of outages or charging interruptions and maximizing customer service rates (charging experiences).

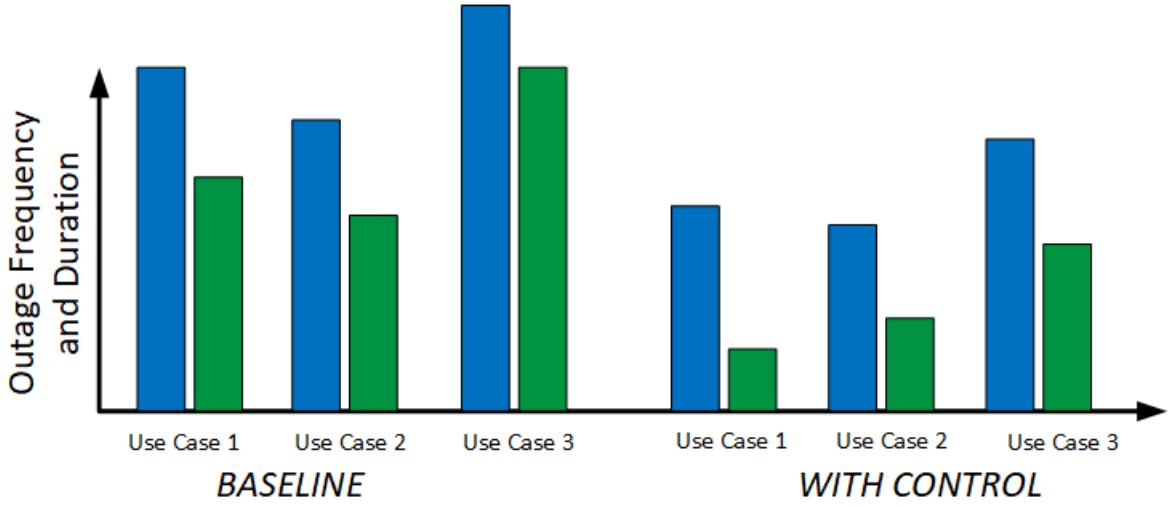
Metric	Definition
Station Interruption frequency average	the average number of interruptions that a customer would experience versus a baseline
Station Interruption duration average	the average outage duration for each customer served versus a baseline
Station Interruption service recovery	the difference of energy delivered versus baseline

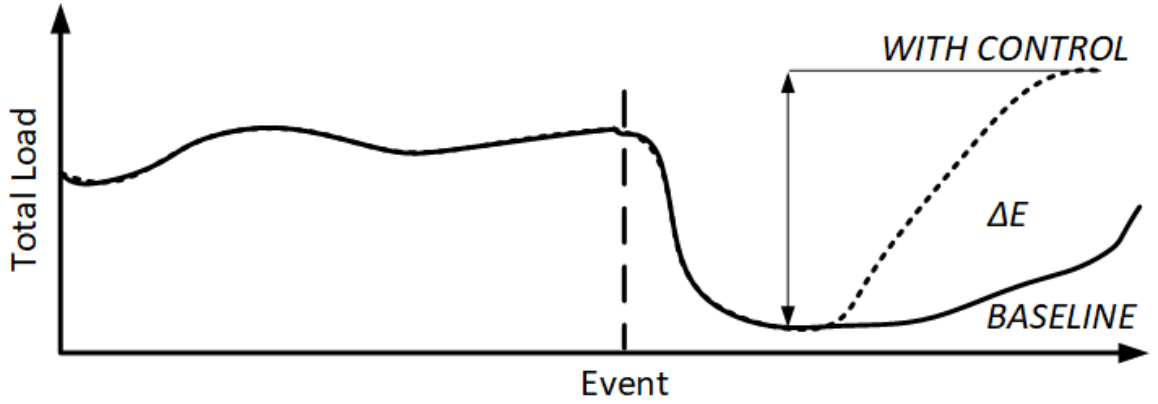
Technical Approach: Generalized Approach for Evaluation

- Using statistical methods, Markovian and Monte Carlo, and using a CHIL platform develop output (outage and duration improvement) metrics for EV charging
- Baseline: Control schemes and approaches not implemented. Outage timing and recovery based on existing information
- New Methods: Control and detection methods deployed.



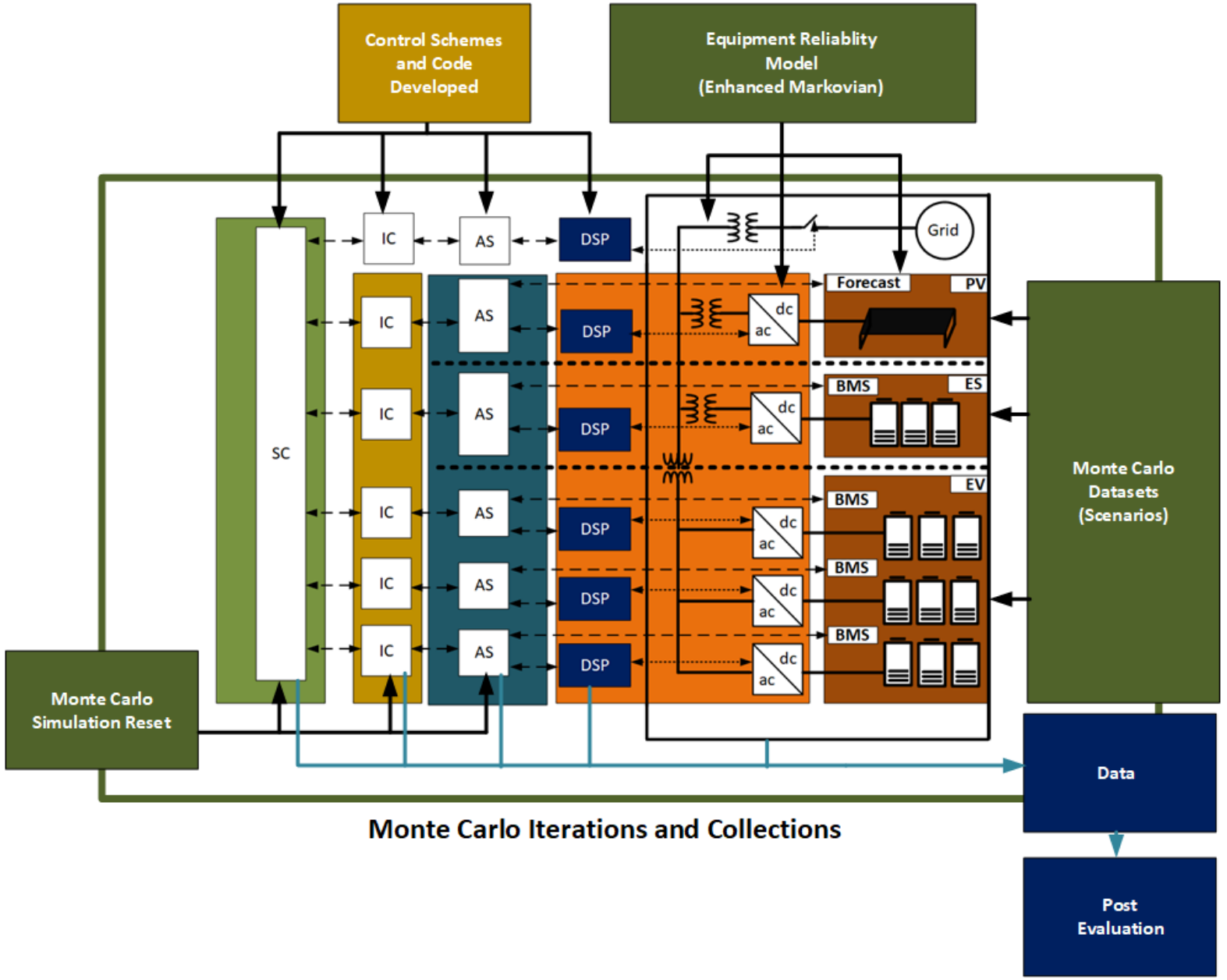
Anticipated Outcome: Measurable improvement



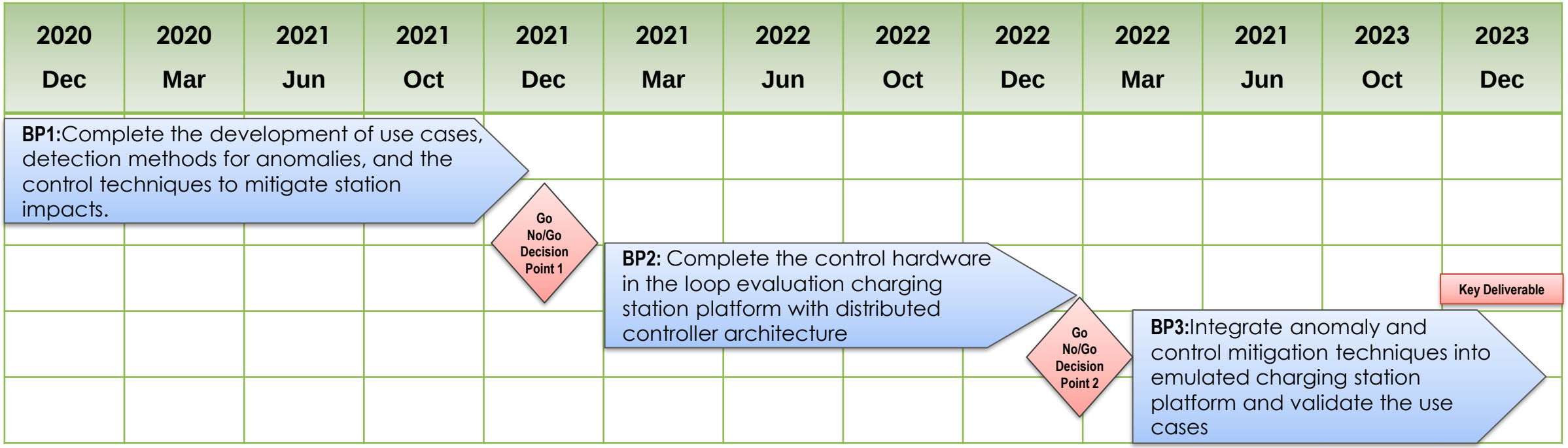


Evaluation Strategy

- Different electrical models can easily be adapted with use cases and scenarios
- Scripted process to generate use cases and scenarios considering Monte Carlo approaches.
- Data stored and evaluated per each run and evaluated
- Results: Comparison of metrics



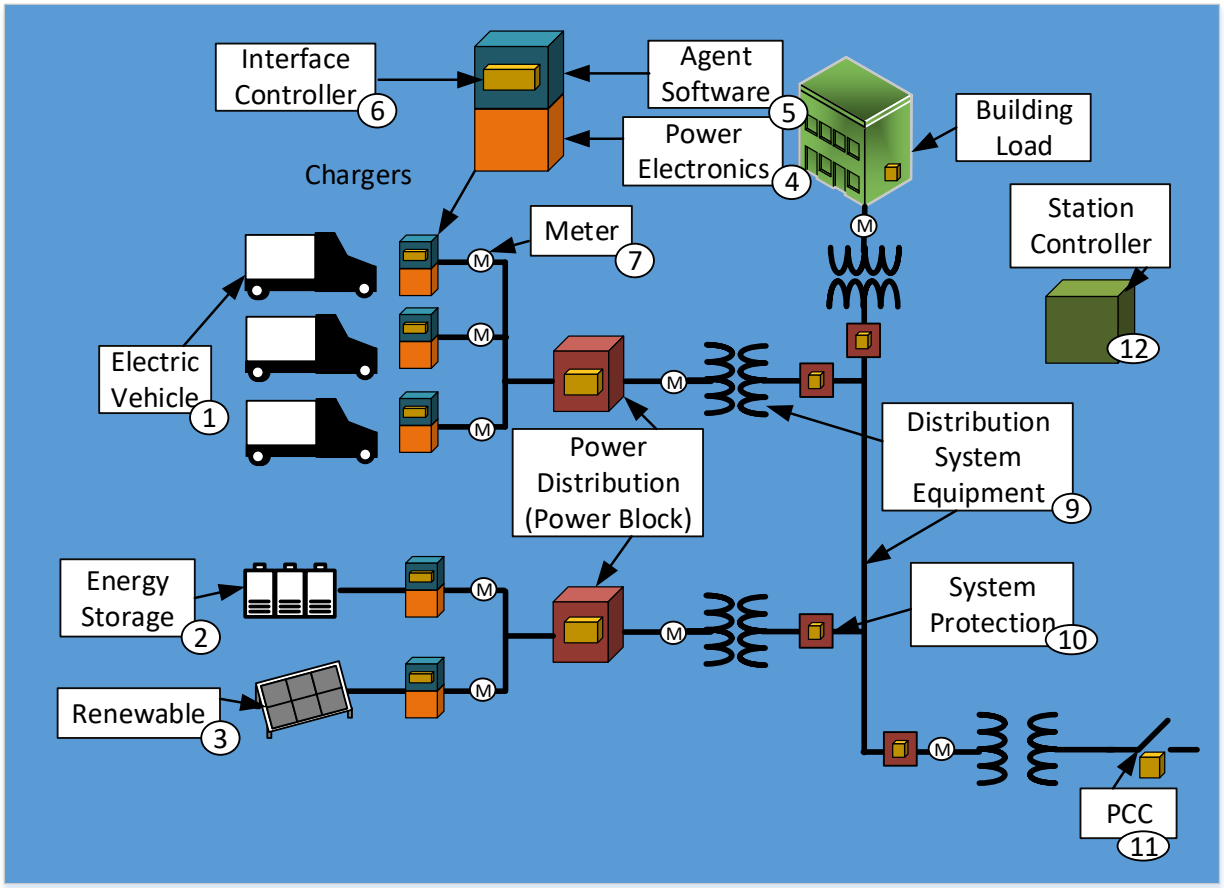
Project Timeline



- **Go/No-Go Decision Point 1**: Complete the simulation of the charging station for at least one use case and validate electrical models
- **Go/No-Go Decision Point 2**: Complete the emulation of the use cases developed in the emulated charging station through controller-hardware-in-the-loop (CHIL) platform
- **Key Deliverable for BP 3**: Demonstrate the use cases performed with anomaly and control mitigation techniques integrated through the emulated CHIL charging station

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Technical Accomplishments – BP I

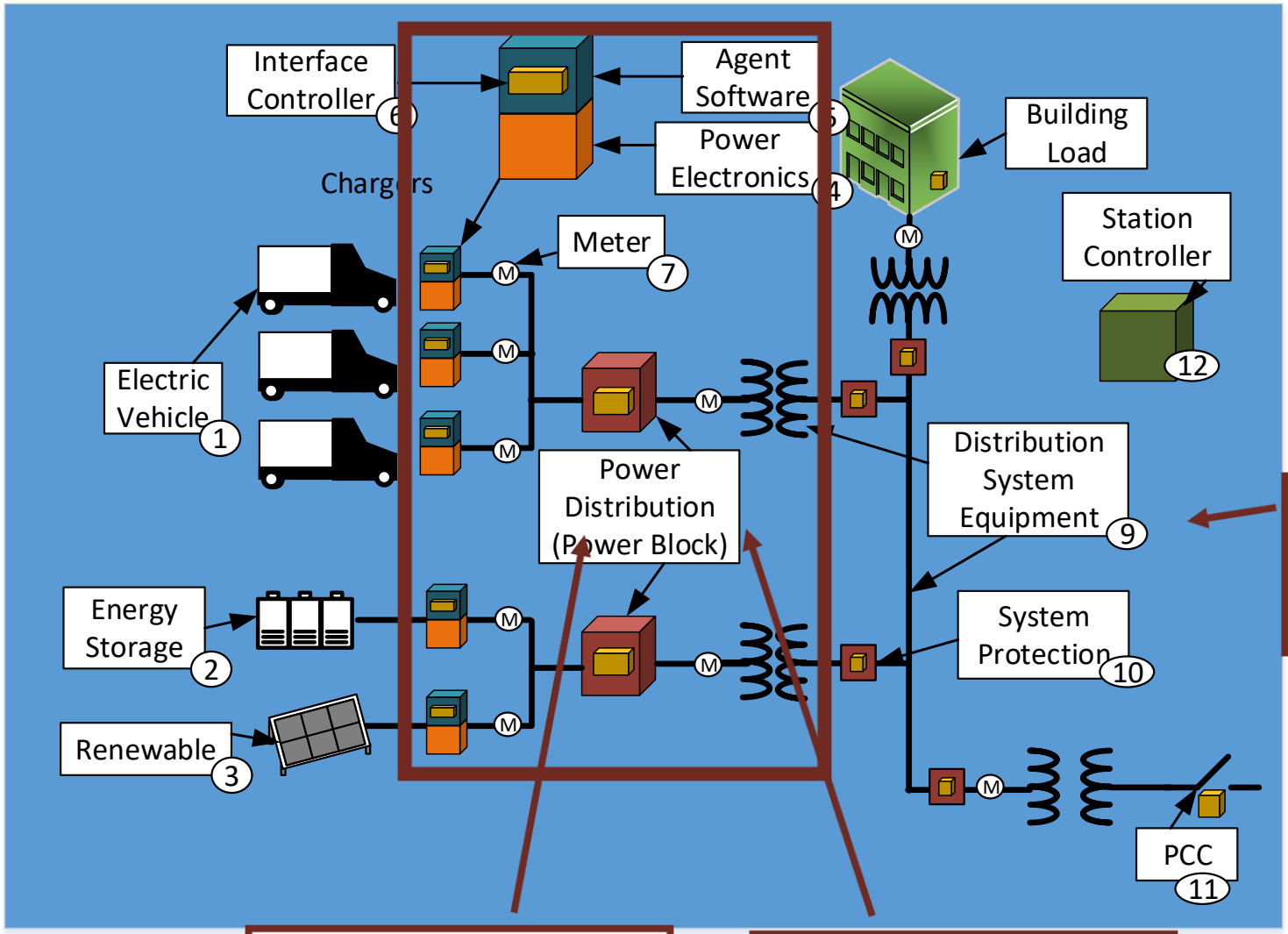


Use Cases Mapping to Sections of the Station

Considerations for use case formulation ?

- Include station response as a major focus including the potential for multi-phase isolation (i.e. **using a microgrid strategy) in a step-by-step fashion**.
- Station response may include several aspects such as **shedding loads, isolating chargers, ramping up energy storage, and/or isolation from the grid**.
- **Soft drop-off strategies** should be explored including leveraging stationary energy storage (including secondary use battery packs and ultracapacitors).
- Methodologies and tools to accurately and reliably **detect abnormal behavior of individual chargers and the charging station.**
- R&D focused on charging control **technologies, processes, and protocols**.
- **Exploration of open architectures** should also be pursued, identification of power electronics needs therein, and integration of station and smart charge management.

Technical Accomplishments – BP I ORNL Resilient Response Use Cases



Use Case 1: External Event: Grid Fault

Islanding outcome, resilient charger operation

Use Case 2: Internal Event: Power Block Component Fault

Boundary condition evaluation

Use Case 3: Internal Event: Electrical Interconnection Failure

Boundary condition evaluation

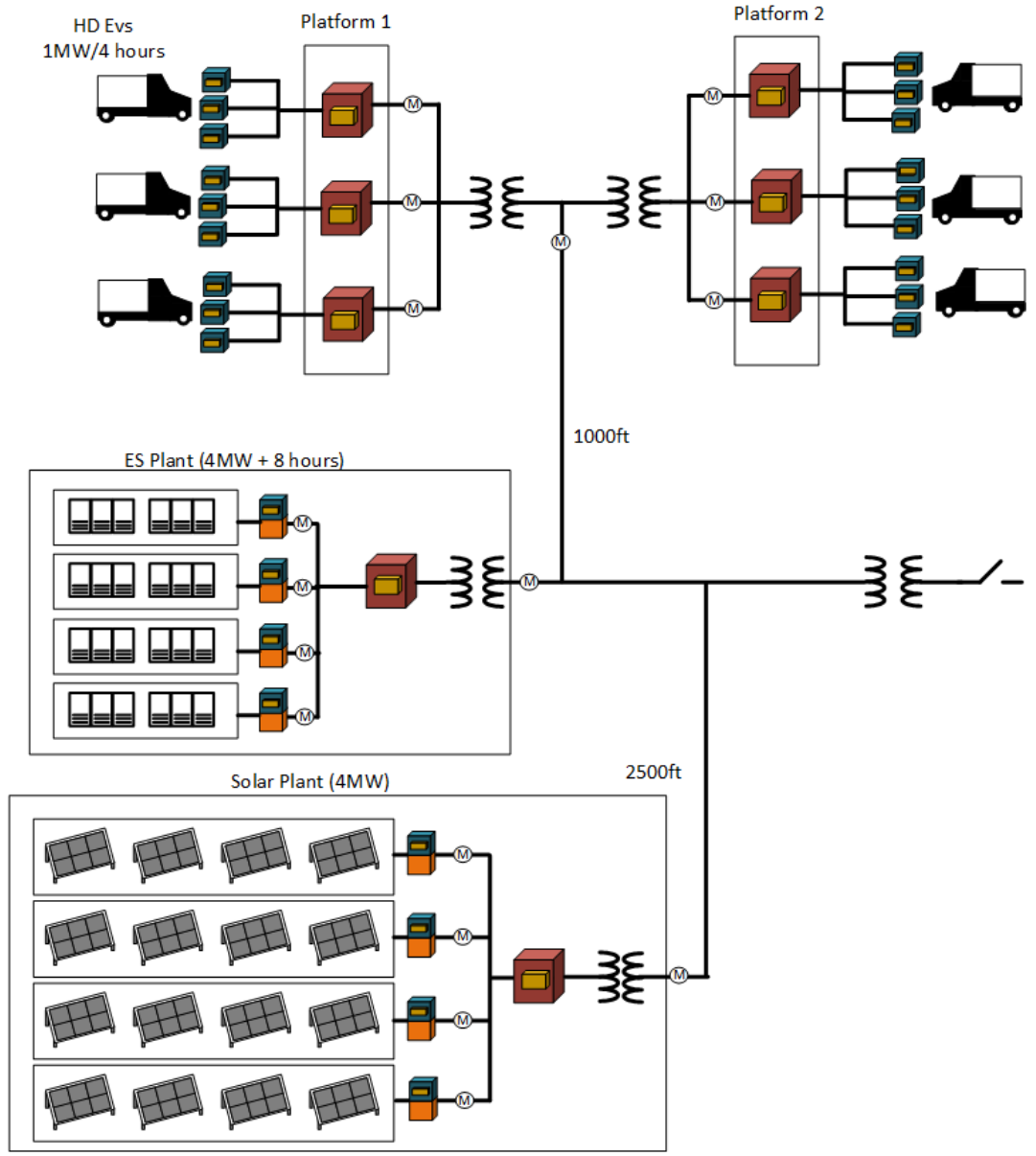
Technical Accomplishments – BP I: ORNL Use Case Example

Physical and Architecture Diagrams	Down selected Use Cases	Modeling Scenario Parameters	Description	Assumptions
Points: • **8 (Power Distribution /BLOCK Unit),** • **5 (Power electronics interface), and** • **4 (Agent software)**	Use Case 1 (External event): Grid Fault Grid Fault, Islanding Need (Advanced Grid Functions) Resilient operation of the individual chargers , renewable PE interfaces	Vehicle Charging Profile	% Changes in charging power and energy	Mix of LD/MD/HD
		Renewable Sizing / Condition	% Energy supplied by resources (kW and weather profile driven)	Station level renewable resource
		Building Loading Sizing:	% Energy consumption local building loads	Station level load (lumped load)
		Energy Storage Size:	% Energy and Power rating of energy storage system - energy, capacity, average SOC, primary purpose	Station level energy storage resource
		Fault Type	L-G, L-L, L-N	Mix of LD/MD/HD
		Fault Location	Isolation and Restoration is Possible / NotPossible	Mix of LD/MD/HD
		Converter Capabilities	Charger control options	Mix of LD/MD/HD

Detailed use cases – A fault on the station distribution network (could be L-G, L-L, L-N). The expectation is the system should be able to isolate the fault quickly and attempt to restore power depending on the location in respect to the system architecture. Contributions to the fault from renewables, energy storage, and the electric grid will govern how fast protection systems respond and the type of protection utilized. The rate of EV charging at the station during the fault and isolation capabilities will provide additional insights into potential protection activations. The converter system control options and response to electrical disturbances will provide the value of different control options to this condition.

Technical Accomplishments – BP I: Use Case Example: Shipping Facility with Heavy Duty Fleet Vehicles

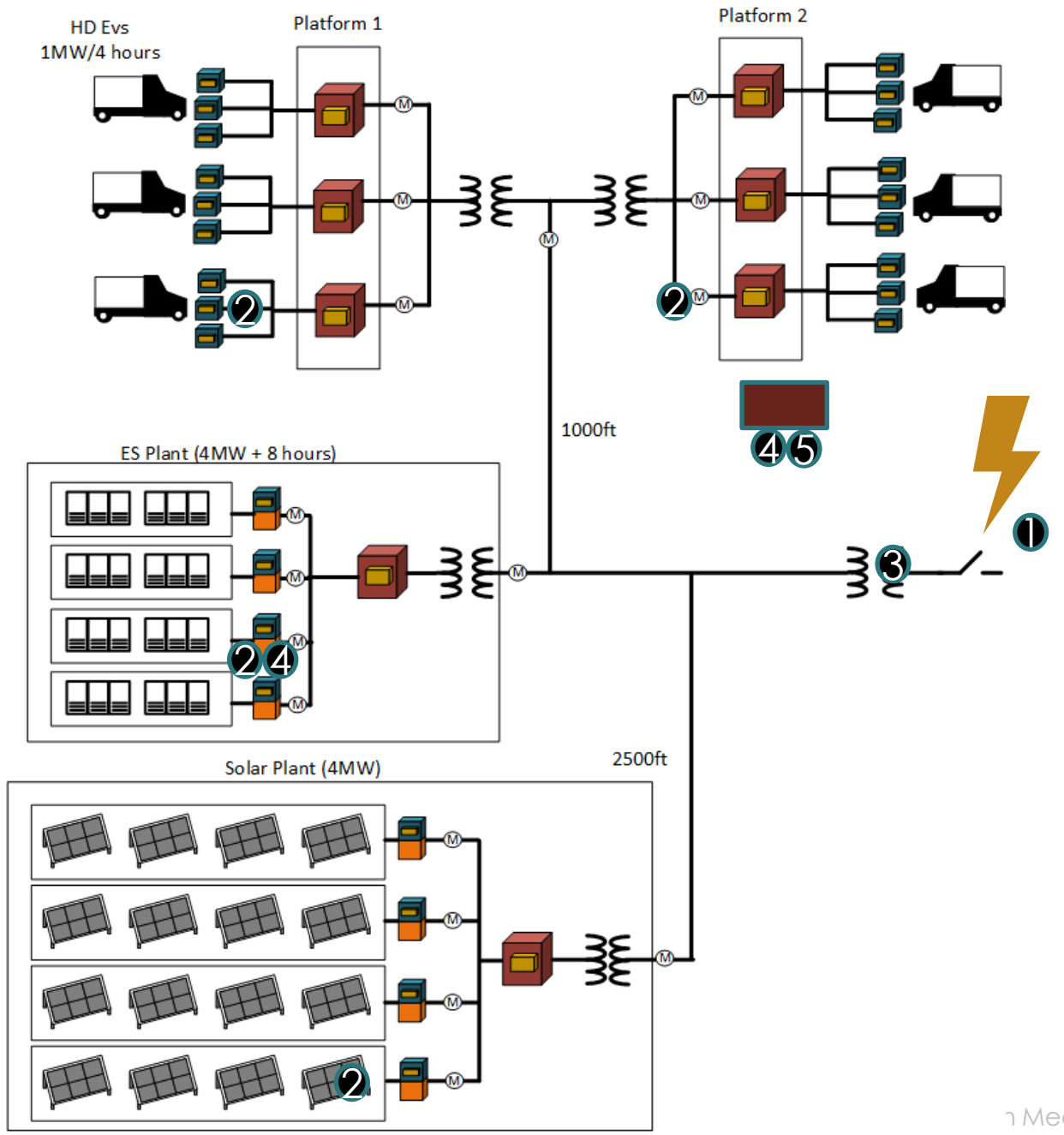
- HD EVs
  - 1MW max charging through 3 dispensers
  - 6 Charging Stations (1MW capacity)
  - EV needs: 1MW/3 hours of energy (maximum charging capability)
- ES Plant
  - 4MW / 8 hours
  - Just inside the site (1000ft)
- Solar Plant
  - Maximum Power at Full Irradiance, 4 MW
  - ½ mile from site but behind the meter.



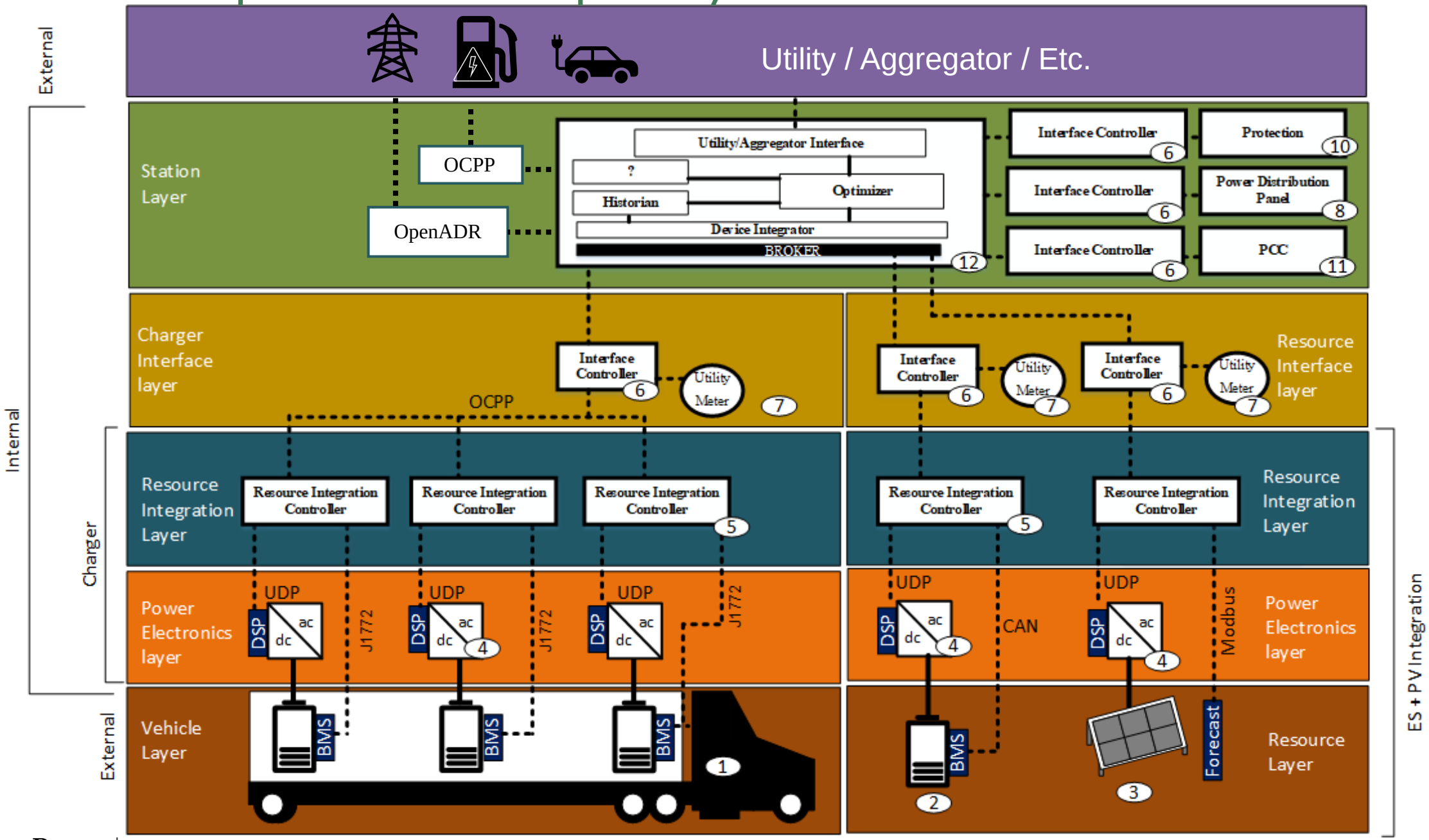
Technical Accomplishments – BP I Use Cases to Evaluate

Use Case #1: Grid Fault

- Voltage drops to zero per unit and is maintained at this level
- Power electronic systems detect and try to ride through. They reach timeout and trip.
- PCC opens and isolates system
- Station controller issues off-grid mode operations to power electronic systems.
- ES Plant enters grid forming mode and provides main supply of power
- Station enacts charging of as many charging stations as possible based on available generation and storage capacity.

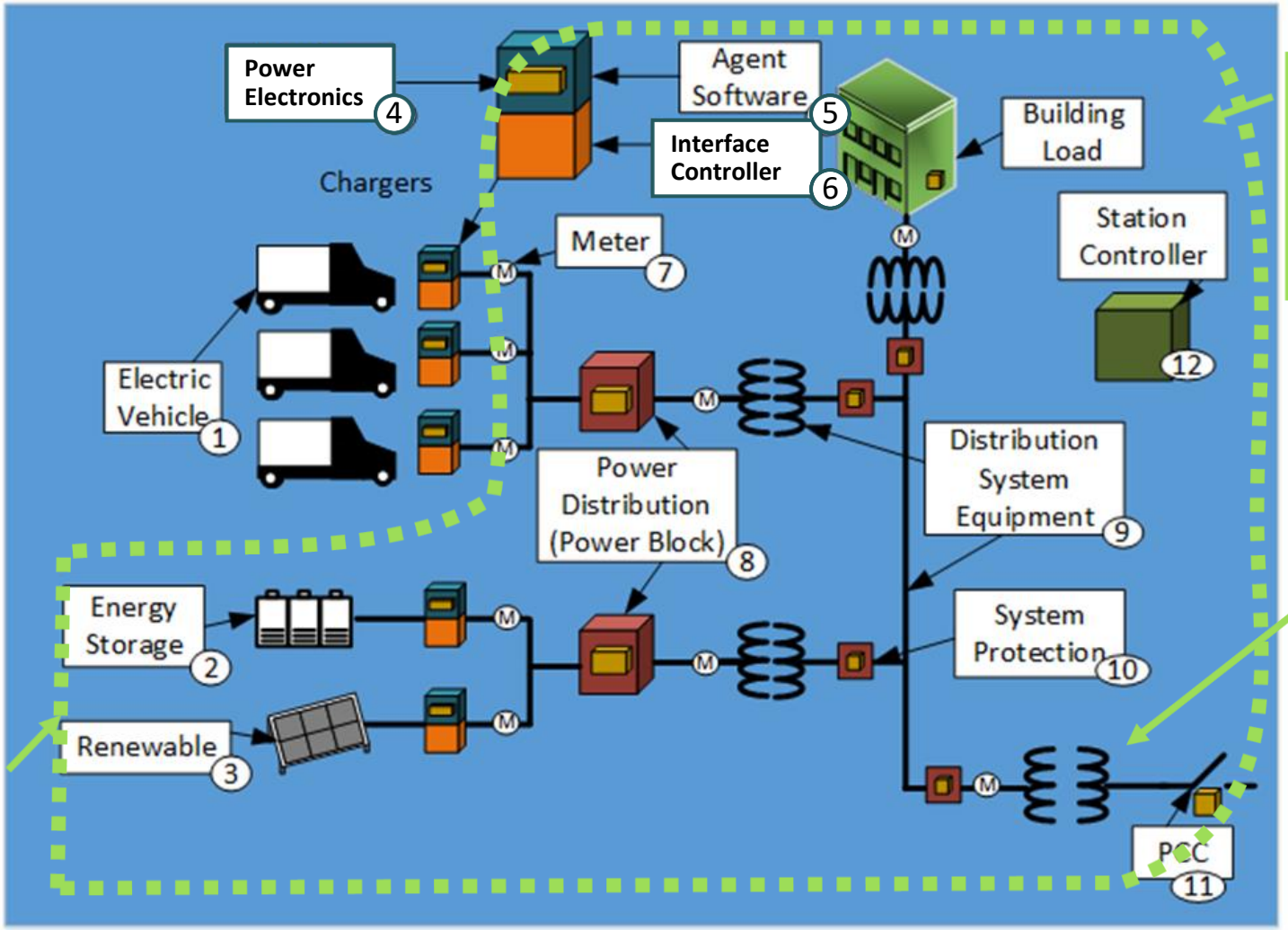


Technical Accomplishments – BP I: Proposed System Architecture



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Technical Accomplishments – BP I: PNNL Resilient Response Use Cases



Use Case 5: Internal Event: EVSE anomaly

Controls command Interface Controller and Power Block in response to EVSE communication / control issues

Use Case 6: Internal Event: Storage / Renewable Controller anomaly

Controls command Interface Controller and Power Block in response to RE device control issues

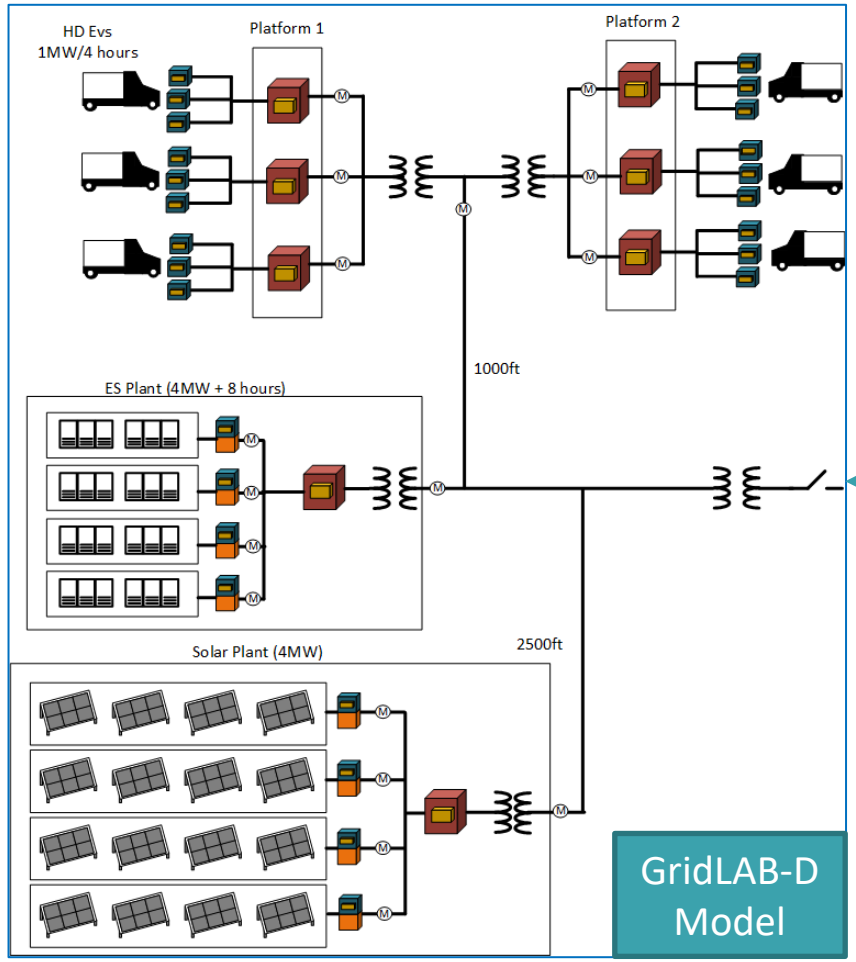
Use Case 4: External Event:

Grid Stress anomaly

Controls command Interface Controller and Power Block in response to Grid Stress

OpenADR2 & OCPP2.0 protocols

Technical Accomplishments – BP I: PNNL EV Charging Architecture Development: AC Plaza Distribution System



HELICS

Open-source, co-simulation system aligns temporal data from multiple sources.

DirectX // Caldera
Charge Profiles

Discrete event simulator for vehicle arrivals.
Temporal EV Energy Required, battery size, and SOC, EV Energy Delivered

Grid Conditions
Temporal PCC voltage input
Temporal PCC Power and sub-transmission

Controller
VOLTTRON-managed power control

Building & Renewables Asset Integration
Building, Stationary Storage and Solar Generation Integration

Architecture / Key Component Description:

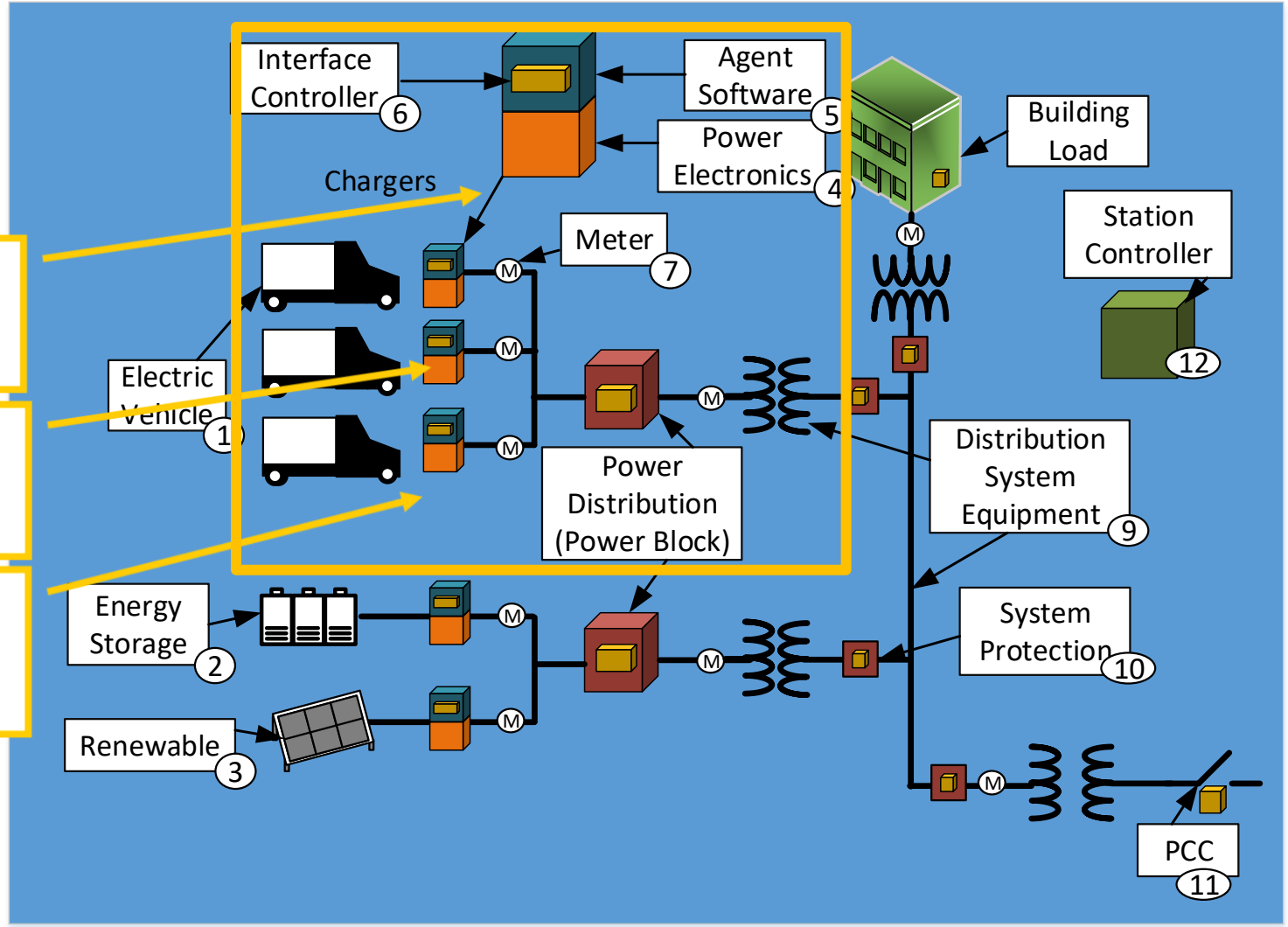
- AC Plaza / Fleet Power Distribution
- HD EVs
  - 1MW max charging through 3 dispensers
  - 6 Charging Stations (1MW capacity)
  - EV needs: 1MW/3 hours of energy (maximum charging capability)
- ES Plant: 4MW / 8 hours, location: just inside the site (1000ft)
- Solar Plant: Maximum Power at Full Irradiance, 4 MW; location: ½ mile from site but behind the meter.

Technical Accomplishments – BP I: INL Resilient Response Use Cases

Use Case 8: External Event: EV/EVSE Communications to EV Agent Failure
Agent failure / disruption

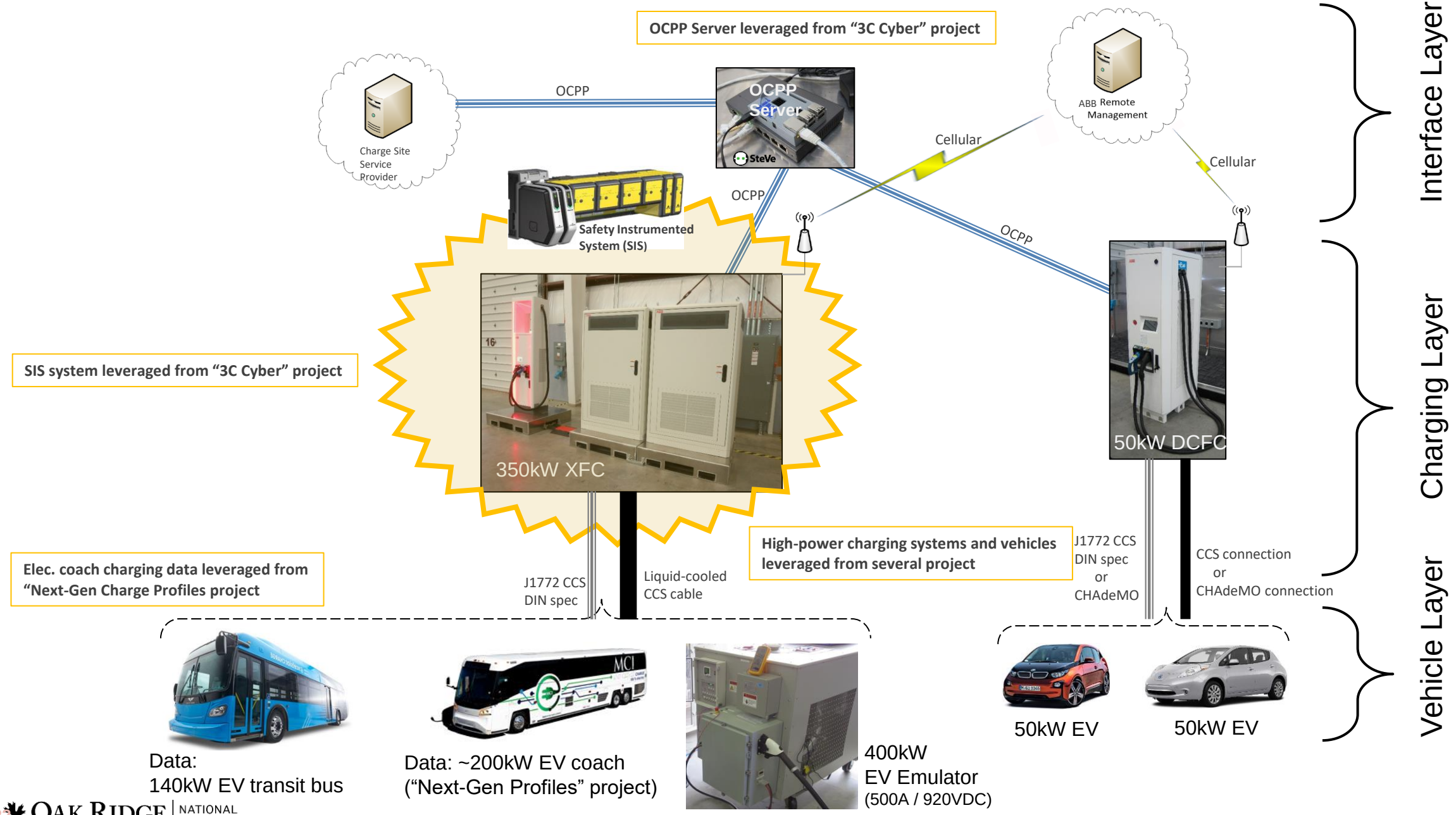
Use Case 9: Internal Event: EVSE or EV controls communications failure / disruption

Use Case 7: External Event: EV/EVSE Communications Fault
Recover and restart charging

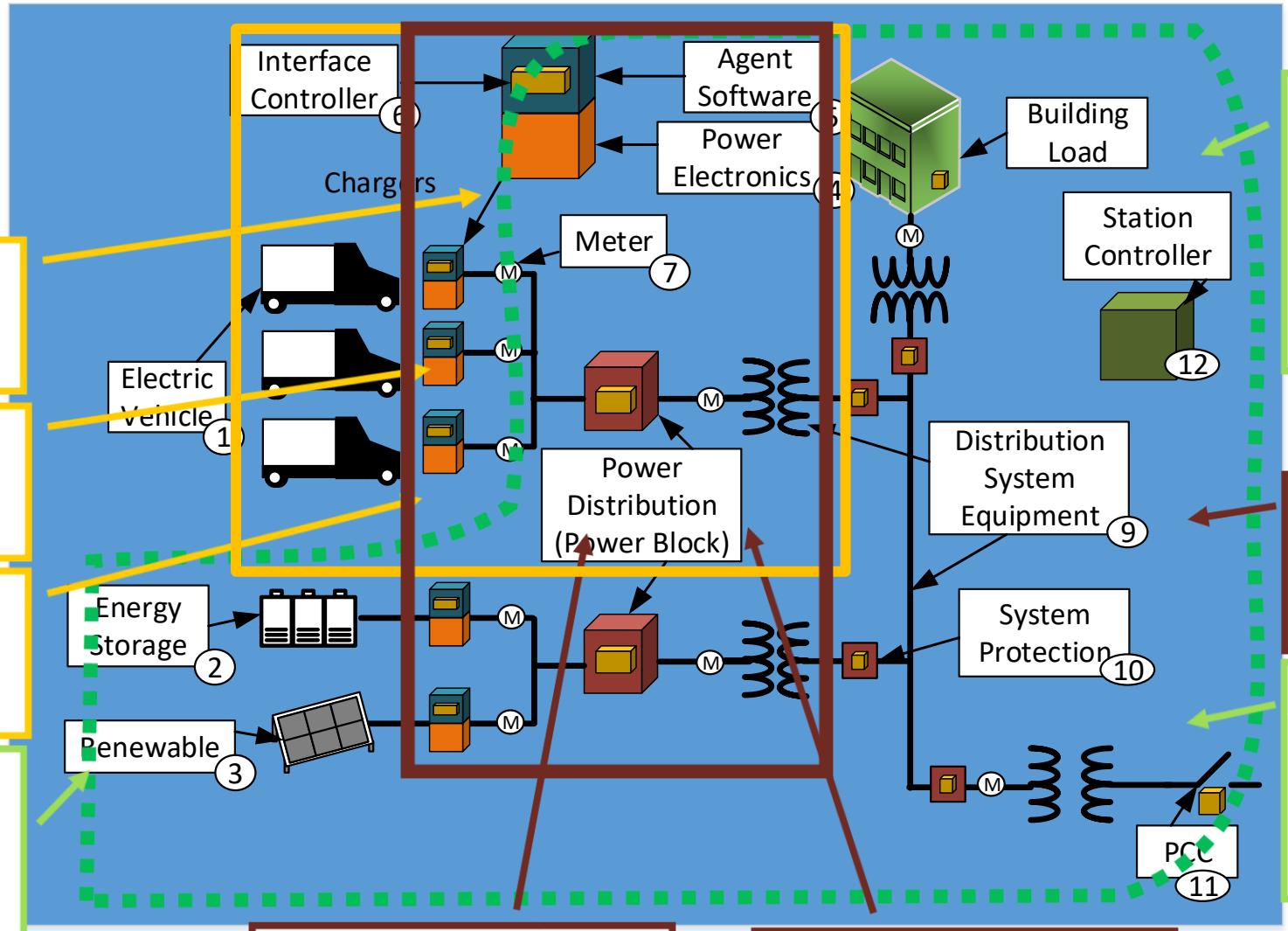


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Technical Accomplishments –INL: Architecture Diagram



Technical Accomplishments – BP I ORNL/INL/PNNL Resilient Response Use Cases



Use Case 8: External Event: EV/EVSE Communications to EV Agent Failure
Agent failure / disruption

Use Case 9: Internal Event: EVSE or EV controls communications failure / disruption

Use Case 7: External Event: EV/EVSE Communications Fault
Recover and restart charging

Use Case 6: Internal Event: Resilient response to Storage / Renewable Controller performance

Control output provides guidance to Interface Controller resulting from RE device control issues

Use Case 5: Internal Event: Resilient response to EVSE, EV, Controller performance

Controls provide guidance to Interface Controller resulting from EV/EVSE device control issues

Use Case 1: External Event: Grid Fault

Islanding outcome, resilient charger operation

Use Case 4: External Event: Resilient response to Grid Stress (DR / Brownout)

Load Profiles and Control applied at Power Distribution Blocks

Use Case 2: Internal Event: Power Block Component Fault

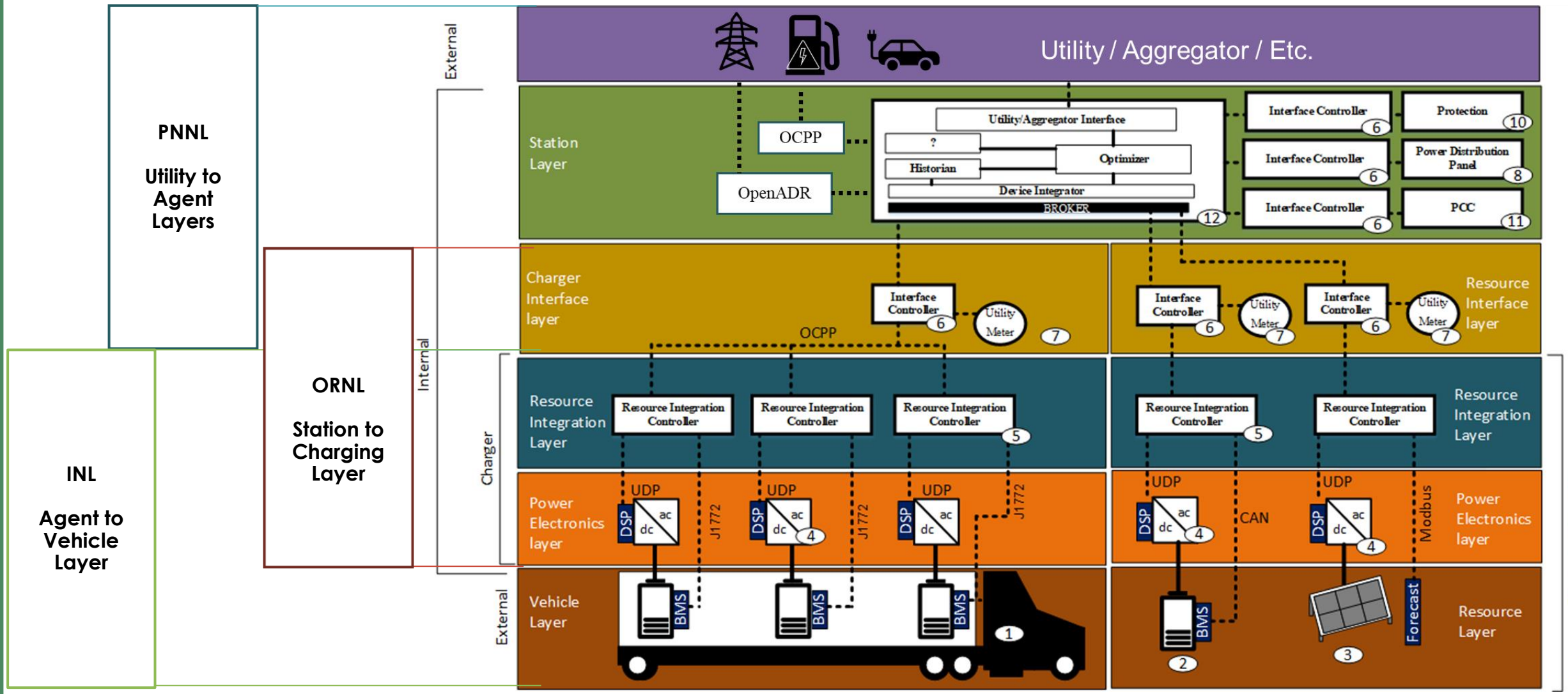
Boundary condition evaluation

Use Case 3: Internal Event: Electrical Interconnection Failure

Boundary condition evaluation

Technical Accomplishments – BP I

Initial Control Architecture and Use Case Overlap



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Collaboration and Coordination with Other Institutions

- ORNL (Project lead): Project management, Power Electronics and Controls for charging station models development, ABB: Supporting the station controller architecture
- Pacific Northwest National Laboratory (PNNL): Development of control approaches to respond to XFC anomalies, Co-simulation platform doe the charging station
- Idaho National Laboratory (INL) : Development of methods to simulate and detect XFC anomalies; hardware test bed for the charging station anomaly detection evaluation
- Virginia Commonwealth University (VCU): Anomaly detection algorithms development
- Assets leveraged from other DOE VTO projects
  - Safety Instrumented System (SIS) & OCPP server from the "3C Cyber" project
  - MCI coach data from "Next-Gen Profiles" project
  - 400kW EV charging emulator and XFC leveraged by multiple projects

Remaining Challenges and Barriers

- Availability of charging profiles for extreme fast chargers
- Charger topologies for MD and HD vehicles
- Charging station architecture for extreme fast chargers

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

Proposed Future Research

- **FY 2022**

  Complete the control hardware in the loop evaluation charging station platform with distributed controller architecture

- **FY 2023**

  Integrate anomaly and control mitigation techniques into emulated charging station platform and validate the use cases

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

Summary

- **Relevance**: Develop control and anomaly detection techniques to improve the resiliency of the electric grid and charging stations
- **Approach**: Develop use cases for charging station anomalies and analytical approaches to anomaly detection and system level control techniques to mitigate impacts.
- **Technical Accomplishments**:
  - Developed the use cases and the station architecture to evaluate the use cases
  - Developed the framework to evaluate the station resiliency.
- **Collaborations and Coordination with Other Institutions**:
  - ORNL (Project lead): Project management, Power Electronics and Controls for charging station models development
  - Company: ABB: Supporting the station controller architecture
  - National Labs: Pacific Northwest National Laboratory (PNNL): Development of control approaches to respond to XFC anomalies
  - Idaho National Laboratory (INL) : Development of methods to simulate and detect XFC anomalies
  - University: Virginia Commonwealth University (VCU): Anomaly detection algorithms development
- **Future Work**:
  - Develop the charger models
  - Develop the anomaly detection and control methods for the charging station resiliency.

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