Cybersecurity for Grid Connected eXtreme Fast Charging (XFC) Station (CyberX)

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ABB Inc.

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ELT205

ABB

Overview

Timeline

- Project start date: 01/2019
- Project end date: 06/2021
- Percent complete: 85%

Barriers

- Designing XFC station considering future extensions such as integrated energy storage
- Identify/detect anomalies in the XFC station using adaptive approach
- Integrate prototype result into power HIL testbed for real-world validation (agile management for travel constraints)

Budget

- Total project funding
  - Total: $2.1 M
  - DOE share: $1.68 M
  - Cost share: $0.42 M (20%)

Partners

INL: EV simulator and Power hardware-in-the-loop for demonstration, Don R Scoffield (lead), Barney Carlson (lab)

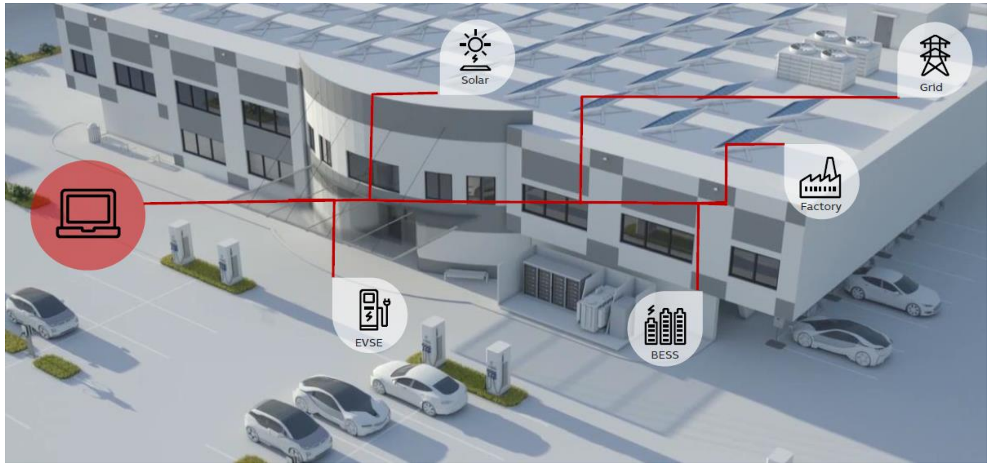
APS Global: EV station threat analysis and demonstration, Rick Hansen (lead), Duncan Woodbury

XOS Trucks: Providing demonstration electric vehicle for testing of demonstration, Austin Benzinger (lead)

Relevance

Increasingly connected Electric Vehicle (EV) charging station system solutions provide new opportunities and challenges:

- EV charging infrastructure and supply equipment (EVSE)
- Electric vehicles and vehicle on-board systems
- Battery energy storage systems (BESS) and distributed energy resources with potential grid and facility integration



The consequence of providing smart charging management and eXtreme Fast Charging (XFC) management systems is requiring more external connections from the EV station which need secure interfaces.

Objectives:

- Determine key attack paths for EVSE and connected systems based on statistical probability, effort level/cost, and impactful events/chains of events, and cyber-physical security approach to detecting anomalies
- Research, develop, and demonstrate a reference XFC (>350kW) station to reduce the risk and impact of cyber intrusions
- Design a resilient XFC station management system to safeguard EVs, EVCI (electric-vehicle charging infrastructure), connected equipment such as Battery Energy Storage Systems (BESS), EV owners, and EV station operators

Approach

Milestones

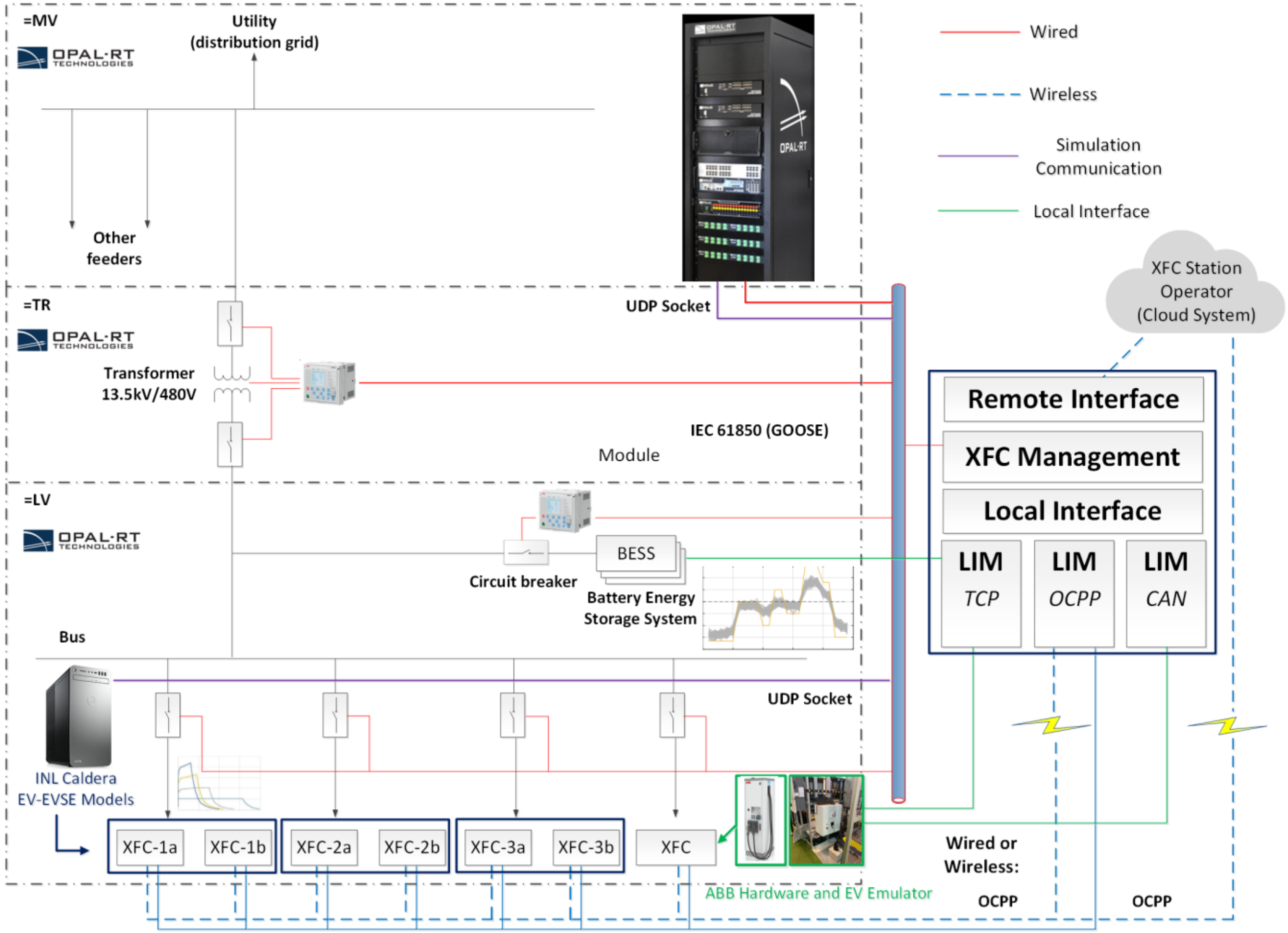
- Planned milestones and go/no-go decisions for FY 2019 and FY 2020/21

No.	Milestone	Date	Type
M1	Complete design documentation of XFC station	6/31/2019	Quarterly Progress Measure
M2	Complete threat analysis report	12/31/2019	Annual Milestone
M3	Complete report of resilient control architecture	12/31/2019	Annual Milestone
M4	Grid connected XFC station model, threat analysis, design documentation for XFC station, and developed defense mechanism	12/31/2019	Go/No Go
M5	Prototype implementation of resilient control architecture	~~6/31/2020~~ 11/30/2020	Quarterly Progress Measure
M6	Hardware integrated with HIL co-simulation platform and demonstration	~~12/31/2020~~ 6/30/2021	Quarterly Progress Measure
M7	Complete report of CyberX performance analysis	~~12/31/2020~~ 6/30/2021	Annual Milestone
M8	Knowledge dissemination to ABB’s EV charger and eMobility business	~~12/31/2020~~ 6/30/2021	Annual Milestone

Approach

Detailed Tasks for CyberX Project Budget Period (Year 1)

- **Task 1.1: XFC station and control system - Completed**
  - Task 1.1.1: System layout and design
  - Task 1.1.2: Building base XFC station model & use cases
  - Task 1.1.3: Steady state use case modeling and analysis
- **Task 1.2: Threat analysis - Completed**
  - Task 1.2.1: EV and EVSE threat analysis
  - Task 1.2.2: XMS and utility control system threat analysis
- **Task 1.3: Secure XFC station control methodology development - Completed**
  - Task 1.3.1: Secure the communication infrastructure
  - Task 1.3.2: Develop CADS for individual XFC station
  - Task 1.3.3: Develop HLSE for XFC station
  - Task 1.3.4: Develop a mitigation mechanism for abnormal operation



Approach

Detailed Tasks for CyberX Project Budget Period (Year 2/2.5)

- **Task 2.1: Steady state validation – Low Power Verification**
  - Task 2.1.1: Prototype of algorithms, commercial platform
  - Task 2.1.2: Prototype intrusion scenarios according threat analysis
  - Task 2.1.3: Test the system against intrusion scenarios
- **Task 2.2: Real time validation – Low Power Verification**
  - Task 2.2.1: Integrate implemented CyberX platform with HIL testbed
  - Task 2.2.2: Adapt intrusion scenarios to the HIL environment
  - Task 2.2.3: Test the system against intrusion scenarios
- **Task 2.3: Performance analysis – High Power Verification**
  - Task 2.3.1: Performance measurement matrix
  - Task 2.3.2: Performance analysis reporting
- **Task 3: Knowledge dissemination**

Unique aspects - *(1) XFC station management system (XMS) with cybersecurity features (2) Prototype implementation using HIL testbed*

Low Power Verification @ ABB in Raleigh

High Power Verification @ INL in Idaho

Technical Accomplishments to Date

Task Info	Tracking Metric	Goal for Period	Accomplishments	Completion	
				Expected	Actual
1.1 XFC Design Tasks (M1)	Design and simulate grid connected XFC station model	Successful simulation and testing of normal operation of XFC station	(1) Model based on 13.5kV to 480V distribution system (2) EV charging and battery integration use cases shown (3) Tested design with 3 abnormal conditions (4) Incorporated INL caldera data and converted model to real-time	Milestone 1 6/30/2019	Milestone 1 6/30/2019
1.2 Threat Analysis Tasks (M2)	Number of threat models developed and defined	Develop at least 8 threat models; demonstrate 1 model	(1) Developed system threat models to measure risks and impacts (2) Developed 7 main branching threat models (3) Demonstrated three 3 threat models, identifying critical events (4) Demonstrated XFC meter measurement spoofing attack concept	Milestone 2 12/31/2019	Milestone 2 12/31/2019
1.3 Resilient Control Architecture Tasks (M3,M4)	Number of cyber secure concepts developed for XFC station operation	Develop at least 2 cyber secure concepts for XFC station	(1) Developed communication monitoring and analysis for key protocols (2) Demonstrated monitoring, analysis, and machine learning for mitigation approach (3) Demonstrated capability to detect false data likelihood in state estimation method (4) Demonstrated abnormal EV state of charge mitigations based on Anomaly detection	Milestone 3 12/31/2019 Go/No-Go 1/31/2020	Milestone 3 12/31/2019 Go/No-Go 1/31/2020

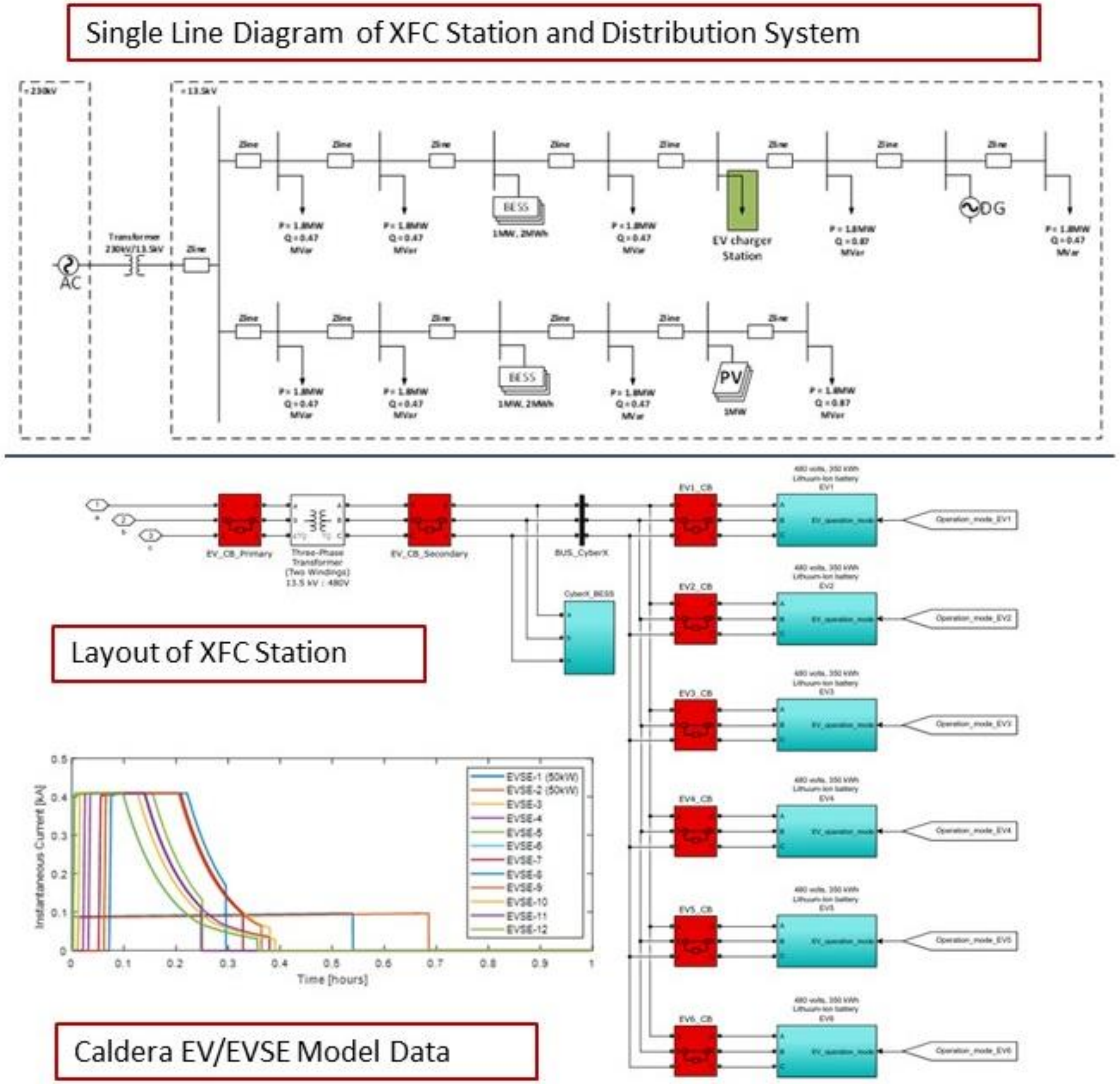
Technical Accomplishments to Date

Task Info	Tracking Metric	Goal for Period	Accomplishments	Completion	
				Expected	Actual
2.1 Prototype resilient control architecture (M5)	Deploy and test cybersecurity algorithms with steady state simulation	Successful deployment and testing cybersecurity algorithms in simulation platform	(1) Developed remotely accessible simulation testbed with BESS, DER and communications (2) Deployed time-series estimation, state estimation, and classification resiliency features (3) Developed and tested key intrusion scenarios	Milestone 5 6/30/2020	Milestone 5 11/30/2020
2.2 Real time validation (M6)	Deploy and test cyber security algorithms in XFC station Cyber Physical Test Bed	Successful deployment and testing of cyber security algorithms in XFC station Cyber Physical Test Bed	(1) Developed portable real-time test platform with data and monitoring of supply equipment (2) Adapted key intrusion scenarios to hardware test platform and tested with physical hardware (3) Demonstrated three 3 threat models, identifying critical events	Milestone 6 12/31/2020	Milestone 6 5/31/2021
2.3 Performance analysis (M7)	Execute performance analysis of the developed algorithm, and generate measurement matrix	Successful performance analysis	(1) Developed communication monitoring and analysis for key protocols (2) Demonstrated monitoring, analysis, and machine learning for mitigation approach (3) Demonstrated capability to detect false data	Milestone 7 12/31/2020	Milestone 7 (Expected) 6/30/2021
3.1 Transfer the results to ABB's EV charging business (M8)	Transfer the results to ABB's EV charging business unit	Project results presentations and prototype product	(1) Delivered documentation of developed features to internal product teams (2) Bi-weekly meetings with transfer teams (3) Publications and disclosures in progress	Milestone 7 12/31/2020	Milestone 7 (Expected) 6/30/2021

Technical Accomplishments to Date

Milestone 1: XFC Design Results

- Representative extreme fast charging (XFC) station and feeder system modeled within Simulink and then Opal-RT
- Based on the American Center for Mobility (ACM)'s planned circuit topology:
  - Distribution system elements at 13.5kV
  - Charging network and BESS elements at 480V
  - DERs such as Diesel Generators and Solar PV modules
  - Protection and control systems
- EV chargers simulated by INL Caldera model
- Connect to real-time model through Opal-RT dynamic load
- Communications systems prototyped
- Forms the basis of the future HIL tests at INL facilities



Technical Accomplishments to Date

Milestone 2: Threat Analysis Generalized Results

- Representative model of 7 charging site components: XFC, BESS, XMS, Transformer, Rectifier, SCADA & Remote Management Systems
- Based on architecture specifications and practical analysis by APS Global and INL, 3,982 attack paths modeled
- Mapped attack paths to statistical probabilities to identify most impactful chains and individual events
- Initial conclusions general to all XFC EVSE
  - Front panel cellular modem – most likely attack surface to be targeted
  - Rapidly start/stop charging to affect charging cable – most likely cyber physical target

1	**Target Protocol Downgrade Attack (Cellular) (XFC) (Remote)**	Threat chain to end consequence →	**Rapidly Start and Stop Charging Session to Affect Cable (CP) (XFC)**
2	Target Cellular Base Station (Cellular) (XFC) (Remote)	Threat chain to end consequence →	Rapidly Start and Stop Charging Session to Affect Cable (CP) (XFC)
3	**Target Baseband Firmware Stack (Cellular) (XFC) (Remote)**	Threat chain to end consequence →	**Rapidly Start and Stop Charging Session to Affect Cable (CP) (XFC)**
4	Target Network Service Ports (OS) (XFC) (Remote)	Threat chain to end consequence →	Rapidly Start and Stop Charging Session to Affect Cable (CP) (XFC)
5	**Target System Component in Supply Chain (SWD) (XFC) (Local)**	Threat chain to end consequence →	**Rapidly Start and Stop Charging Session to Affect Cable (CP) (XFC)**

Technical Accomplishments to Date

Milestone 3 and 4: Resilient Control Architecture Results

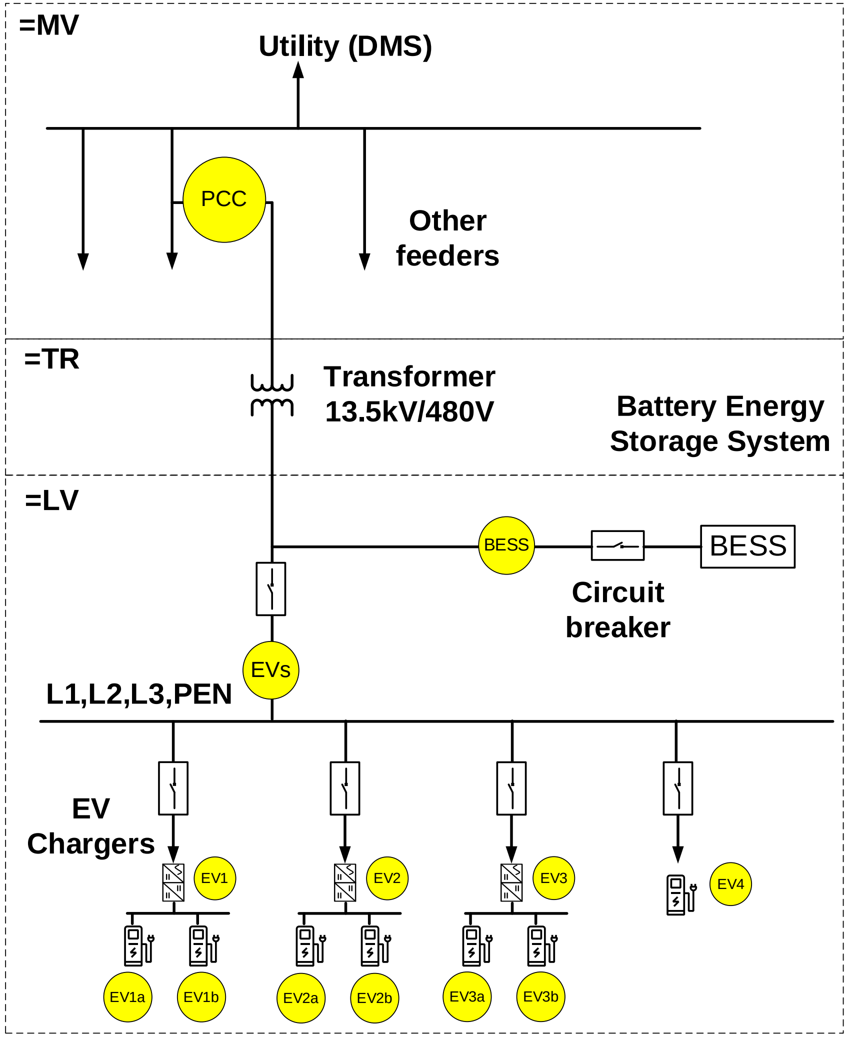
EV Station Control Model including BESS integration (Charge and discharge optimization)

Station Level Weighted State Estimation

- Total of 13 points (7 measurement and 6 sub-measurements) for state estimation provided to the XMS Gateway form a State Estimation Matrix
- Measurements are then weighted based on confidence
- Detection method implemented for falsified EV State of Charge (SoC) and current data based around Kirchoff Current Law (KCL) conditions represented in State Estimation Matrix
- Provides measurement error estimates and false data likelihood

Coordinated Anomaly Detection System (CADS)

- Using classification and regression tree (CART) machine learning algorithm to determine expected charging time/measurements of vehicle
- Inputs are charging power, battery type, EV make/model, battery SoC at arrival, type of EV, and charging time
- Example threats based on manipulated SoC and current measurement at the EV supply equipment level



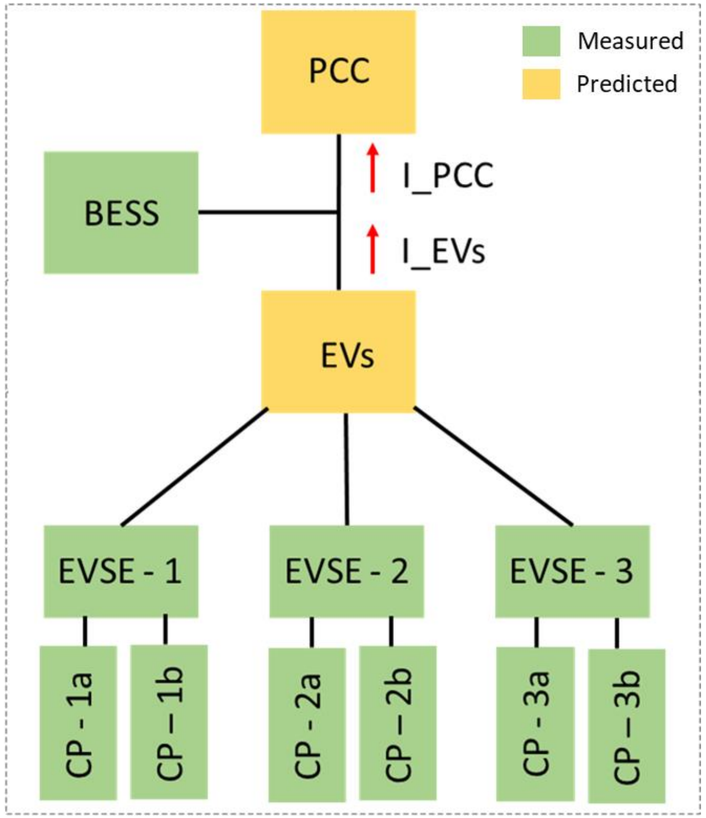
Technical Accomplishments to Date

Milestone 5: Prototype implementation of resilient control architecture

Customizable EV charging and BESS optimization management system user interface

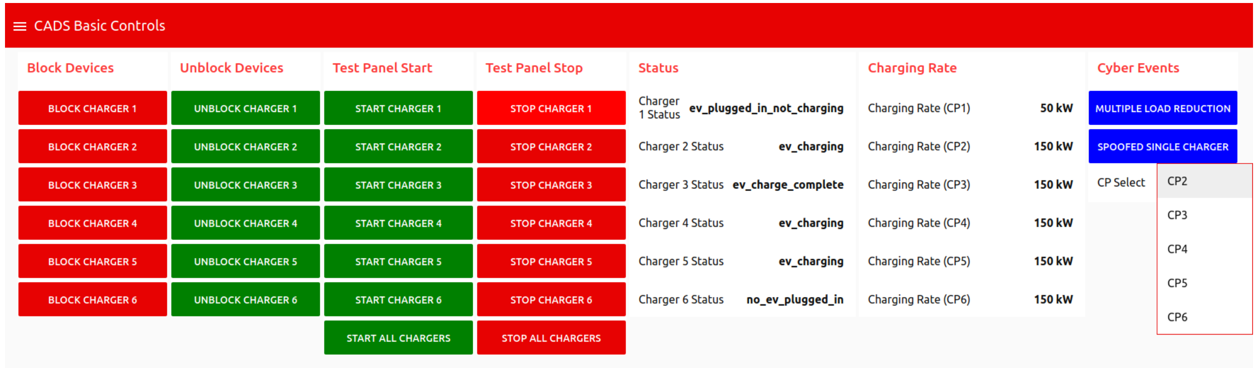
EV charging site can be configured/customized using engineering tools:

- Configuration file for charging site parameters informs site level optimization
- Communication interface logger supporting connection of EV Chargers (OCPP, OPC-UA local), site protection equipment (IEC61850), and BESS/DER (MODBUS)
- Local connection to EVSE products for gathering charger state and session parameters in real-time
- CADS algorithms running in real-time operating on logged data



Coordinated Anomaly Detection System Verification

- Improved state estimation methods by including real power and implemented in steady
- Improved machine learning methods to operate on time-series data in real-time and provide multiple aggregate current estimations based on logged data
- Status and session data included in time series estimation



Technical Accomplishments to Date

Milestone 6 and 7: Real-time validation and Performance Analysis

- Initial setup visit to INL EVI Laboratory and verified XMS connectivity with supply equipment
- Tested OCPP logging, control, and transaction features of prototype management system with connected supply equipment
- Installed real-time local interface for gathering charger state, DC outputs, EV state of charge, and session information and statistics
- Gathered device specific communications and measurements for further training of machine learning models with physical hardware
- Adapting developed intrusion scenarios to hardware implementation
  - CCS breakout and test set developed for EV to EVSE communication monitor
  - Customized OCPP server instance for adversarial assessment of CADS features
  - Custom-developed ISO 15118 and DIN 70121 partial protocol implementation

Responses to Previous Year Reviewers' Comments

- *Reviewer comment:* The overall approach of cyber anomaly detection system (CADS) is good but is not robust enough. It needs to be extended to account for extreme environmental temperatures, sensor bias, and grid parameter anomalies such as voltage and frequency sag.
  - *Response*: Extreme temperature and some sensor errors can be accounted for by polling and parsing charging session stop reasons using our local interface. In generating and gathering the data for the machine learning training, the impact of voltage or frequency sags at the PCC is not currently considered as nearly ideal PCC voltage is assumed. However, ABB's site solution products have optional features/hardware to measure and log the voltage, current and frequency at the PCC. Including these measurements into the training data is a natural extension to the proposed approach.
- *Reviewer comment(s):* Good progress was made, but more hardware demonstration is needed // It may be necessary to extend the timeline to account for mandated travel restrictions and supply chain interruptions.
  - *Response*: As noted during the presentation, the project was granted a six-month no cost extension to allow researchers opportunities to get vaccinated, travel restrictions to ease, and additional time for hardware troubleshooting with reduced/minimal time in lab facilities. Final hardware testing visits and demonstrations are scheduled and planned with alterations to reduce footprint of and risk to visiting researchers.
- *Reviewer comment:* The project is highly relevant for addressing cybersecurity gaps for high power EVSEs. The project is characterizing threats and prototyping systems to identify and respond to EVSE cyber threats.
  - *Response*: Coordination with our project partners has brought broader knowledge and generalizable findings.

Collaboration and Coordination

- **Project collaborators**
  - ABB (prime), industry
  - INL (sub), national lab
  - APS Global (sub), industry
  - XOS Trucks (sub): industry

- **Communications**
  - Weekly meeting, ABB internal
  - Bi-weekly meeting, Project partners
  - Monthly updates with DOE
  - As needed meeting with DOE and partners

- **ABB: Cyber event detection and mitigation architecture and practices, algorithm development and validation with HIL testbed**
  - Anomaly detection, machine learning, communications, and system modeling
- **INL: EV modeling, EV Cybersecurity, and Power hardware-in-the-loop simulator for demonstration**
  - EV/EVSE modeling, HIL testbed and power systems
- **APS Global: Electric distribution system model and threat analysis**
  - EV/EVSE cybersecurity and threat analysis
- **XOS Trucks: Electric vehicle for testing of demonstration**
  - EV engineering and demonstration platform

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Remaining Challenges and Barriers

- Simulating anomalous conditions and identify/detect anomalies in the XFC station
- Validating feasibility of developed algorithms for detecting key threat models using the power HIL testbed and vehicle or vehicle platform charging sessions/use cases
- Providing agile response to scheduling and availability to allow for travel to final demonstration sites

Proposed Future Works

- **Ongoing FY-20**
  - Adjusting the system testbed and XMS prototype platform to the INL EVI Laboratory based on hands-on time with EV supply equipment and communications
  - Further adapt the tested intrusion scenarios to the hardware setup

- **FY-21**
  - High Power HIL testing to be completed using EV demonstrator platform at INL EVI Laboratory
  - Performance analysis and final demonstration at INL EVI Laboratory
  - Knowledge Dissemination

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

Summary

- Secure architecture grid connected XFC (>350kW) station modeled for Hardware in the Loop demonstration
- Six completed milestones and consistent progress on last two milestones
  - Completed design documentation of XFC station and modeling
  - Completed threat analysis report
  - Completed report of resilient control architecture and go/no-go decision point
  - Completed prototype of resilient control architecture and XMS with steady state validation
  - Completed real-time validation using portable test platform
  - Setup visit completed for final performance analysis and hardware tests, final tests scheduled
- Validated CyberX Management System layer for “CADS” cyber attack detection and mitigation with key scenario testing
- Final Power HIL tests and agile management to face travel and other restrictions in timely fashion

Technical Back-Up Slides

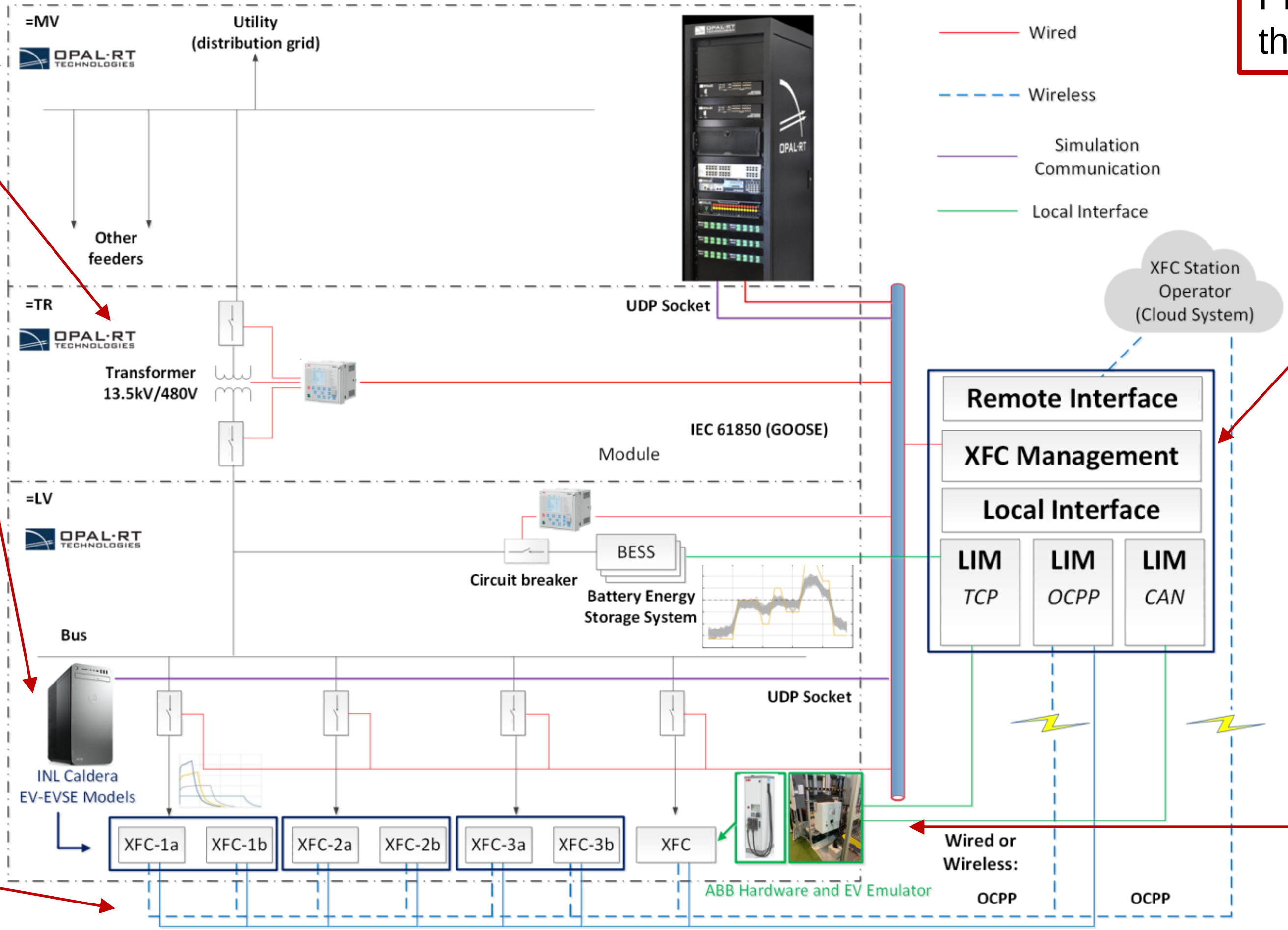
XMS Communication and HIL Testbed

Simulate distribution grid and XFC station BESS, protection

Emulate additional EVSEs on Linux device(s) using INL models

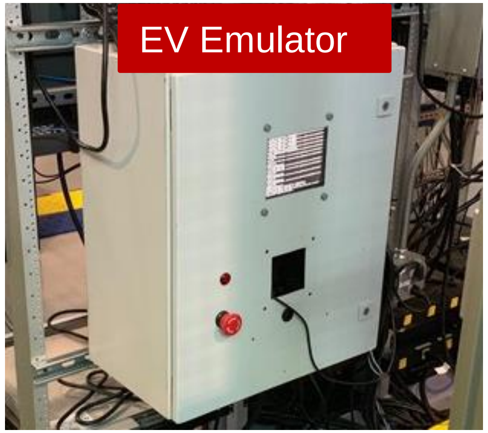
-Run Caldera on workstation/ gateway w/in VM or Container
-Socket communication of P and Q to Opal-RT from Caldera
-Socket from Opal-RT to receive Vpu
-OCPP streaming of metering info

Emulate EVSEs external communication interface to connect XMS



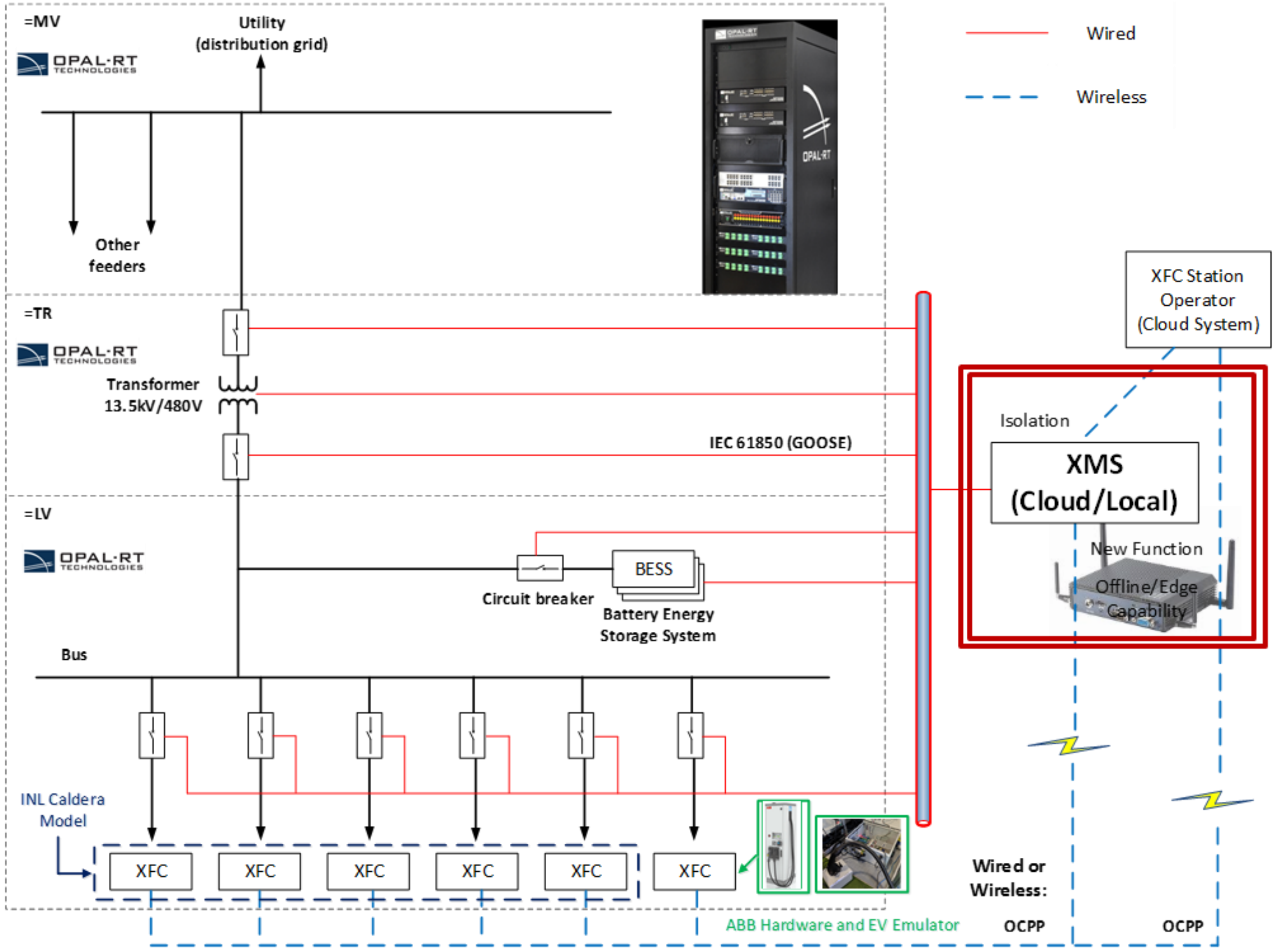
Provide local gateway for EVSEs that can interface w/ grid

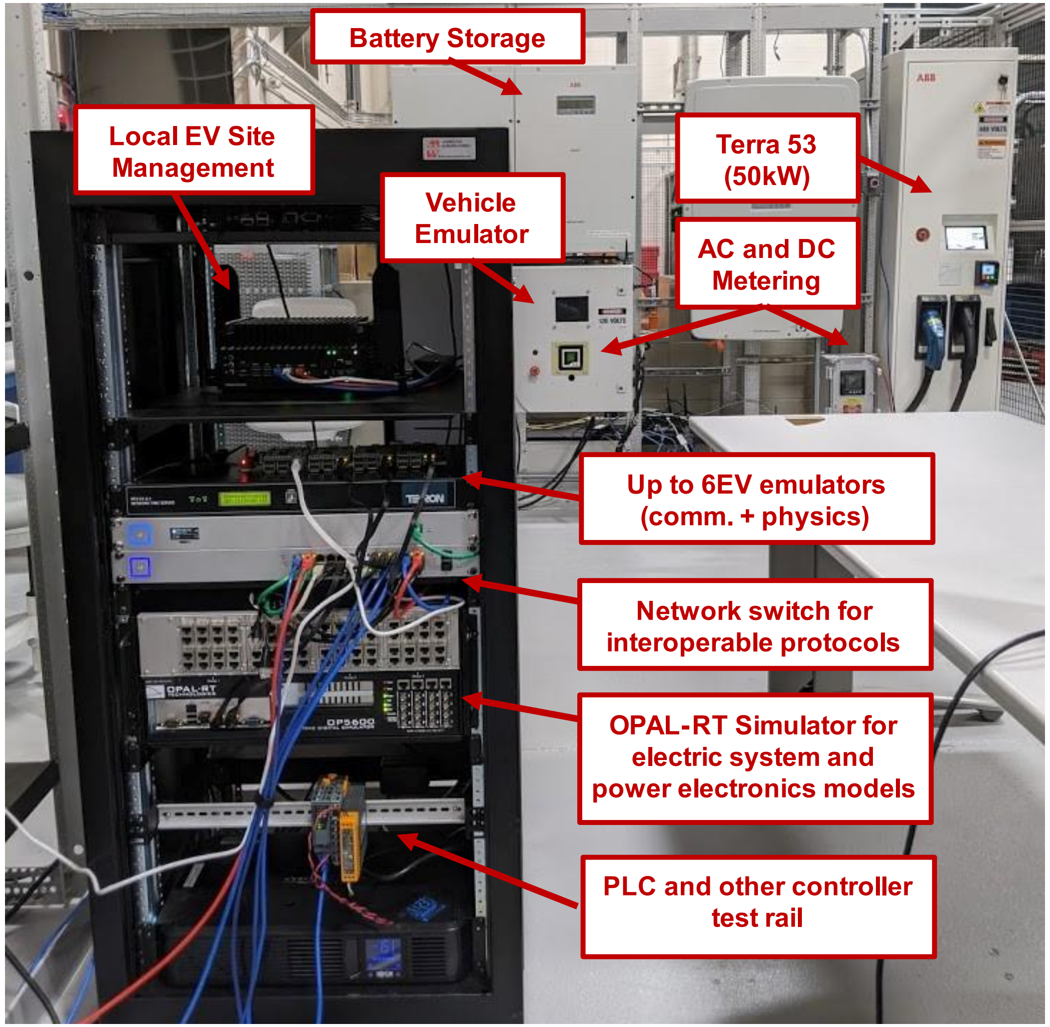
Provide OCPP central server core functions



Connect ABB hardware and EV emulator (local) or EV demo platform (INL)

Portable EV Site Testbed – Physics + Comm. Simulation, Local EV Management

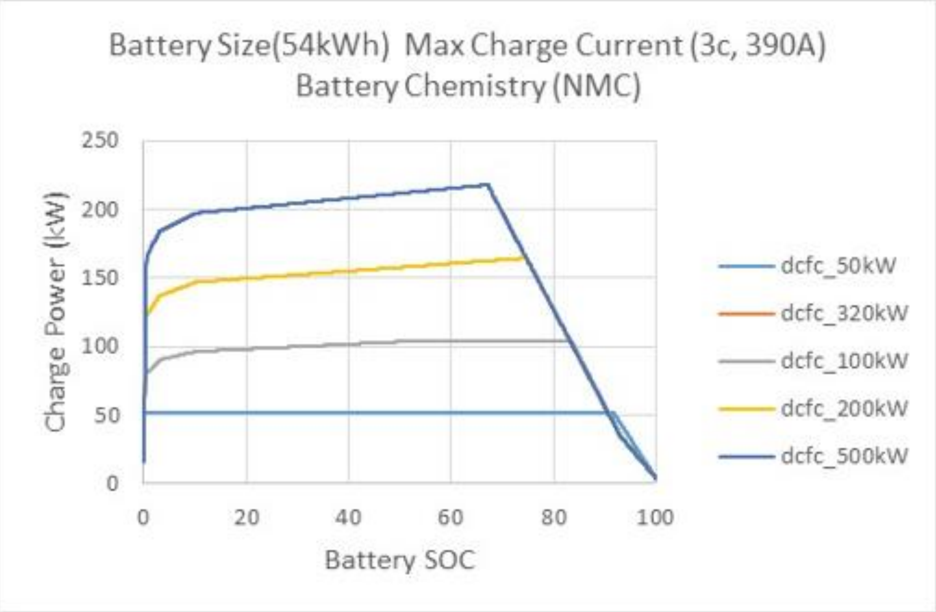


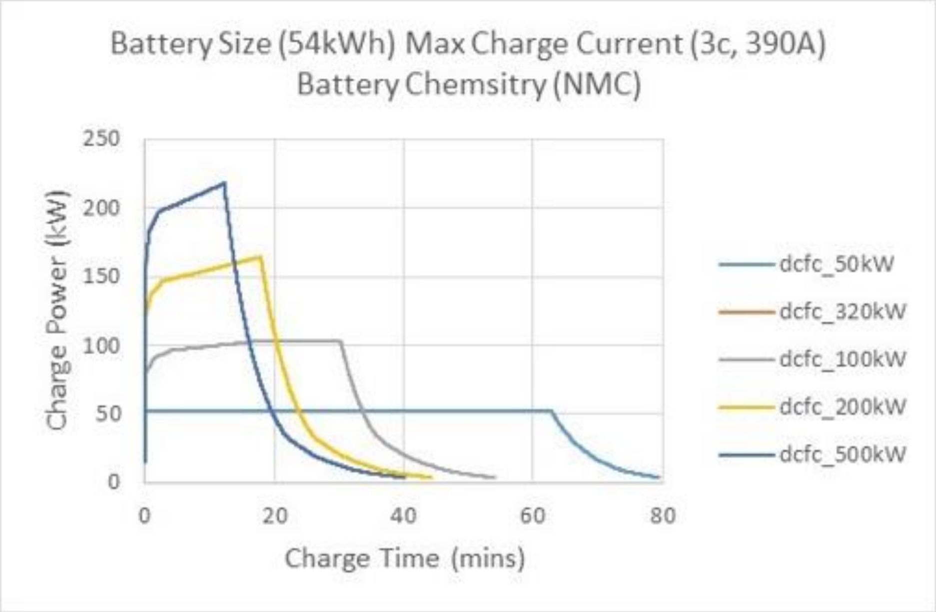


Resources and Capabilities (cont.)

High fidelity XFC charging models (INL)

- INL has done extensive battery testing for various battery chemistries
- Using test data able to generate high-fidelity charge profiles for PEVs that are not commercially available

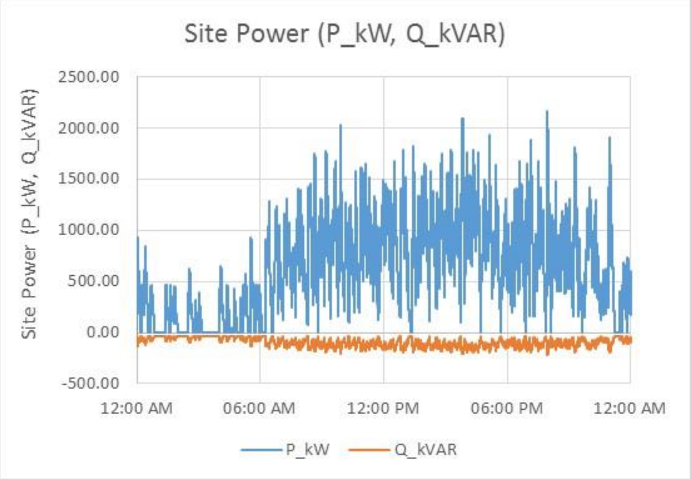




Resources and Capabilities (cont.)

High fidelity XFC charging models (INL)

- XFC site load profiles can be very volatile
- Volatile behavior may cause False Positives in anomaly detection systems
- Accurate charging models needed when designing system to avoid False Positives



- XFC site charge profile generated from charging models
- XFC site with 3 chargers and 6 total charge points
- All PEVs charged at site able to charge at 150 to 350 kW maximum dependent on existing connections at time of charge

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