Scalable Electric Vehicle Smart Charging Using Collaborative Autonomy

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Overview

Timeline

- Project Start: Oct ‘18
- Project End: Sep ‘21
- Percent complete: 30%

Budget

- Total Project
  - DOE $2.4M
- Funding for FY 2019: $766K
- Funding for FY 2020: $805K

Barriers Addressed

- Smart Charging/Smart Grid Interface
  - Demand response (DR)/ ancillary services at the local/multi-vehicle and regional/aggregate fleet levels

Partners

- Lead: Lawrence Livermore National Lab (LLNL)
- Industry: ChargePoint

Negotiating with others

Relevance

Impact

- The number of Plug-in Electric Vehicles (PEV) is rapidly growing, requiring controlled charging to avoid destabilizing the grid and to ensure energy security.
- We will develop and validate an algorithmic framework that uses collaborative autonomy to implement demand response techniques enabling smart chargers to respond to voltage and frequency events in the power grid in a timely fashion, thereby reducing demand variability and improving grid reliability.

Objectives

- Develop a collaborative algorithm that will enable local groups of charging station controllers to coordinate demand response and ancillary services such as frequency and voltage regulation
- Meet technological, policy, and contractual constraints imposed at the level of the smart charging stations
- Accommodate practical considerations (dynamic PEV load, multiple charging networks) to provide platform for innovation
- Real-world demonstration using commercially available chargers and PEV.

Collaborative autonomy for managing demand response for EV charging takes advantage of the distributed nature of the charging system and allows for a scalable approach while improving grid reliability and resilience.

Milestones

Milestones	Year 1				Year 2				Year 3			
	1	2	3	4	1	2	3	4	1	2	3	4
Objective 1: Develop Resilience-Driven Demand Response Algorithm												
1.1: Investigate software and hardware techniques and requirements	■											
1.2: Create a simulator to test algorithm		■	■	■								
1.3: Design Algorithmic Framework		■	■									
1.4: Test performance of algorithm				■								
Objective 2: Extend Framework to Incorporate Cost Minimization for Individuals												
2.1: Improve performance of ADMM* framework					■	■						
2.2: Extend the framework to manage multiple self-interested parties						■	■					
2.3: Test real-time and cost minimization performance in simulation								■				
Objective 3: Technology Demonstration Transition to Industry												
3.1: Refine software and algorithmic framework									■	■		
3.2: Technology demonstration with Skyfall hardware-in-the-loop simulation										■	■	■
3.3: Collaborate with ChargePoint to Explore Technology Transition											■	■

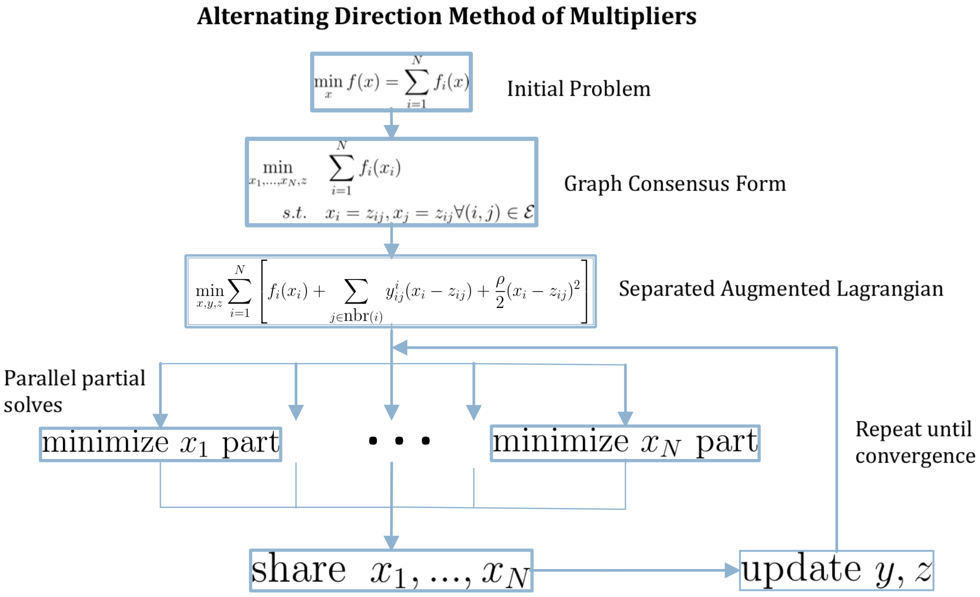
*ADMM = Alternating Direction Method of Multipliers

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

Approach

Collaborative Autonomy

- Use powerful distributed optimization methods, such as ADMM, to implement demand response, frequency regulation, and voltage regulation
- Use computational power of charging stations to compute charging schedules using ADMM without centralized control



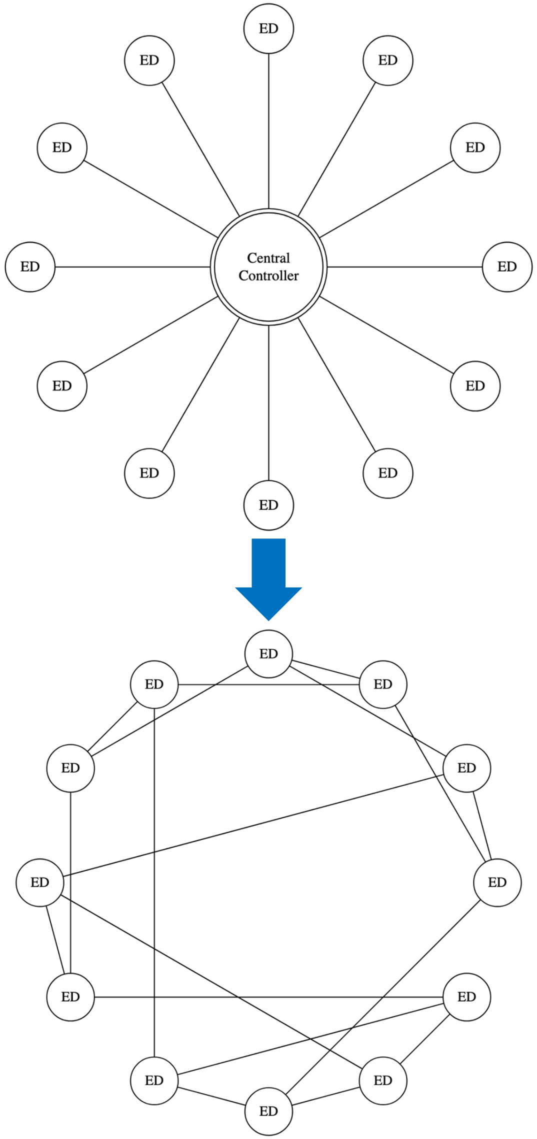
Simulation, Testing, and Demonstration

- Hardware-in-the-loop simulation (real devices running actual code) for testing at Skyfall, LLNL's cyber-physical testbed
- Simulation at scale (up to 10,000+ charging stations for demand response, down to sub-second time intervals for frequency and voltage regulation) using coupled simulations through HELICS
- Demonstration on deployed charging equipment

Our approach combines algorithm development, modeling and hardware in the loop coupled simulations leveraging HELICS co-simulation platform and HPC to develop, validate and demonstrate decentralized algorithms for EV charging management.

Benefits of the Approach

- Achieve scale by moving from centralized control to decentralized charge management
  - Edge devices (ED), such as charging stations, now communicate directly, and can perform local optimizations
- Tolerate hacked nodes with robust algorithms, and remove single point of failure
- Collaborative Autonomy platform allows implementation of other demand response algorithms



Collaborative Autonomy improves scaling and reliability and encourages innovation. Resilience is built in, not bolted on.

Technical Accomplishments & Progress

- Defined application requirements for load shifting and demand response
- Evaluated computational and communication capabilities of charging stations
- Devised two charging models suitable for decentralized implementation based on literature survey and subject matter expert interviews
- Implemented both charging models and performed initial efficiency and correctness testing
- Initial development of Skynet, software platform that will enable decentralized collaborative autonomy algorithms

In our first year we are focusing on defining the requirements and constraints and developing the proof of concept.

Communications Capabilities of Charging Stations

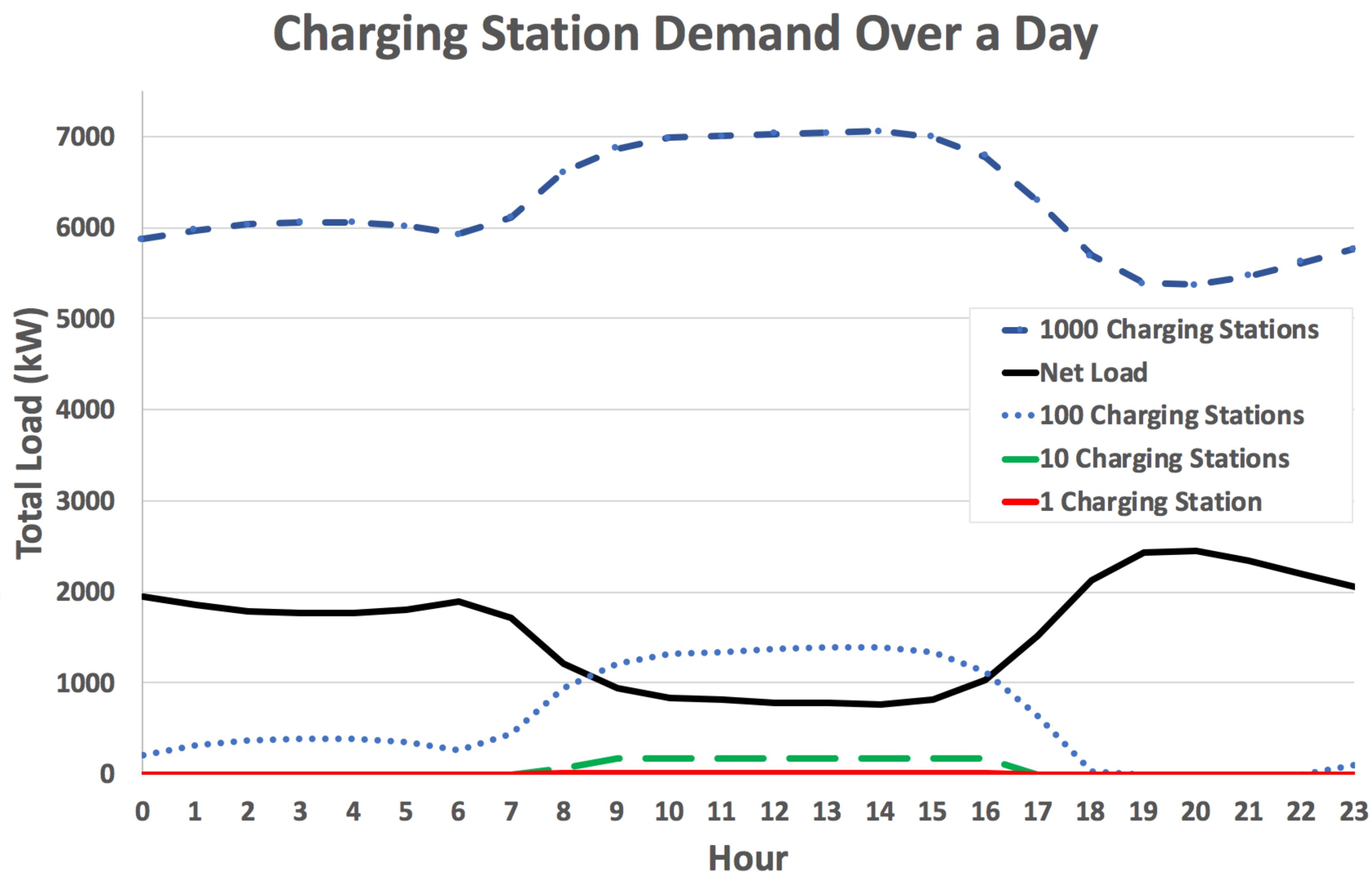
	Media	WiFi	LTE 4G	5G ULL	Wired
Maximum Messages Per Period	15 minutes	450,000	4,500	450,000	45,000
	4 seconds	2,000	20	2,000	200
	1 second	500	5	500	50
	Bandwidth	1.3 Gbps	100 Mbps	10 Gbps	1 Gbps

LTE = Long-term Evolution; 4G = 4th generation; 5G = 5th generation;
ULL = Ultra-Low Latency; Gpbs = gigabits/second; Mbps = megabits/second

- Most common communication technologies shown
- 15-minute time period for DR, 4 seconds for FR, 1 second for VR
- It is assumed that nodes will dedicate at most ½ of each period to communication

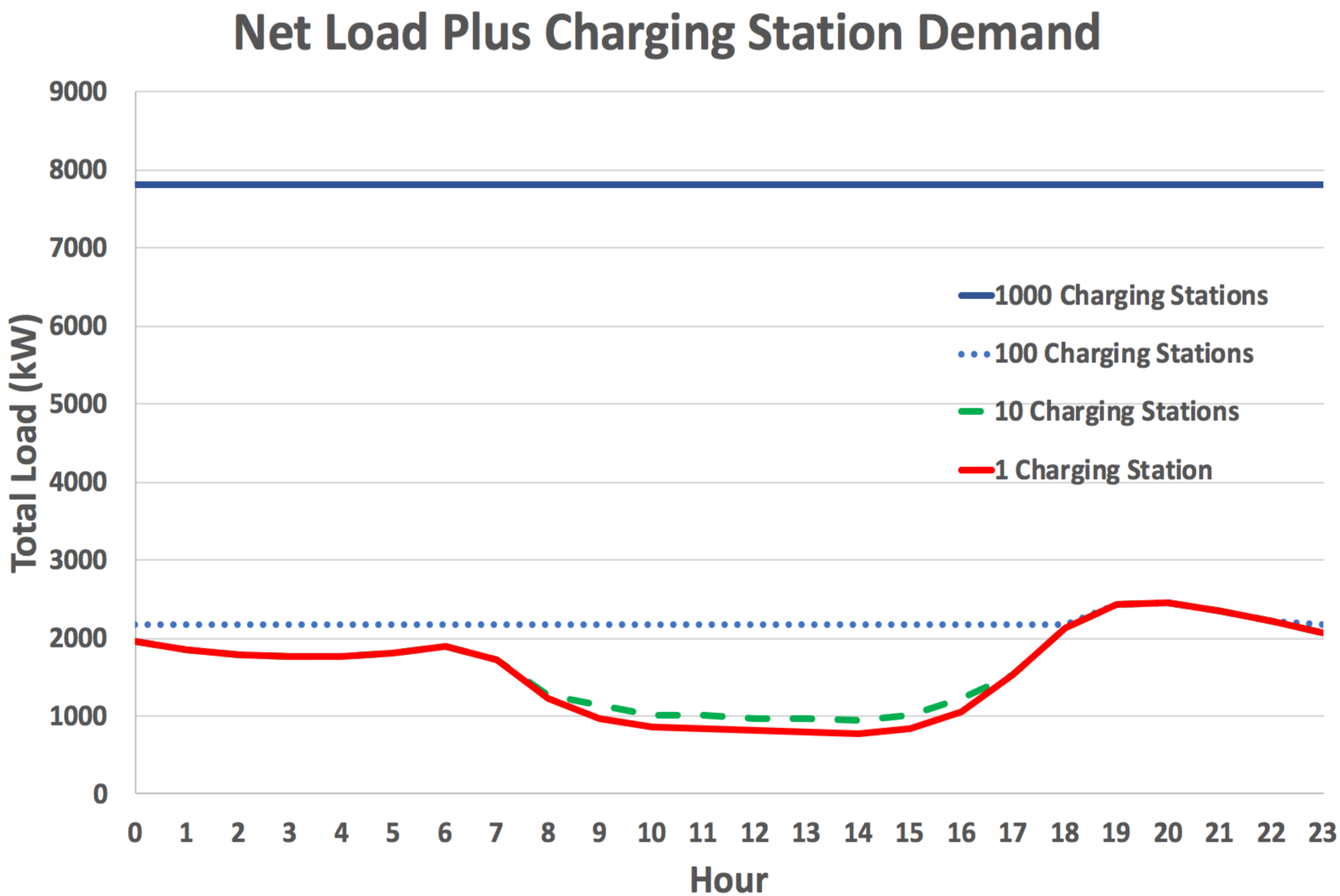
Response thresholds of applications and communication capabilities of technology influence scaling.

Charge Management with Load Constraints



Net Load model based on CAISO data. Total demand limited to 8000 kW (kilowatts). Each charging station serves 3 PEV, and can draw 18kW max.

Valley Filling the Duck Curve



1000 CS approach max load. 100 CS show valley filling. 1 or 10 CS have negligible effect. Net Load from 6—10pm cannot be flattened by reducing charge load.

Skynet: A Software Platform for Decentralized Collaborative Autonomy

✓ = Being developed by this project

❑ **Heartbeat**
- Maintain awareness of device and network liveness
- Incorporate new devices

☑ ✓ **Data**
- Collect data
- Manage data robustness
- Gossip protocols for spreading out data

❑ **Decision-Making**
- Distributed agreement

❑ **Basic Math**
- Matvecs
- Solving systems of equations
- Optimization (e.g. ADMM)

☑ ✓ **Control Actions**
- Determine which device carries out action

❑ **Communications**
- Send/receive messages with outside world

Skynet will provide a platform allowing the implementation of multiple programs using Collaborative Autonomy solving different problems.

Response to Previous Year Reviewers' Comments

- This project is a new start this year.

Collaboration and Coordination

- LLNL: Contract lead, software development, and hardware-in-the-loop simulation and testing.
- ChargePoint: input and expertise on charging profiles, charging hardware and software development environment, and testbed for live demonstration.
- Additional Vendors: we are negotiating with additional charging station vendors to join the project.

Remaining Challenges and Barriers

- Testing scaling in multiple dimensions—up in number of nodes and down in convergence time to facilitate additional ancillary services
- Accurate projections require hardware-in-the-loop testing and large-scale simulations
  - Hardware-in-the-loop confirms small-scale estimates
  - Only simulation can scale to projected future fleet size
- Multiple, competing actors
  - Charging network operators and/or individual vehicle owners may have conflicting motivations and optimization criteria

Our work in the remaining 2 years will address these barriers through hardware-in-the-loop simulation with high performance computing and applying the concept of simultaneous games from game theory.

Proposed Future Research (FY19 and FY20)

- FY 19: Development of a suite of test cases for use throughout the project
  - Use data supplied by ChargePoint as basis for test case generation
- FY 19: Simulation including hardware-in-the-loop and ns-3
  - Incorporate hardware to accurately model interactions and allow simulation at scale of projected growth models
- FY 19: Determine timing limits of our approach for application to difference services
  - Use benchmarking, simulation, and estimation to ascertain the relationship between problem size (number of charging stations) and time to convergence
- FY20: Porting of prototype to ChargePoint hardware
- FY 20: Incorporation of multiple competing charging networks
  - Investigate casting of cooperative games as optimization problems amenable to collaborative autonomy

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

Summary

- Relevance
  - Anticipated growth in # of PEVs requires scalable charge management solutions for energy security
- Approach
  - Decentralized charge scheduling—no centralized control, increasing scale and robustness
  - Collaborative autonomy using charging stations as compute nodes
  - Testing, simulation, demonstration
- Technical Results
  - Defined requirements, capabilities, and alternative algorithms and solution methods
  - Initial algorithm design, implementation, and preliminary testing
- Future Work*
  - Simulation
  - Incorporation of multiple charging networks
  - Determining scaling limits/relationships

Collaborative autonomy-based algorithms for managing demand response will enable scalable charging management while supporting ancillary services, ensuring grid reliability and improving resilience.

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