Executive Summary:

The Microgrid Fast Charging Station (MFCS) Design Platform

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XENDEE

INL Idaho National Laboratory

Executive Summary for the Microgrid Fast Charging Station (MFCS) Design Platform

BRIEF

On April 30th, 2021, XENDEE Corporation and Idaho National Laboratory finished the first version of the Microgrid Fast Charging Station (MFCS) Design Platform as well as tested and validated it with two in-depth case studies for islanded and non-islanded operation.

The platform itself utilizes XENDEE's advanced modeling systems and INL's Hardware In the Loop (HIL) system to ensure project viability and technical feasibility. It also intelligently maps all cables, transformers, and distributed technology interactions to anticipate and mitigate problems during peak usage or adverse conditions. Finally, the system is designed to optimize dispatch and generation at each time step of the day allowing the Microgrid to take advantage of energy sales to the utility and best manage the charging of an electrical fleet. This allows operators to reliably build bankable Microgrid systems and to operate them to reach the maximum efficiency even under the dynamic needs of electric vehicle fast charging.

OVERVIEW

This project is the first step in developing a holistic design and validation framework for roadside Microgrid configurations that deliver optimal electric vehicle fast charging, grid interaction, and value-added grid services as well as a bankable foundation for a reliable and sustainable nationwide electric vehicle (EV) charging network. The MFCS project is a joint research and development initiative created by XENDEE Corporation and Idaho National Laboratory with funding by the U.S. Department of Energy, Office of Electricity.

With a focus on the next generation of roadside infrastructure, the project team has identified charging requirements, load profiles and power requirements that are particular to fast charging heavy duty trucks and EV charging at scale, defined two test cases to simulate and validate the capabilities of fast charging Microgrids, and assured compliance with standards for functionality and interconnection. The two test cases represent a grid connected MFCS with 5.83 MW of fast charging capacity as well as an islanded MFCS with 3.75 MW of fast charging capacity. Using these case studies, the project team has successfully validated the integrated Microgrid design and analysis tool for high power fast charging of large Megawatt loads for vehicle fleets and trucks. Additionally, power flow and distributions system modeling (e.g., voltage, frequency, transformer and cable sizing, etc.) have been integrated with the economic design and validated via real-time simulations at Idaho National Laboratory.

The MFCS project also includes and integrates *(a)* the development and evaluation of a technical planning and economic analysis tool for the design and implementation of Microgrid Fast Charging Stations, (b) the design of the Microgrids' underlying infrastructure, (c) and the appropriate testing algorithms to interpret the results. Additionally, it is the first tool of its kind that integrates power systems engineering for electric vehicle charging with Distributed Energy Resources (DER) modeling that also connects local distribution and utility interactions with the financial design to capture the lowest costs and the fastest return on investment.

The steps below were concluded within this phase of the project for the two selected test cases including:

1. Research on charging infrastructure costs, unit sizes, fees, EV truck status quo, driving distances, DER technology costs, public and private-sector electrification goals, and research on how these goals can influence the optimal design of a MFCS project.
2. Research and algorithm design for economic and financial modeling of MFCS.
3. Energy System Analysis extended by XENDEE's:
   a. Process of constructing models and scenarios to address goals relevant to MFCS design, optimal DER portfolio and optimal controller dispatch and logic.
   b. Financial projections to assess business cases of Microgrid design and operation.
4. Power System Analysis extended by XENDEE's:
   a. Process of integrating energy systems analysis results into creation of circuits.
   b. One-line diagram for planning purposes.
   c. Power flow models for the Hardware in the Loop analysis.
   d. Balance of system sizing for cables and transformers.
   e. Snapshot power flow showing response of power systems under full loading conditions.
   f. Quasi-static time series (QSTS) studies showing response of power systems to time-dependent conditions.
5. Real-time simulation of power flow evaluation at Idaho National Laboratory.
6. Assessment of missing capabilities and platform limitations.

At this point, the completed R&D together with the MFCS platform allows the Microgrid and EV industry to address and assess the:

1. Lowest cost technology mix for fast charging of EV and truck fleets; optimal capacities for photovoltaic (PV), electric storage, generators, Combined Heat and Power (CHP), etc.; the NPV or the ROI for the project including the EV fleet loads.
2. Optimal operation of the system to minimize costs or maximize the revenues. Optimal charging and discharging of the electric storage and EV fleet to minimize the overall costs.
3. Optimized management of EV fleet charging.
4. Optimal placement of FCS and local generation resources to mitigate bottlenecks in the utility system.
5. Impact of grid outages on the EV charging and costs/oversizing of equipment.
6. Sales of excessive energy back to the utility or revenues from providing Ancillary Services.
7. Proper electrical engineering for cables and transformers.

All the steps and features listed above can be addressed for grid-connected FCS projects as well as for completely disconnected ones (islanded cases).

The next R&D steps for the project will include electromagnetic and transient analyses algorithms, Vehicle to Grid (V2G) as well as Vehicle to Building (V2B) modeling and revenue streams, DC Microgrid versus AC Microgrid FCS structures, as well as the roll-out of the platform for nation-wide testing.

INTRODUCTION/SET-UP

The project team's platform for modeling and analysis was developed for the implementation of Microgrid Fast Charging Stations in both populated, grid serviced areas, as well as isolated locations along interstate highways with no utility service.

The platform was developed using data from the University of California San Diego (UCSD) network and on-campus Microgrid which provides 85% of the electrical needs with DER, including electricity delivered to 135 ChargePoint EV charging stations. The modeling results typify an EV charging location that is close to an interstate highway, must meet multiple critical loads apart from the EV stations, and is connected to a distribution network for a major city.

High quality data was made available through real metered demand matrices for specific buildings, EV fleet demand data from each charger and charging session, and a complete model of the campus circuit infrastructure, which was mirrored in the simulation model. The quality and extent of the campus Microgrid data made it possible to study a range of scenarios.

UCSD also hosts a central natural gas fired co-generation plant, a fuel cell, a battery energy storage system (BESS), and 28 PV systems installed at different locations within the site. The BESS is primarily used to balance the campus's PV generation and for demand charge management. It has recently begun to be used for occasional participation in the California Independent System Operator (CAISO) demand response auction market.

A full power flow model that depicts the transformer locations, cables, associated ratings and installed DERs of the entire UCSD Microgrid on the main campus was also made available. The Microgrid is a radial distribution system with three substation transformers that step down to 12.47 kV from 69 kV, and 287 transformers that step down to 0.48 kV. Utility-grade Schneider Electric IO electricity meters are installed on 70% of the campus loads, generation, and storage equipment. The model has 1289 buses. For increased computational speed, reduced feeder models of the campus have been created using the distribution feeder reduction algorithms, retaining key buses at which building loads aggregate and that have generators or EV. A representation of the campus distribution network is shown as a one-line diagram of a reduced model in Figure 1. The data has been used to build two test-cases: a grid-connected MFCS and an islanded (without any utility connection) MFCS test-case.

Figure 2 shows a further reduced model of the same campus, with the existing EV chargers, PV, and batteries utilized for the grid-connected test case. For the islanded test-case, a sub-section of the full campus distribution system was used for the modeling (see Figure 3) to reflect a smaller islanded system, as we would expect it at a remote highway charging station.

In conclusion, the rich data quality allowed the project team to model upgrades to the UCSD network, determine the optimal renewable energy mix, and consider other DERs to minimize the costs for electric vehicle and truck charging. This also facilitated realistic analyses of the impact on the distribution system that would be introduced by these upgrades, and allowed the project team to evaluate them using Idaho National Laboratory's simulations.

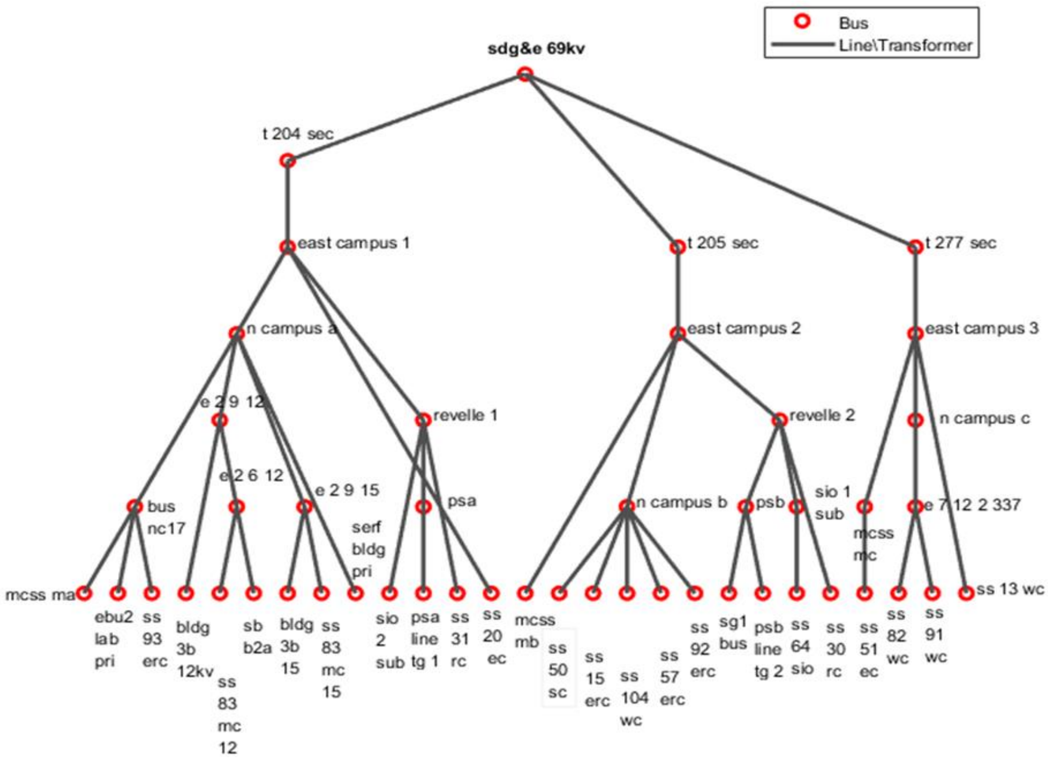

Figure 1: Single-line diagram of the reduced 48-bus UCSD Microgrid model. The text labels refer to the name of the bus in the UCSD Grid Database.

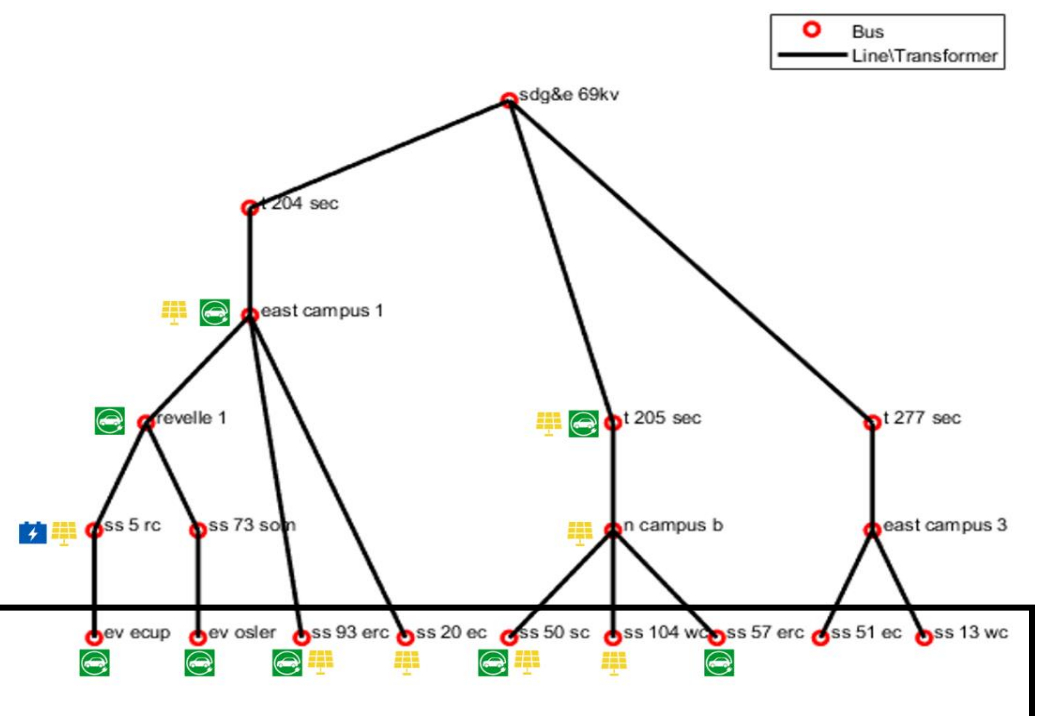

Figure 2: Single-line diagram of the reduced 20-bus UCSD existing Microgrid model, grid connected test-case (only EV and renewable generation technologies are shown). The text labels refer to the name of the bus in the UCSD Grid Database. Existing DC Fast Charging stations are located at ev ecup and ev osler.

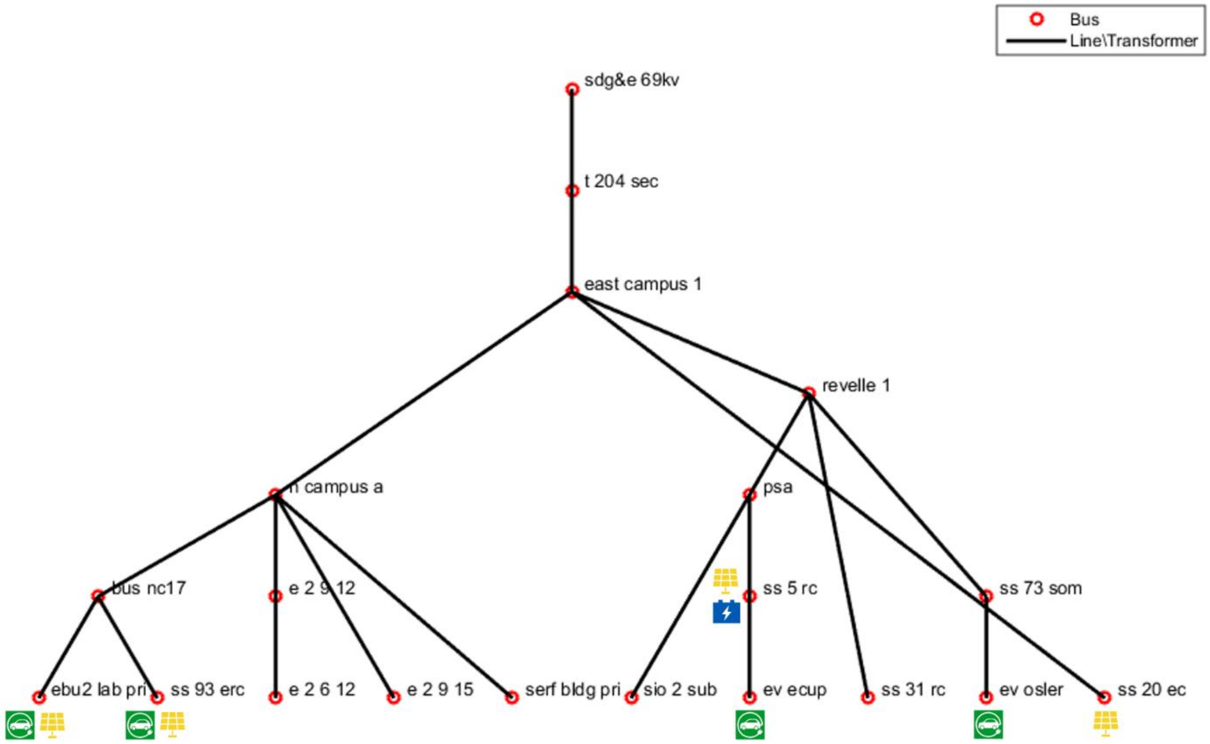

Figure 3: Single-line diagram of the reduced 20-bus UCSD existing Microgrid model used for the islanded case study. The text labels refer to the name of the bus in the UCSD Grid Database. DC Fast Charging stations are located at ev ecup and ev osler.

EV Loads for Energy Systems Modeling

EV charging stations are handled differently from building loads in the techno-economic optimization model of XENDEE (the part of the platform that deals with the basic financial design of the EV project). The total daily fleet demand is defined in kWh, and the solver optimizes when that fleet demand is met within constraints set on charging availability of the modeled stations. Existing total fleet demand was defined using historical charging data, which provides data on total energy during each charging session. EV stations were mapped to the buses in the UCSD feeder model and the total energy of the aggregated EV stations at each bus was summed. The MFCS can be designed at a scale of tens of MW power as indicated by Table 1.

For this report, analyses on grid-connected and islanded test cases were conducted for two scenarios:

- Baseline Scenario- representing the system as-is, with existing EV stations and DER assets
- Design Scenario- adding combinations of new DCFC charging stations and/or DER assets

Test cases	Baseline	Design Scenarios with Added EV
Grid-Connected	0.83 MW	5.83 MW
Islanded	0.5 MW	3.75 MW

Table 1: Maximum EV charging capacities in the different cases.

In the design scenario, new DER assets, additional PV and BESS are considered as options at multiple nodes to optimize asset placement, minimize losses, and avoid bottlenecks in the distribution system. This multiple node optimization is key to the proper EV charging and Microgrid design and is a unique feature for this project. The specific design scenarios were constructed for both grid-connected and islanded test cases. Both baseline and design scenarios are developed with the XENDEE techno-economic optimizer. In this techno-economic optimization, the provided EV charging station locations, the DER investments, as well as dispatch operation were optimized to find the most attractive financial solution. The results from this step were further studied with both snapshot power flow analyses and QSTS analyses to estimate the impact on cables and transformers.

Snapshot power flow studies are run on the design scenario circuits (actual UCSD circuits) to identify any weaknesses in new circuit designs. Any overloads and voltage drops are identified and resulting data is used to make sizing adjustments. For example, cable sizing is adjusted by increasing ampacity, and transformer sizing is altered by increasing the kVA rating. After cables and transformers are sized, a second power flow study is run to determine system response and verify that the sizing changes address weaknesses in the circuit introduced by new EV loads and/or generation sources. In this way, the MFCS is connected to the circuit, offering secure and reliable interactive management.

Another key feature of this project and XENDEE is to identify optimal charging times to mitigate challenges and bottlenecks in the system. The islanded test case includes a scenario that restricts potential charging times to force fleet demand to be met during short windows, reflecting the technical and financial impact of higher demand from EV charging stations ("Overnight Charging" scenario).

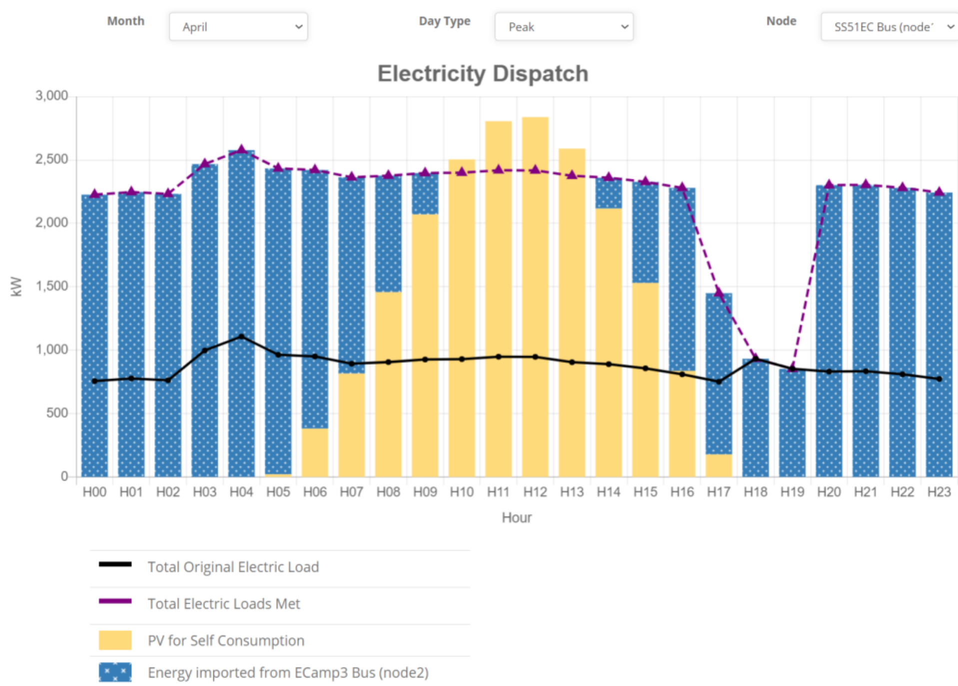

Figure 4: Dispatch at the location of 20 new fast charging stations (bus ss_51_ec) on an April day with peak monthly demand, grid-connected case. It can be clearly seen how the expensive time of use electric rates in the evening are avoided for fleet demand charging.

Financial System Design and Operation/Managed Charging

To understand the energy costs, optimal technology mix, as well as operation of the MFCS, selected examples from the project are shown below.

1. To support installing a truck fleet charging stop at the rural station modeled in the islanded scenarios with 3.75MW of charging capacities, only an additional 140 kW of PV is required as long as the daily EV fleet demand can be distributed across all hours in the day (case “Design with New EV Stations/DER”).
2. However, if charging availability is restricted to force the additional 16.5 MWh daily fleet demand for the Class 8 trucks to be met at night, 340 kW of new PV is installed. Neither additional storage capacity nor fuel cells are required, as the existing 2.8 MW fuel cell modeled in the baseline scenario is still sufficient for meeting most of the electricity balance, and the total PV capacity does not exceed site demand, limiting storage-charging opportunities. This case underscores that managed charging schemes will help to reduce costs.

In conclusion, the additional EV load prompts slightly increased use of the storage in the “Design with New EV Stations/DER” scenario, and modeling “Overnight Charging” for the Class 8 trucks further increases annual storage cycling by a factor of 10, as a significant portion of total site demand is concentrated in a smaller window. Efficient charging of the storage to provide more evening dispatch will then require the increased PV capacity of 340 kW, compared to 140 kW when XENDEE can optimize distribution of all EV charging across the day. This shows the importance of storage when considering alternative configurations of the FCS Microgrid in the model.

Bus	New DCFC[1] Stations	Existing Fuel Cell [kW]	New PV [kWdc]	Existing DCFC Stations	Existing PV [kWdc]	Existing Storage [kWh]
ev_osler	26			4		
ss_5_rc		2800			29	5000
e_2_6_12			340			
ss_93_erc					338	
ss_20_ec					288	
ebu_2_lab_pri					81	

Table 2: Bus location and capacity of all DER assets and EV charging stations. Results are from the Design with New EV Stations/DER, Overnight Charging scenario.

The platform can also show placement and sizing of the DER technologies and EV charging stations assuming certain scenarios, for example the “Design with New EV Stations/DER” or truck “Overnight Charging.”

Managed Charging

In the islanded case, the optimal EV charging times are mostly scheduled for hours when building load is lowest and the fuel cell can provide sufficient power to meet both the building loads and the EV fleet demand (shown as the gap between Total Electric Loads Met and Total Original Electric Load in Figure 5).

[1] DCFC: DC Fast Charging

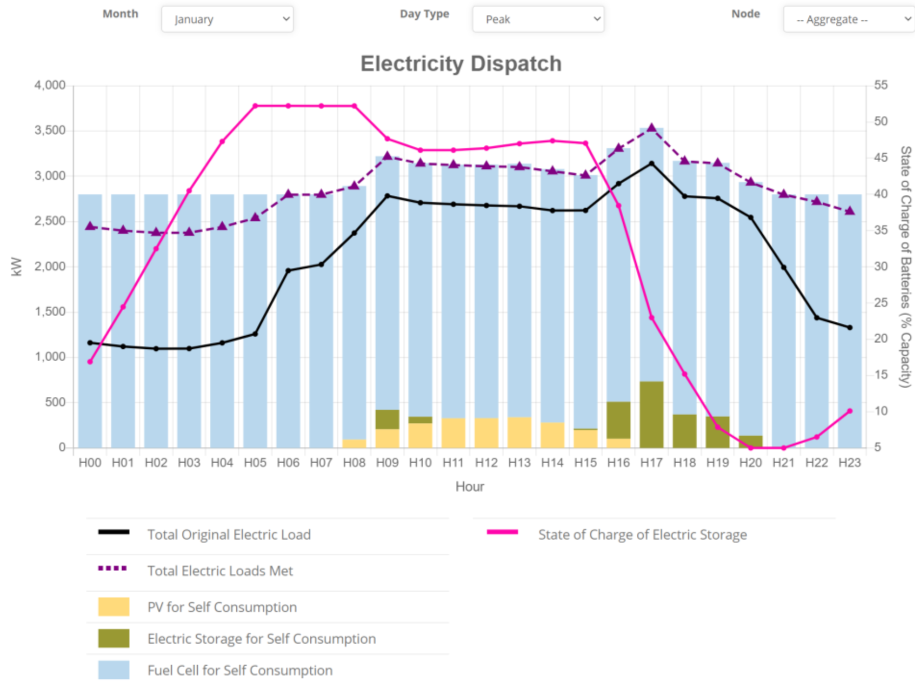

Figure: 5 System-wide dispatch for a January day with peak monthly demand in an islanded location and facing the "Design with New EV Stations/DER" scenario.

When all freight truck charging is restricted to the hours between 10 pm and 6 am ("Overnight Charging" scenario), the:

- Fuel cell power is devoted entirely to meeting system demand during the freight charging hours.
- Storage charging times shift from early morning to midday, and a combination of fuel cell power and PV power contribute to storage charging (compare Figure 5 and 6).

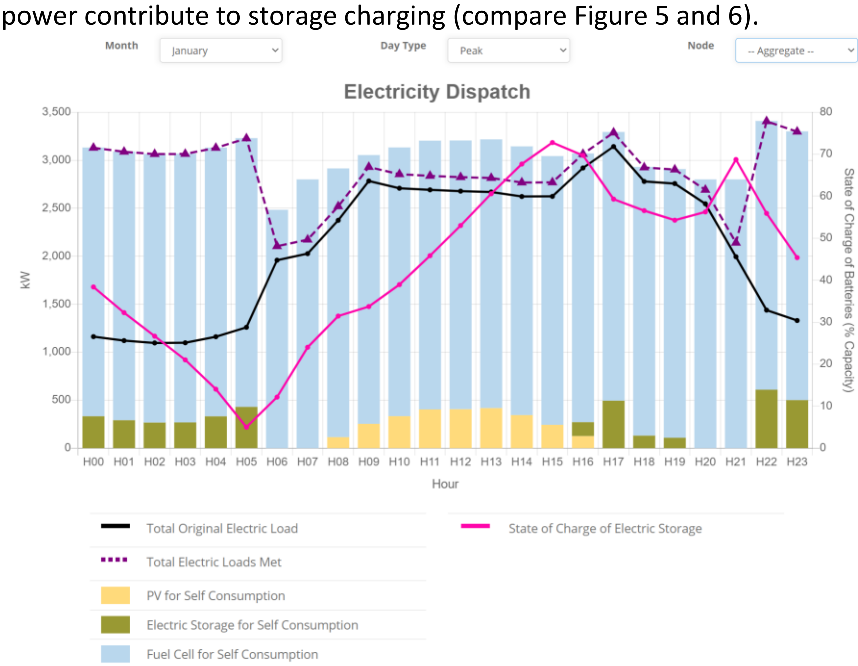

Figure 6: System-wide dispatch for a January day with peak monthly demand in an islanded location and facing the "Design with New EV Stations/DER" and "Overnight Charging" scenarios.

According to the analysis, revenue generated by adding DCFC stations that are primarily used by freight trucks is around $4.1 million for the grid connected scenarios and $2.2 million for the islanded scenarios. Prior to adding the new fast EV chargers, the revenue from the existing charging stations is negligible in all cases.

Project feasibility is affected by accounting for charging station installation costs – both infrastructure upgrade costs, as well as ownership structure – and the impact this will have on the Microgrid. To account for ownership structure, sites can be modeled from the perspective of an entity claiming responsibility for both installation and operation of all DER assets and charging stations, as well as capture all the revenue for use of charging stations. Conversely, different set-ups such as purely claiming responsibility for the EV charging stations are also possible.

Power Flow Analysis

The entire electrical system, including the new fast charging stations were analyzed under snapshot and QSTS power flow conditions with maximum loading and generator output. This identifies any issues with cable and transformer sizing including:

- Overloading at connected transformers.
- The incorporation of new DER assets selected and placed by the optimization.
- Calculating the additional strain on the cables from new technologies.
- Currents at each of the overloaded cables, providing a benchmark for increasing the ampacity.
- The rating for overloaded transformers and suggested changes.

Following the sizing modifications, the circuits for all scenarios show no issues in voltage, element loading, or voltage regulation. The grid equipment is now sufficiently sized and provides significant active and reactive power to balance the demands at full loading.

Power Flow Analysis Results and Valuation

The INL team simulated and validated the power flow analyses conducted by XENDEE for the grid-connected use cases in the real-time digital simulator (RTDS®). The results match within 5%. The RTDS model for the UCSD Microgrid is presented in Figure 7.

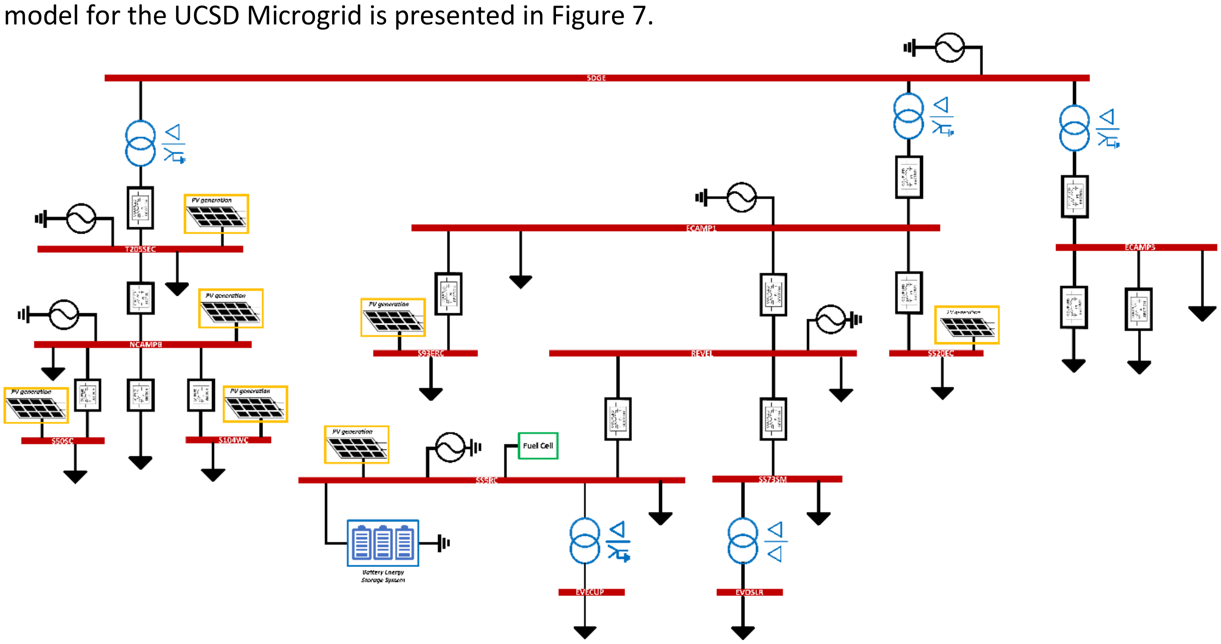

Figure 7: RTDS/RSCAD Model of UCSD Microgrid, grid connected case

Sr #	Gen	RTDS		XENDEE		Error (%)	
		V (p.u)	Angle	V (p.u)	Angle	V (%)	Angle (%)
1	SOURCEBUS	1.00	0.00	1.00	0.00	0.25	0.00
2	ECAMP1 PV	0.97	-28.82	0.98	-29.50	1.28	2.29
3	FUEL CELL	1.02	-28.01	1.01	-28.60	-0.87	2.07
4	NCAMPB GEN	1.00	-29.39	0.98	-28.50	-2.11	-3.13
5	NCAMPB PV	0.99	-29.34	0.98	-28.50	-1.45	-2.96
6	NEW ECAMP1 PV	1.00	-28.82	0.98	-29.50	-1.08	2.29
7	NEW ECAMP3 PV	0.99	-30.43	0.99	-30.30	0.16	-0.41
8	NEW NCAMPB PV	1.01	-29.50	0.98	-28.50	-3.62	-3.50
9	NEW SS104WC PV	0.99	-29.35	0.98	-28.50	-1.69	-2.98
10	NEW SS13WC PV	0.99	-30.43	0.99	-30.30	0.06	-0.42
11	NEW SS50SC PV	1.00	-29.34	0.98	-28.50	-1.84	-2.94
12	NEW SS51EC PV	1.01	-30.42	0.99	-30.30	-2.31	-0.39
13	NEW SS57ERC PV	1.00	-29.34	0.98	-28.50	-2.16	-2.94
14	NEW SS5RC PV	1.02	-28.04	1.01	-28.60	-1.04	1.96
15	NEW SS73SOM PV	0.98	-28.70	1.00	-28.80	1.69	0.33
16	NEW T205 PV	0.99	-29.35	0.98	-28.60	-0.61	-2.62
17	REVEL1 GEN	0.97	-28.73	1.00	-28.80	2.55	0.24
18	SS 20 EC PV	0.97	-28.82	0.98	-29.50	1.07	2.29
19	SS 5 RC PV	1.00	-27.63	1.01	-28.60	0.88	3.38
20	SS 93 ERC PV	0.97	-28.85	0.97	-29.70	0.04	2.86
21	SS104WC PV	0.99	-29.35	0.98	-28.50	-1.63	-2.98
22	SS50SC PV	0.99	-29.34	0.98	-28.50	-1.58	-2.94
23	SS5RC GEN	1.00	-27.62	1.01	-28.60	0.92	3.43
24	T205 GEN	0.99	-29.35	0.98	-28.60	-0.60	-2.62
25	T205 SEC PV	0.99	-29.37	0.98	-28.60	-1.03	-2.68
26	BESS	1.02	-27.97	1.01	-28.60	-0.69	2.21

Sr #	Bus	RTDS		XENDEE		Error (%)	
		V (p.u)	Angle	V (p.u)	Angle	V (%)	Angle (%)
1	SDGE B	1.00	0.00	1.00	0.00	0.00	0.00
2	ECAMP1	0.97	-28.82	0.98	-29.50	1.30	2.29
3	S93ERC	0.97	-28.85	0.97	-29.70	0.30	2.86
4	REVEL1	0.97	-28.70	1.00	-28.80	2.66	0.36
5	SS5RC	1.00	-27.63	1.01	-28.60	0.90	3.39
6	T205 S	0.99	-29.36	0.98	-28.60	-1.00	-2.66
7	NCAMPB	0.99	-29.34	0.98	-28.50	-1.44	-2.96
8	SS50SC	0.99	-29.34	0.98	-28.50	-1.45	-2.94
9	T204 S	0.97	-28.93	0.98	-29.50	1.24	1.93
10	S104WC	0.99	-29.35	0.98	-28.50	-1.50	-2.98
11	S57ERC	0.99	-29.34	0.98	-28.50	-1.45	-2.94
12	T277 S	0.99	-30.43	0.99	-30.30	0.26	-0.41
13	ECAMP3	0.99	-30.43	0.99	-30.30	0.32	-0.41
14	SS20EC	0.97	-28.82	0.98	-29.50	1.26	2.29
15	SS51EC	0.99	-30.42	0.99	-30.30	0.30	-0.39
16	SS13WC	0.99	-30.43	0.99	-30.30	0.27	-0.42
17	SS73SM	0.97	-28.70	1.00	-28.80	2.64	0.33
18	EVECUP	1.00	-60.63	1.00	-60.00	0.12	-1.05
19	EVOSLR	0.97	-33.26	0.99	-30.30	2.03	-9.76

Table 3: Infrastructure Upgrade Case: Power Flow Results Comparison of XENDEE and RTDS for Generators and Buses, in one of the grid connected cases.

Table 3 shows the RTDS® and XENDEE base case p.u. voltage magnitudes, phase angles and percentage error for generators and buses. The error is within ±5% for all the generators and buses. Total supplied MW/MVAR from the generators is 64.305/20.24. Maximum voltage bus is SS5RC with 1.0061 p.u. and minimum bus voltage is S93ERC with 0.9704 p.u. The maximum voltage bus modeled in XENDEE is also SS5RC with 1.0075p.u and minimum bus voltage is SS93ERC with 0.9734p.u.

The whole project underscores the complexity of MFCS projects and the need for a research based and validated approach that integrates all economic and technical aspects of the project phases to capture the greatest operating efficiency.

Acknowledgment

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