Impact of EV Infrastructure on the University of Southern California MicroGrid

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Impact of EV Infrastructure on the University of Southern California MicroGrid

Based on Smart Grid Regional Demonstration Project – Los Angeles

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***Abstract*—with the growing penetration of the electric vehicles to our daily life owing to their economic and environmental benefits, there will be both opportunities and challenges to the utilities when adopting plug-in electric vehicles (PEV) to the distribution network. In this paper, a thorough analysis based on real-world project is conducted to evaluate the impact of electric vehicles infrastructure on the grid relating to system load flow, load factor, and voltage stability. University of Southern California (USC) Distribution microgrid was selected and tested along with different case scenarios utilizing the electrical distribution design (EDD) software to find out the potential impacts to the grid.**

Keywords—electric vehicle; smart grid; grid impact; load; power flow; stability; DEW

I. INTRODUCTION

A distribution system study, power flow, feeder voltage regulation, and short-circuit analysis, becomes necessary for planning and evaluating the suitability and impacts of Plug in Electric Vehicles (PEVs) and Photovoltaic (PV) in the distribution system.

This research paper is based on the Los Angeles Department of Water and Power (LADWP) Smart Grid Regional Demonstration Project (SGRDP), which is a leading edge demonstration project intended to support the goal of the DOE Smart Grid Demonstration Project (SGDP) funded under the American Recovery and Reinvestment Act (ARRA) of 2009. The intent of the DOE's SGDP is to explore advanced smart grid systems and evaluate performance for future applications in the electric power industry.

To support these DOE SGDP objectives, LADWP and its research partners, the University of Southern California (USC), the University of California at Los Angeles (UCLA) and Jet Propulsion Lab (JPL) are working together under the LADWP SGRDP to demonstrate innovations in key areas of smart grid (SG) technologies. This includes Advanced Meter Infrastructure (AMI), Demand Response (DS), Customer Behavior (CB), Cyber Security (CS), and Electric Vehicles (EV). The LADWP SGRDP is a five-year, $120 million project that encompasses installation of smart-grid equipment, collection of system data, construction of equipment models, performing power system studies, formulation of operating strategies, and development of software and techniques related to the above-mentioned areas of smart grid.

The objective of this paper is to present some early result of the EV demonstration project, specifically the infrastructure impact of EV, including system modeling, power flow studies, and demonstration activities utilizing the USC Distribution System as a test system. The EV impact demonstration studies are conducted, under different load increment conditions and different system load profiles. The results of these studies will be used to validate and benchmark those obtained from real-time data.

This paper first gives an overview of the EV demonstration project activities and describes the USC Distribution Test System(Section II). Section III presents an overview of different study scenarios and base cases, while Section IV describes the results and analysis of those cases. Finally, the conclusions based on this analysis and suggestions for potential future work are presented in Section V.

II. OVERVIEW OF THE SYSTEM USED

A. Technology and system utilized

To analysis and evaluate the impact of EV to the grid, the following activities are under taken:

- USC distribution network reflecting a large urban complex in the LADWP system was selected to enable analysis of EV distribution effects as described above.
- Distribution system modeling software Distribution Engineering Workstation (DEW) by Electrical Distribution Design, Inc. (EDD) is to be used to model the distribution network, which enables the construction of a complete working model for the entire power grid, from the transmission level through primary and secondary distribution networks.

The research work was conducted under ARRA Smart Grid Regional Demonstration Project and funded by the US Department of Energy and Los Angeles Department of Water and Power.

- The EDD models and the system representations allow the attachment of multiple EV-charger loads of various classifications
- The EDD models and the system representations are designed to reveal the aggregate effect of the multiple EV-charger loads at substation connections to the transmission grid
- A sensitivity analysis are setup on the test systems with the goal of revealing the substations within the LADWP territory that have the greatest impact on the transmission grid when they are similarly subjected to EV loads. The sensitivity studies conducted are discussed in Section III.

B. *Configurations of the Smart Grid Systems, Subsystems and Components*

The network configurations of the test systems and the system modeling considerations are discussed in this section. The actual system studies test results are provided in Section IV.

The distribution system under consideration is the USC Distribution System. USC park campus is the main campus of the university that is, located in Los Angeles, California. Due to its size, data of the test feeder can not be made available in this paper. The USC Distribution microgrid structure and its EDD model structure are shown in Fig 1, and Fig 2, respectively.

The feeder's nominal voltage is 4.8 kV. Loads are comprise of three-phase (balanced or unbalanced) and single phase systems. Three-phase loads are connected in wye or delta while single-phase loads are connected line-to-ground. All loads are modeled as constant kW and kVAR (PQ), constant impedance (Z) or constant current (*I*) depending based on the actual system load. Other system data include:

- Two substations connect to the LADWP electric grid
- Four Feeder stations
- 19 Feeder circuits
- 5 parking structures: PSA, PSB, PSD L, PSD R, PSX

The base case system condition are given in Table I.

TABLE I. POWER FLOW RESULTS OF USC DISTRIBUTION SYSTEM

		EDD Result
Total Feeder Flow	***kW***	26,413.71
	kVAR	14,633.21
	kVA	30,317.07
Total Losses	***kW***	89.02
	kVAR	272.28
	kVA	292.22

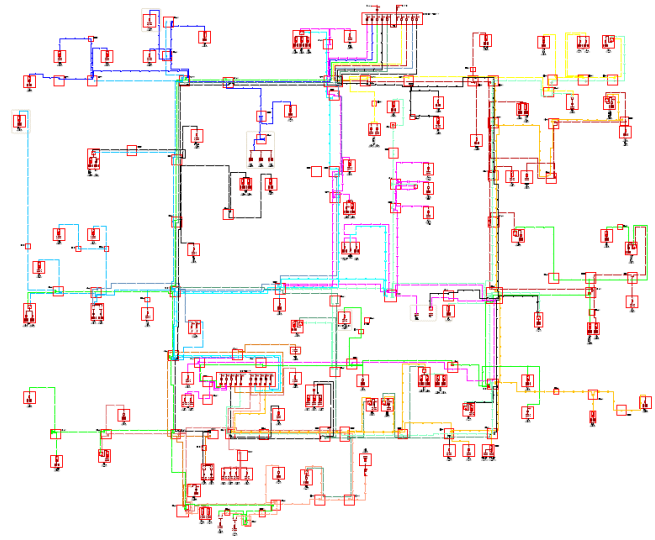

Fig. 1. One-line Diagram of USC Distribution Microgrid

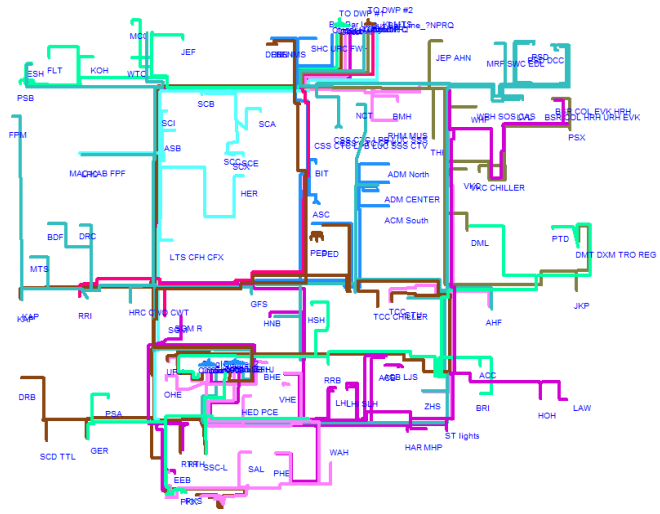

Fig. 2. USC Distribution Microgrid in EDD

III. DESCRIPTION OF THE METHODOLOGIES AND ALGORITHMS UTILIZED

As described in Section II, USC Distribution microgrid representation is provided with the EDD modeling. The methodologies used and the scenarios selected are to meet some of the key EV project objectives are described below.

A. *Distribution System Load Level Consideration*

In order to define the load level to study, a consideration need to be made on the varying nature of the power system load. Due to the daily and season changes of the power system loads, certain simplifying assumptions need to be considered when analysis system issues that depend as well as impact the system loading and capabilities.

A typical summer season load curve for the California Independent System Operator (CAISO) is shown Fig 3. In developing a simplifying consideration, the load curve is

represented with three load levels or periods: peak, intermediate, and off-peak as shown in Fig 4.

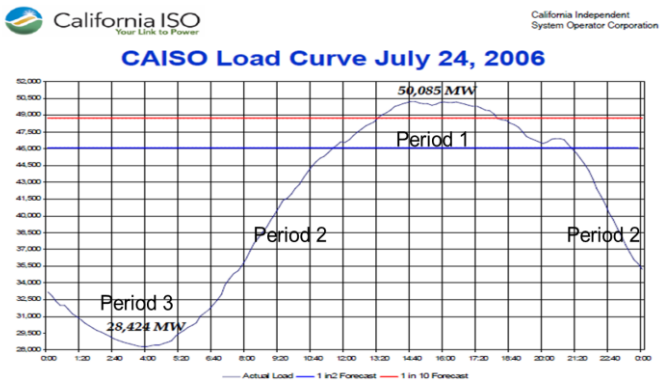

Fig. 3. CAISO's Summer Load Curve as a Representative Loading for the Development of the Load Periods

These load periods are defined as follows:

- Period 1: Peak Load (100%),
- Period 2: Intermediate Load (55%),
- Period 3: Off-peak Load (30%)

The estimate in the percentage of the peak load for the Periods 2 and 3, consideration is made the impact of the daily changes to the summer peak load condition that is the basis for Period 1.

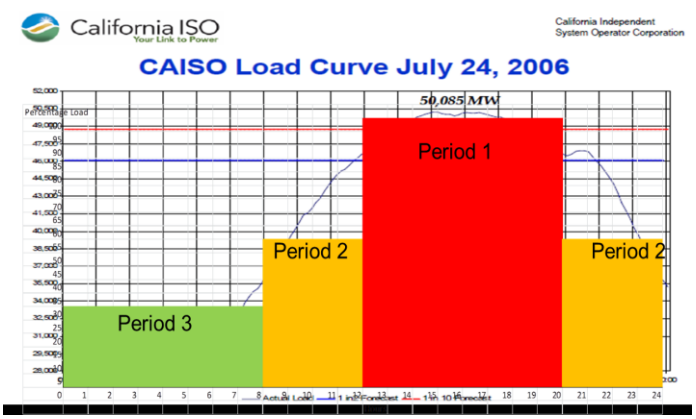

Fig. 4. Load Period Definition

B. *EV Load Integration Scenarios*

Three EV load increase scenarios (Cases) are been analyzed. These cases are defined as follows:

1) Case 1: Random EV Load Increase:

Increase each load (spot or distributed) until bus or system limit (transformer loading, voltage, and line limit) is reached

2) Case 2: 10% System Incremental increase Per Spot Bus

Increase 10% (or higher) circuit or system incremental starting from the far end of the circuit

3) Case 3: Distributed Incremental Increases

Increase loads throughout the system in percentage proportion to the load at the bus (spot load only)

C. *Load Flow, Load Factor and Stability Limits*

Load flow analysis using EDD program was conducted for each of the cases by incrementally increasing EV or other storage loads until system limits are reached. The limits for consideration typically are the equipment limits and other system based limits, such as voltages, load factors, and system stability. For distribution systems of the nature we are studying, system stability issues are not a consideration. Thus, the only issues we are dealing with are power and current flow, and voltage level consideration. Specifically, these are the limiting conditions that are monitored for the system studies.

- Transformer Loading Limit: current rating of 100% (normal), current rating of 225% (emergency)
- Voltage limit: 114-126V (normal); 110-127V (emergency)
- Line Loading Limit: 100% (emergency)

The above criteria are used in determining the level of incremental EV or other storage devices that can be connected to the test systems.

IV. Summary of Results

The study results related to the system studies are presented in this section. First, summary of the study results is given. Then the results are discussed and analyzed.

A. *Summary of result plots*

Nine cases where run using the three case scenarios and three load levels (periods). The study run cases have already been described in Section III. The study results of these cases are summarized below, Fig 5 – Fig. 10:

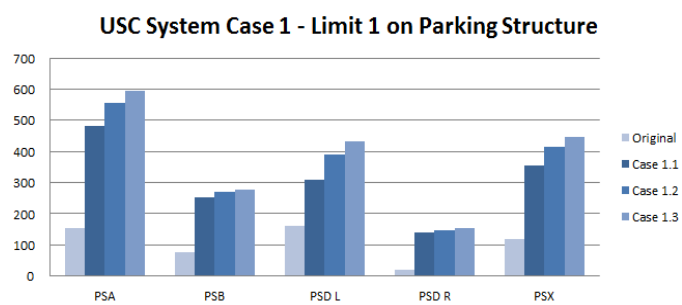

Fig. 5. Result for USC Microgrid CASE 1 - Limit 1

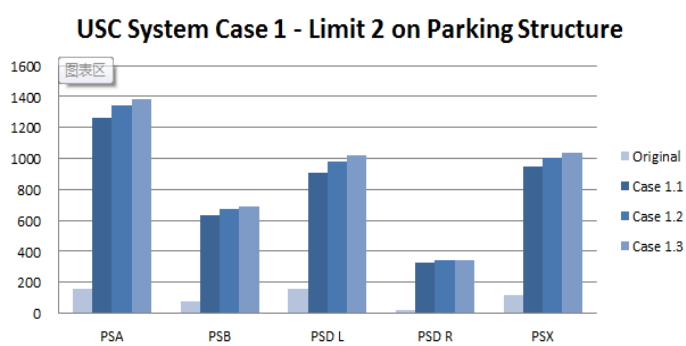

Fig. 6. Result for USC Microgrid CASE 1 - Limit 2

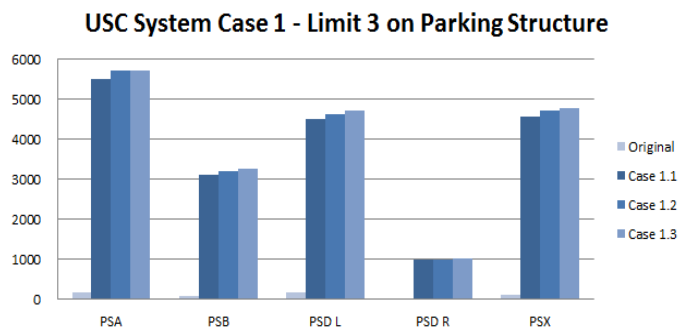

Fig. 7. Result for USC Microgrid CASE 1 - Limit 3

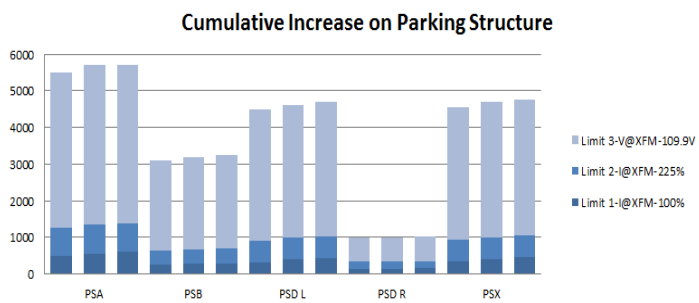

Fig. 8. Result for USC Microgrid CASE 1 - Cumulative

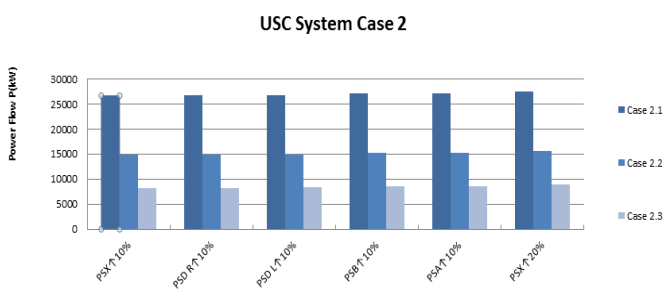

Fig. 9. Result for USC Microgrid CASE 2

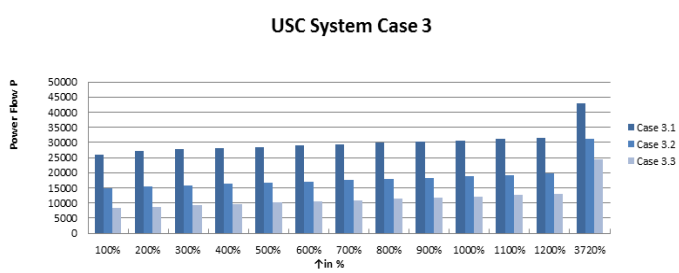

Fig. 10. Result for USC Microgrid CASE 3

B. *Analysis of the CASE results*

In this section's analysis, we assume that each electric vehicle charging in level 1 has capacity of 2 kW (20A) at 120V with 12 hours to be fully charged. Level 2 charging has capacity of 8 kW (32A) at 240V with 6 hours to be fully charged. The load flow analysis has been run for all three cases and the system has been checked for voltage and current violations. The limits for 120-volt base is set from 110-127V, as has already been mentioned in Section III

The result of Case 1 shows that:

- For PSA, around 500 kW, 1300 kW, 5600 kW more demand can be attached, in order to reach the first, second, and third limit, respectively. It is equivalent to 250 PEVs in level 1 charging or 62 PEVs in level 2 charging, in order to reach the first current limit at transformer attached ahead of the load bus.
- For PSB, we can add about 650 kW and 3100 kW more demand, in order to reach the first and second limit, respectively. It is equivalent to 325 PEVs in level 1 charging or 81 PEVs in level 2 charging to reach the first current limit at transformer.
- For PSD-Left, almost 360 kW, 950 kW, 4600 kW more demand can be put to reach the first, second, and third limit, respectively. It is equivalent to 180 PEVs in level 1 charging or 45 PEVs in level 2 charging to reach the first current limit.
- For PSD-Right, we can attach about 138 kW, 300 kW, 1000 kW more demand, in order to reach the first, second, and third limit, respectively. It is equivalent to 69 PEVs in level 1 charging or 17 PEVs in level 2 charging, in order to reach the first current limit at transformer attached ahead of the load bus.
- For PSX, nearly 400 kW, 946 kW, 4550 kW more demand can be added to reach the first, second, and third limit, respectively. It is equivalent to 200 PEVs in level 1 charging or 50 PEVs in level 2 charging, in order to reach the first current limit at transformer before the load bus.

The result of Case 2 shows that:

In this test strategy, the system will reach its first current limit when all 6 load buses increase their kW demand by 10% while PSX increases 20%, and the current limit will occur at the transformer attached ahead of PSX. The results show that we can increase almost 855 kW more to the whole system to reach the first limit, which is equivalent to 427 PHEVs in level 1 charging or 106 PHEVs in level 2 charging.

The result of Case 3 shows that:

In this test strategy, the system will increase all the 6 load buses' kW demand by 100% each time with respect to themselves, and the first current limit will occur when all the load buses increase by 300% at the transformer attached ahead of PSX, while the second and third current limit will occur when all the load buses increase by 400% and 600% at the transformer attached ahead of PSA and PSD-Left, respectively. The fourth and fifth current limit will occur at 700% increment at PSB and PSD-Right. The last limit is the voltage limit will occur when all the load buses increase 3720% at load bus PSA. The results also show that we can increase 1265 kW more to the whole system to reach the first limit, which is equivalent to 632 PHEVs in level 1 charging or 158 PHEVs in level 2 charging.

When testing at 55% and 30% loading capability, system can withstand a few more load demand before reach those limits.

CONCLUSION

This paper presents a detailed analysis based on SGRDP to evaluate the impact of electric vehicles infrastructure on the grid relating to system load flow, load factor, and voltage stability. USC Distribution microgrid was selected and tested under different case scenarios in the EDD to assess the potential impacts to the grid.

The USC microgrid was tested at 100%, 55% and 30% capacity to evaluate the maximum loading capability by running three case scenario tests. Firstly, we find out the maximum load increase at each load bus on the system. Secondly, we tested the system ability to handle 10% kW demand increment of the USC Distribution System at each load simultaneously and stop when the systems reaches the limit. Finally, we increase all the load buses by 100% each time with respect to the load buses and find out the maximum loading capability.

Transformers that are attached ahead of the load buses were encountered current limit issue when testing CASE 2 and CASE 3. The current limit was chosen to be neglected and keep testing until reach the next violation. Larger size transformers are needed to solve this problem.

The next step of this research is to update the current data obtained from the smart meters including the EV charging information, add Distribution Generator (DG) and PV panels into the USC microgrid to give a more accurate analysis of the EV impacts to the grid. Furthermore, the vehicle to grid (V2G) technology will also be tested to understand the potential impact on USC microgrid when charging and discharging EVs at different time and loading scenarios.

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