Impact of Electric Vehicle Infrastructure on the City of Chatsworth Distribution System

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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. Chatsworth distribution system 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; Chatsworth

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 Chatsworth 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 Chatsworth Distribution Test System (Section II). Section III presents an overview of different case 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:

- Chatsworth distribution system 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

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primary and secondary distribution networks.

- 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 Chatsworth distribution system. Chatsworth is a district of Los Angeles, California, United States; in the northwestern San Fernando Valley. Due to its size, data of the test feeder can not be made available in this paper. The Chatsworth distribution system one-line configuration and its EDD model structure is shown in Fig 1, while the circuit map of the two test feeder Chatsworth 88-22 and 88-23 are shown in Fig 2 and Fig 3, respectively.

There are 26 feeder circuits in the Chatsworth distribution system and the nominal voltage is 4.8 kV. Loads are comprised of three-phase (balanced or unbalanced) and single phase. Three-phase loads are connected in wye or delta while single-phase loads are connected line-to-ground or line-to-line. All loads can be modeled as constant kW and kVAR (PQ), constant impedance (Z) or constant current (*I*) depending based on the actual system load. The system is feed by five lines coming from Northridge-Chatsworth at 34.5 kV.

Fig. 1. One-line Diagram of Chatsworth Distribution System in EDD

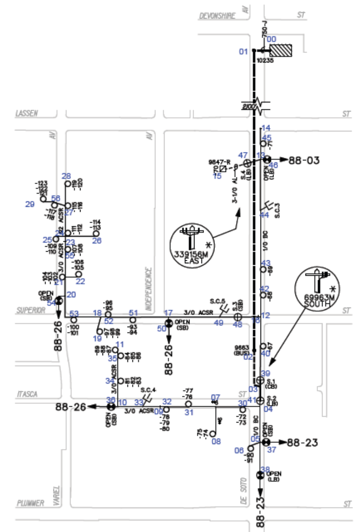

Fig. 2. Circuit map of Chatsworth Distribution System Feeder 88-22

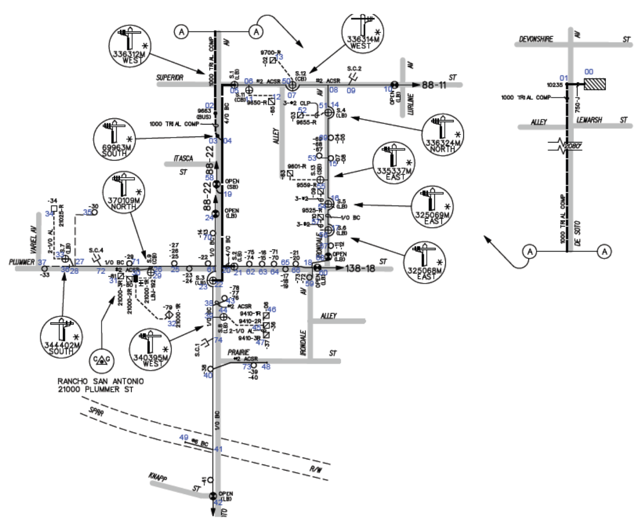

Fig. 3. Circuit map of Chatsworth Distribution System Feeder 88-23

Electric Distribution Design (EDD) software is used to perform power flow solution. The power flow equation is employing Newton-Raphson method with constant P & Q at 1000 maximum number of iterations. The base case system conditions are given in Table I.

TABLE I. POWER FLOW RESULTS OF CHATSWORTH DISTRIBUTION SYSTEM

		Total DS-88	DS 88-22	DS 88-23
Total Feeder Flow	***kW***	67,750	578.59	865.83
	kVAR	-6,175	87.51	133.26
	kVA	69,411	585.17	876.03
Total Losses	***kW***	889	6.77	11.49
	kVAR	2,562	5.56	10.59
	kVA	2,792	8.76	15.63

III. Description of the Methodologies and Algorithms Utilized

As described in Section II, Chatsworth distribution system 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 4. 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 5.

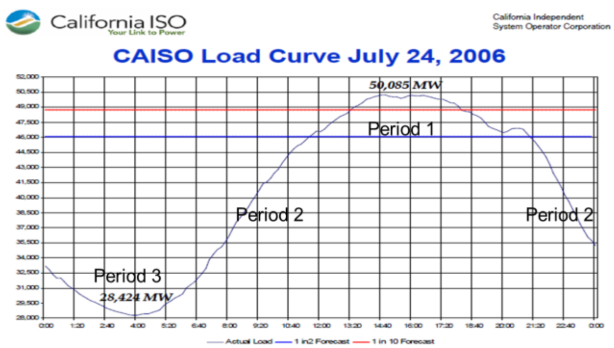

Fig. 4. CAISO's Summer Load Curve as a Representative Loading for the Development of the Load Periods

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.

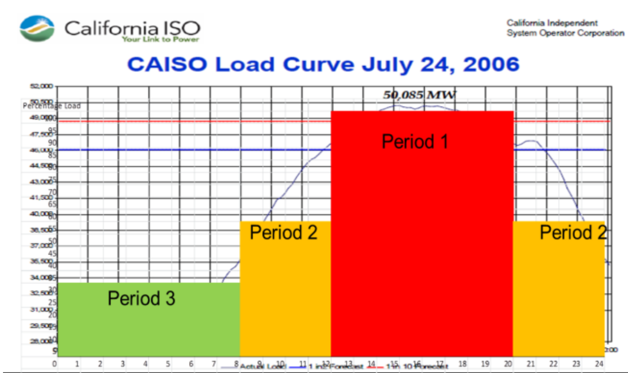

Fig. 5. Load Period Definition

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%

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. For this study, we have two separate studies for the circuit 22 and 23.The study results of these cases are summarized below, Fig 6 – Fig. 11:

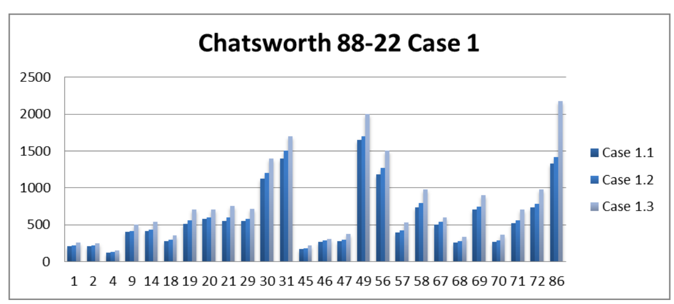

Fig. 6. Result for Chatsworth Distribution System 88-22 CASE 1

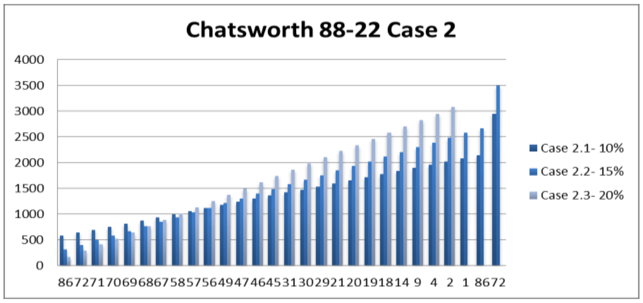

Fig. 7. Result for Chatsworth Distribution System 88-22 CASE 2

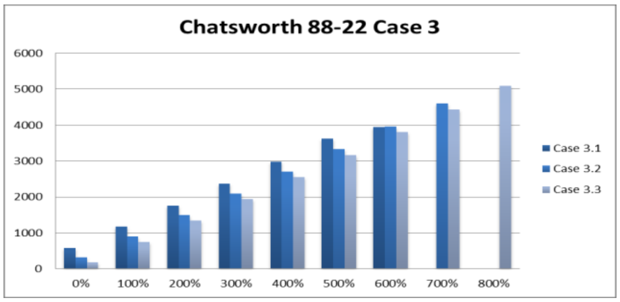

Fig. 8. Result for Chatsworth Distribution System 88-22 CASE 3

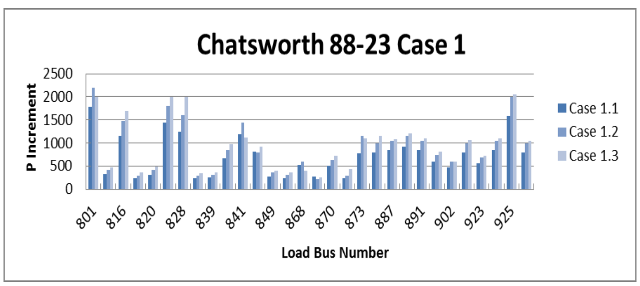

Fig. 9. Result for Chatsworth Distribution System 88-23 CASE 1

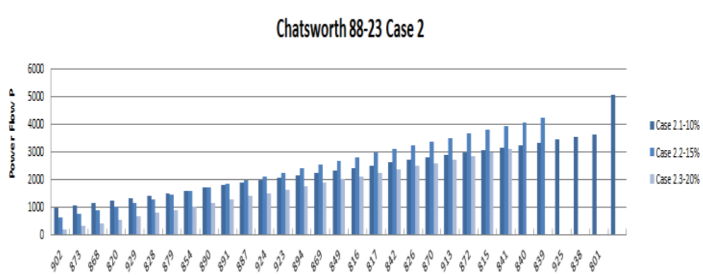

Fig. 10. Result for Chatsworth Distribution System 88-23 CASE 2

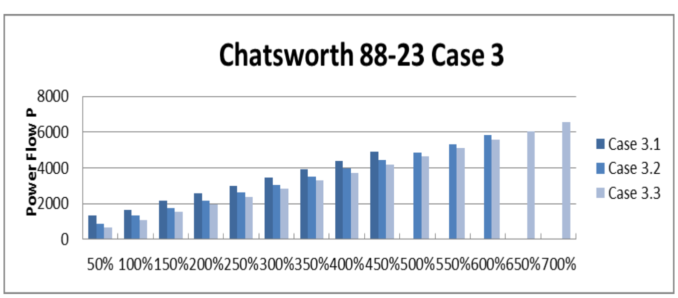

Fig. 11. Result for Chatsworth Distribution System 88-23 CASE 3

B. *Analysis of the CASE results for Chatsworth Feeder 88-22*

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:

- When testing at peak load condition (period 1), 15 out of the all 26 loads we can be attached less than or equal to 100 kW demand, which is equivalent to 50 PHEVs in level 1 charging or 12 PHEVs in level 2 charging, in order to reach the first current limit at transformer attached ahead of the load buses.
- To reach the second current limit, which is 225% of the transformer current, these 15 load buses can be attached less than or equal to 225 kW demand, which is equivalent to 112 PHEVs in level 1 charging or 28 PHEVs in level 2 charging.
- To reach the third voltage limit, which is at the load bus itself, these 15 load buses can be attached less than or equal to 580 kW demand, which is equivalent to 290 PHEVs in level 1 charging or 72 PHEVs in level 2 charging.
- The highest demand came at load bus 86, which is at the far end. For load bus 86, we can attach 320 kW, 752 kW, and 1325 kW to reach the first, second, and third limit, respectively.
- The test results under intermediate load (period 2) and off-peak load (period 3) did not make much difference compared with peak load condition, as shown in Fig 6. The only big difference is the demand at the far end - load bus 86. In Case 1.2, it can be added 350 kW, 780 kW, and 1420 kW to reach the first, second, and third limit, respectively. While in Case 1.3, it can be attached 375 kW, 1149 kW, and 2180 kW to reach three limits, respectively.

The result of Case 2 shows that:

- Under period 1 (peak load), the system will reach its first current limit when 24 out of the all 26 load buses increase their kW demand by 10%, and the current limit will occur at the transmission transformer and voltage regulator at the substation side of circuit 88-22. The results also show that when we increase kW demand of all the 26 load buses by 15%, the system will reach the voltage limit at load bus 04. The results show that we can increase almost 1400 kW more to the whole system to reach the first limit, which is equivalent to 700 PHEVs in level 1 charging or 175 PHEVs in level 2 charging.
- Under period 2 (intermediate load), the system will reach its first current limit when 17 out of the all 26 load buses increase their kW demand by 15%, and

the current limit will occur at the voltage regulator near the substation side of circuit 88-22. The results also show that when we increase kW demand of all the 26 load buses by 20%, the system will reach the voltage limit at load bus 904 with 108V. This implies that we can increase almost 1500 kW more to the whole system to reach the first limit, which is equivalent to 750 PHEVs in level 1 charging or 187 PHEVs in level 2 charging.

- Under period 3 (off-peak load), the system will reach its first current limit when 14 out of the all 26 load buses increase their kW demand by 20%, and the current limit will occur at the voltage regulator near the substation side of circuit 88-22. At the same time, the system will also reach the voltage limit at load bus 04 with 109.6V. The results imply that we can increase 1624 kW more to the whole system to reach the first limit, which is equivalent to 812 PHEVs in level 1 charging or 203 PHEVs in level 2 charging.

The result of Case 3 shows that:

Under the period 1 (peak load), the system will increase all the 26 load buses' kW demand by 50% each time with respect to themselves, and the first current limit will occur when all the load buses increase by 250% at the voltage regulator near substation, while the second current limit will occur when all the load buses increase by 300% at the transmission transformer near substation. The third limit is the voltage limit will occur when all the load buses increase 550% at load bus 70. The results also show that we can increase 1439 kW more to the whole system to reach the first limit, which is equivalent to 729 PHEVs in level 1 or 179 PHEVs in level 2 charging.

While under period 2 and period 3, the testing results are almost the same. In these two cases, the system will increase all the 26 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 voltage regulator near substation. The second limit is the voltage limit will occur when all the load buses increase 700% at load bus 70. The results show that 1724 kW more can be increased to the whole system to reach the first limit, equivalent to 862 PHEVs in level 1 charging or 215 PHEVs in level 2 charging.

The result analysis for Chatsworth circuit 88-23 is similar to what we have done for 88-22 above, therefore no need to do it one more time.

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. Chatsworth distribution system was selected and tested under different case scenarios in the EDD to assess the potential impacts to the grid.

The Chatsworth system 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 Chatsworth system at each load simultaneously and stop when the systems reaches the limit. Finally, we increase all the load buses by 5-20% 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 Chatsworth distribution system 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 Chatsworth system when charging and discharging EVs at different time and loading scenarios.

REFERENCES

[1] Wynne J. "Impact of plug-in hybrid electric vehicles on California's electricity grid". *North Carolina* : *Nicholas School of the Environment of Duke University,* 2009.

[2] Li Na, Huang Mei. "Analysis on Harmonics Caused by Connecting Different Types of Electric Vehicle Chargers with Power Network". *Power Supply Technology,* 2011, 35(1): 170-174.

[3] Clement K, Haesen E, DriesenJ. "Stochastic analysis of the impact of plug-in hybrid electric vehicles on the distribution grid". *In: Electricity distribution, CIRED 2009. 20th International conference on electricity distribution;* 2009,: 1–4.

[4] Bradley T, Quinn C. "Analysis of plug-in hybrid electric vehicle utility factors". *Journal of Power Sources,* 2010, 195(16): 5399-5408.

[5] M. Rastegar, A. Safdarian, M. Fotuhi-Firuzabad, and F. Aminifar, "Impacts of Plug-in Hybrid Electric Vehicle Uncertainty and Grid Unavailability on Home Load Management," in the International Conference on Environment and Electrical Engineering (EEEIC), 2012, pp. 693-698.

[6] Hadley SW. "Impact of plug-in hybrid vehicles on the electric grid". *Technical report ORNL/TM-2006/554.* Oak Ridge National Laboratory, 2006.

[7] N. Hartmann and E. D. Özdemir, "Impact of different utilization scenarios of electric vehicles on the German grid in 2030," Journal of Power Sources, 2011(196), pp.2311-2318.

[8] Yang Hong ming, Xiong Luo cheng, Liu Bao ping. "Analysis of Charging and Discharging for Plug-in Hybrid Electric Vehicles". *Journal of Electric Power Science and Technology,* 2010, 25(3): 8-12.

[9] Denholm P, Short W. "An evaluation of utility system impacts and benefits of optimally dispatched plug-in hybrid electric vehicles". *Technical report.* National Renewable Energy Laboratory, 2006.

[10] Acha S, Green T,Shah N. "Effects of optimized plug-in hybrid vehicle charging strategies on electric distribution network losses". *In: PES, editor. Conference and exposition on transmission and distribution. Prague: IEEE,* 2010: 1–6.

[11] Putrus G, Suw. A, Johnston P. "Impact of electric vehicles on power distribution networks". *IEEE Vehicle Power and Propulsion Conference, Dearborn, USA*, 2009 : 827-832 .

[12] Taylor M J, Alexander A. "Evaluation of the impact of plug-in electric vehicle loading on distribution system operations". *IEEE Power & Energy Society General Meeting, Calgary, Canada,* 2009: 1-6.