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Impact of electric vehicles on the IEEE 34 node distribution infrastructure

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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 impacts of electric vehicles infrastructure on the grid relating to system load flow, load factor, and voltage stability. IEEE 34 node test feeder 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, voltage stability, DEW, IEEE 34.

1. 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 Behaviour (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 modelling, power flow studies, and demonstration activities utilizing the IEEE 34 node test feeder 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 IEEE

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34 node test feeder (Section 2). Section 3 presents an overview of different study scenarios and base cases, while Section 4 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 5.

2. Overview of the System Used

2.1. Technology and system utilized

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

- An IEEE 34 bus test system reflecting an industry standard distribution test model 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 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.

2.2. 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 test results are provided in Section 4.

The distribution system under consideration is the IEEE34 node test feeder. This feeder is an actual feeder located in Arizona. Due to its size, data of the test feeder can not be made available in this paper. The IEEE 34 node test feeder one-line diagram configuration is shown in Fig. 1 below.

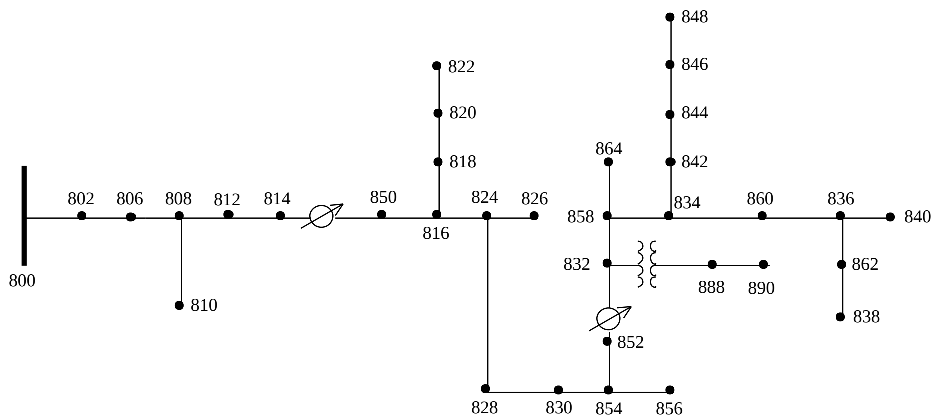

Fig. 1. One-line diagram of IEEE34 node test system

The feeder’s nominal voltage is 24.9 kV. It is characterized by:

- Three phase 4-wire and single phase, 2-wire overhead lines arranged in different configurations.
- Very long and lightly loaded.
- Two in-line regulators required to maintain a good voltage profile.
- An in-line transformer reducing the voltage to 4.16 kV for a short section of the feeder.
- Unbalanced loading with both “spot” and “distributed” loads. Distributed loads are assumed to be connected at the center of the line segment.

- Shunt capacitors modeled as constant susceptance.

Loads are comprise of three-phase (balanced or unbalanced) and single phase systems. Three-phase loads are connected in Y or D 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.

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. Fig. 2 shows the IEEE34 node test feeder system after it has been implemented in EDD software. The base case system conditions are given in Table 1.

Table 1. Power flow results of IEEE 34 node test feeder

Characteristic		EDD Result	Standard
	kW	2043.17	2042.872
Total feeder flow	kVAR	292.14	290.258
	kVA	2063.95	2063.389
	kW	273.41	273.049
Total losses	kVAR	36.96	34.999
	kVA	275.90	275.283
	Ph-A	54.15	51.58
Bus current flow	Ph-B	46.81	44.57
	Ph-C	42.98	40.93

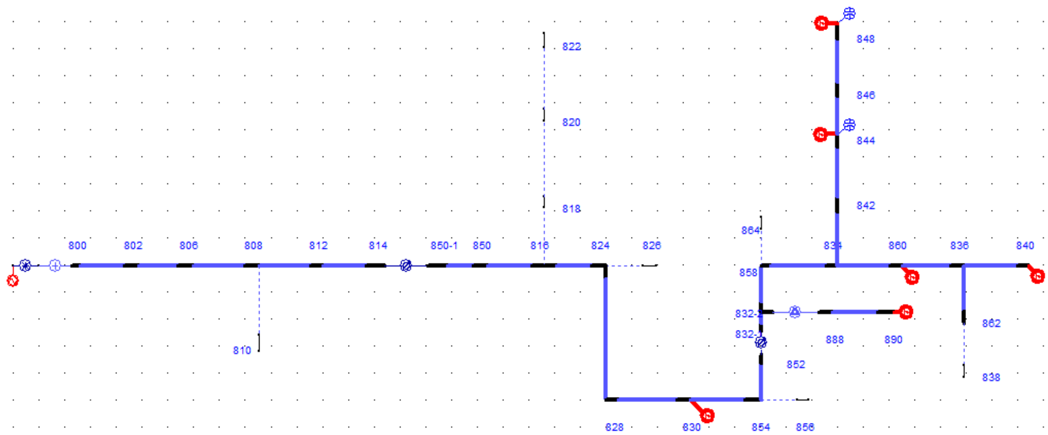

Fig. 2. IEEE34 node test system in EDD.

3. Description of the Methodologies and Algorithms Utilized

As described in Section II, IEEE34 node test feeder 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.

3.1. 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.

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.

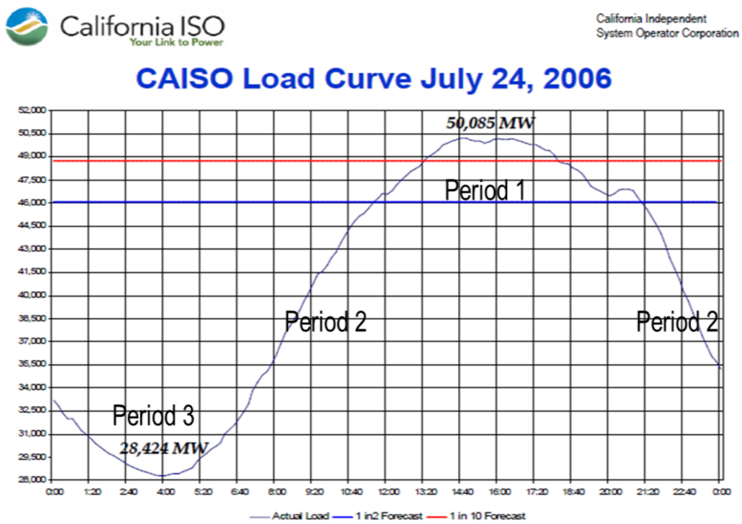

Fig. 3. CAISO's summer load curve as a representative loading for the development of the load periods.

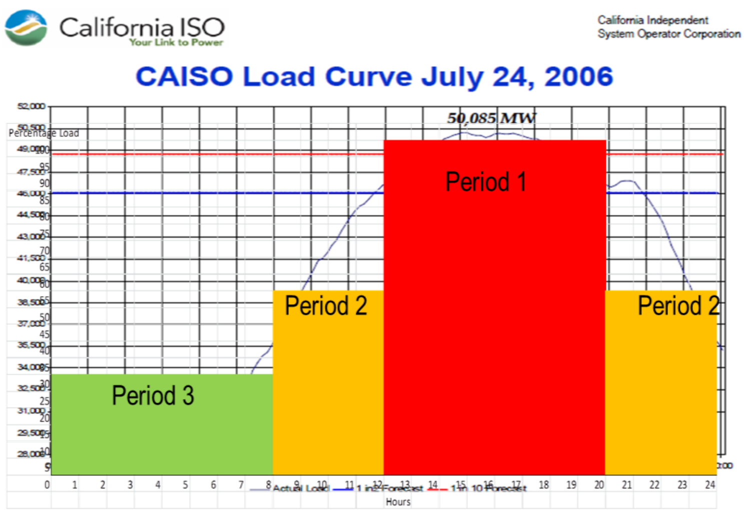

Fig. 4. Load period definition.

3.2. EV load integration scenarios

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

- 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

- 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

- Case 3: Distributed Incremental Increases

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

3.3. 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.

4. 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.

4.1. 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. 13:

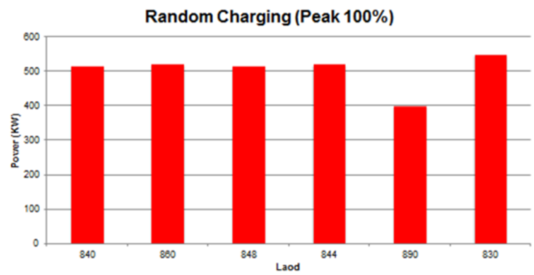

Fig. 5. Result for IEEE 34 node test CASE 1.1.

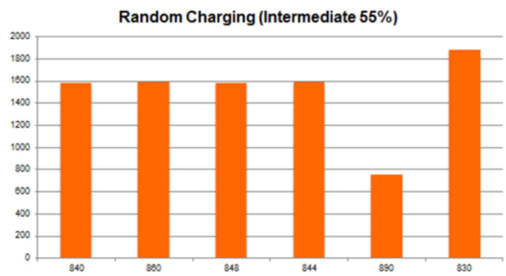

Fig. 6. Result for IEEE 34 node test CASE 1.2.

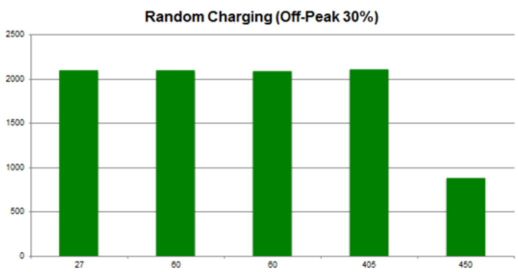

Fig. 7. Result for IEEE 34 node test CASE 1.3.

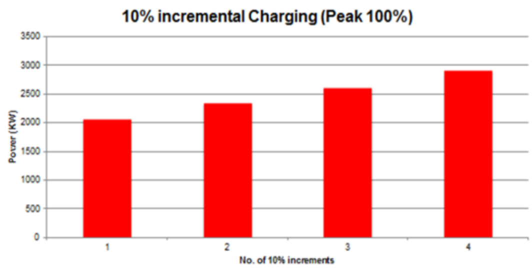

Fig. 8. Result for IEEE 34 node test CASE 2.1.

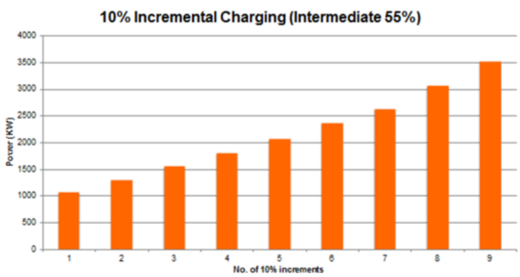

Fig. 9. Result for IEEE 34 node test CASE 2.2

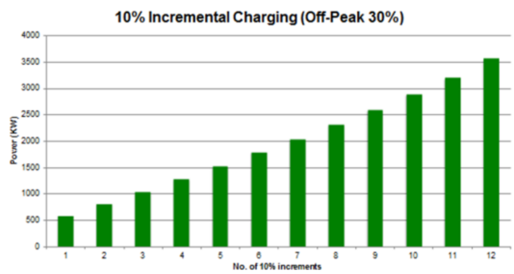

Fig. 10. Result for IEEE 34 node test CASE 2.3

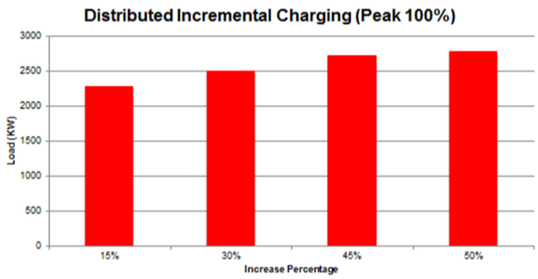

Fig. 11. Result for IEEE 34 Node Test CASE 3.1.

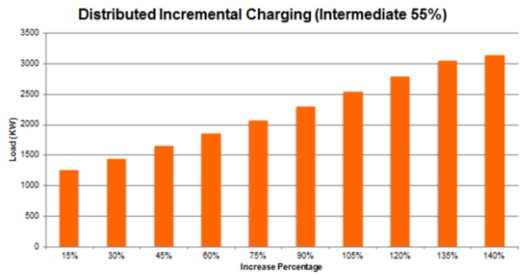

Fig. 12. Result for IEEE 34 Node Test CASE 3.2.

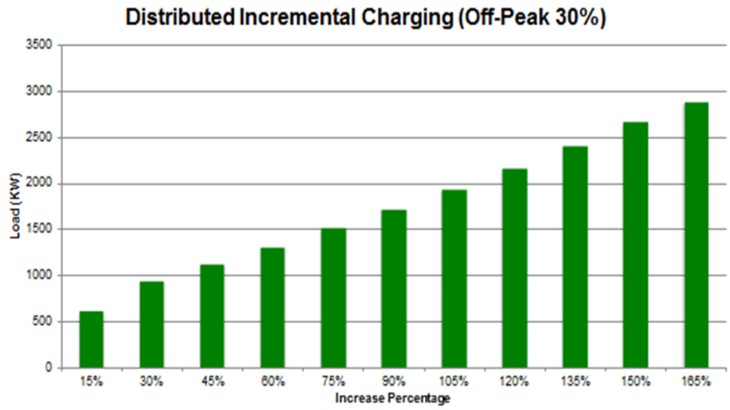

Fig. 13. Result for IEEE 34 Node Test Feeder CASE 3.3.

4.2. 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 load bus 840, 860, 848, 844 under peak load condition, around 377 kW more load can be attached, which is equivalent to 186 PHEVs in level 1 charging or 47 PHEVs in level 2 charging. While for load period 2 and 3, nearly 1580 kW and 2090 kW more demand can be added, respectively.
- For load bus 890 under peak load condition, only 27 kW more load can be added, which is equivalent to 13 PHEVs in level 1 charging or 3 PHEVs in level 2 charging. While for load period 2 and 3, almost 750 kW and 870 kW more demand can be attached, respectively.
- For load bus 830 under peak load condition, 512 kW can be increased to reach the voltage limit, which is equivalent to 256 PHEVs in level 1 charging or 64 PHEVs in level 2 charging. While for load period 2 and 3, nearly 1880 kW and 2450 kW more demand can be increased, respectively.

The result of Case 2 shows that:

- Under period 1 (peak load), the system will reach its voltage limit when the three load buses (840-860-848) increase their kW demand by 10%, and the voltage limit will occur at the node bus 814. The results also show that we can increase 615 kW more to the whole system, which is equivalent to 307 PHEVs in level 1 charging or 76 PHEVs in level 2 charging.
- Under period 2 (intermediate load), the system will reach its voltage limit after all the load buses increase their kW demand by 10%, while load bus 840 and 860 increase 20%, and the voltage limit will occur at the node bus 814. The results also show that we can increase 1640 kW more to the whole system, which is equivalent to 820 PHEVs in level 1 charging or 205 PHEVs in level 2 charging.

- Under period 3 (off-peak load), the system will reach its voltage limit almost when all the six load buses increase its kW demand by 20%, and the voltage limit will occur at the node 852. The results also show that we can increase 2255 kW more to the whole system, which is equivalent to 1127 PHEVs in level 1 charging or 281 PHEVs in level 2 charging.

The result of Case 3 shows that under period 1 (peak load), the system will reach its voltage limit when all the six load buses increase its kW demand by 50% with respect to themselves, and the voltage limit will occur at the node bus 814. The results also show that we can increase 523.5 kW more to the whole system, which is equivalent to 261 PHEVs in level 1 charging or 65 PHEVs in level 2 charging. While under period 2 and period 3, the system will run into voltage limit issue when all the six buses are added their demand by 140% and 163%, which is equivalent to 1465.8 kW and 1675.2 kW, respectively.

5. 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. IEEE34 Node Test Feeder was selected and tested under different case scenarios in the EDD to assess the potential impacts to the grid.

The IEEE34-bus 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 IEEE 34-bus 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 IEEE34 node test feeder 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 IEEE 34 bus system when charging and discharging EVs at different time and loading scenarios.

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