

**EVS26**  
*Los Angeles, California, May 6-9, 2012*

## **Developing a Test Procedure to Evaluate Electric Vehicle Supply Equipment and Chargers**

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### **Abstract**

This paper describes the processes used and the choices made while developing a procedure to evaluate Electric Vehicle Supply Equipment (EVSE) and Plug-in Electric Vehicle (PEV) chargers and provides some results of the testing process. The procedure defines the battery charging system (i.e., the battery charger, EVSE, battery storage system, auxiliary loads, and vehicle). Each test element is evaluated in terms of function, reliability, safety, quality, cost, efficiency and power quality.

The development of a charging system evaluation procedure comes from Southern California Edison's (SCE) responsibility to ensure safe and reliable function and to minimize system impact. Up to one million PEVs have been projected to be operating in SCE's service area by 2020. SCE must not only serve these PEVs, but must ensure that they do not have a negative impact on the utility grid. Therefore it is critical that SCE understand the impact of those battery charging systems. SCE also supports the creation of standards to limit wasted energy and negative power quality impacts that these battery charging systems may create.

SCE is also using the test procedure to evaluate EVSEs and PEV charging systems for implementation in SCE's fleet. The results of this procedure are used to give fleet managers the information needed to acquire the most effective and efficient PEV charging equipment. The results will also tell a fleet manager or PEV owner what EVSE would work best with their selected vehicle or vice versa. The procedure provides for the discovery of PEV and EVSE individual and compatibility issues before the PEV is deployed. The final result ensures optimum performance of the PEV system.

Through this process, SCE has been able to work with manufacturers of PEVs and EVSEs in order to improve the functionality, robustness, and interoperability of the products.

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*Keywords: Charging, Infrastructure, Fleet, Reliability, Safety*

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## 1 Background

The importance of this procedure can be overlooked easily when looking at the impact of a single charging system. However, when the individual results are looked at in the light of possibly large numbers of these systems connected to the utility electric grid it shows a different picture. For example, Electric Vehicle Supply Equipment (EVSE) is comparable in impact to recently regulated small battery chargers and power supplies when in no-battery mode. There is growing concern for the energy wasted by inefficient battery chargers and other devices.

### 1.1 Southern California Edison

Southern California Edison has a service area of 50,000 square-miles with five million meters for its customers. SCE's renewable energy portfolio includes approximately 20% of energy from renewable sources, such as wind and solar.

SCE operates a fleet of over 6,000 assets to develop and maintain its systems, ranging from powered trailers to Class 8 trucks, and we have demonstrated the largest and most successful PEV fleet with over 20 million electric miles driven. At SCE our number one job is to provide safe and reliable electric service, and the fleet managers make sure that the fleet assets are reliable and effective tools for ensuring that the job gets done. A key part of this process is SCE's Electric Vehicle Technical Center (EVTC). The EVTC evaluates advanced technology solutions that meet the fleet's missions, optimize energy, and reduce emissions.

### 1.2 Energy Star Program

The Energy Star program [1] was started in 1992 by the EPA in an effort to assist consumers in making energy-wise purchasing decisions. The Energy Star program is a voluntary labelling program that began with just a few electronic products, and has since expanded to include major appliances, lighting, office equipment, home electronics, residential heating and cooling, and even new homes and commercial and industrial buildings. The most recent additions included small power supplies and small consumer appliance battery charger systems. This program, however, does not comprehensively address larger battery chargers or vehicles, and does not address EVSEs at all.

## 1.3 California Energy Commission

According to a Frequently Asked Questions (FAQ) sheet published by the California Energy Commission (CEC) in January 2012 [2], as of 2009 there were approximately 170 million battery chargers in California households. Per the graph published in the same FAQ sheet, battery chargers in California currently consume approximately 7,700 GWh/year. Without any standards imposed on battery chargers, this number is expected to almost double over the next 10 years.

The CEC has enacted standards to require a certain level of efficiency from the covered battery charger systems (not including on-road vehicles). The standards apply to active charging mode, maintenance mode, and "no-battery" mode, when no-battery is connected to the charger. They divide battery chargers into two main groups: small and large, with large battery chargers having an input rating of greater than 2 kW. The CEC estimates that the new standards could generate a savings of 2,200 GWh per year in California, for an electrical cost savings of \$306 million per year.

## 2 Developing the Procedure

### 2.1 Scope

The first step in developing the procedure was to identify the scope and test system boundary. The scope of the procedure is to evaluate Electric Vehicle Supply Equipment (EVSE) and Plug-in Electric Vehicle (PEV) battery charging systems in terms of function, reliability, safety, quality, cost, efficiency, and power quality. It is also important to define specifically what is measured and how, and this is depicted with the system boundary. The boundary of the system under test is shown in Figure 1. The figure shows an on-board charger, however an off-board charger would be tested in the same way except that the charger and EVSE would be one block and would be in the place of the EVSE box. Data is collected at the various monitoring points based on the specific test being performed.

### 2.2 Current Standards

Southern California Edison (SCE) researched the applicable codes as its second step in developing the test procedure. The research included the Society of Automotive Engineers (SAE) J1772™ Recommended Practice; the National Electric Code (NEC), Article 625; various Underwriters Laboratory (UL) standards; Electric Power

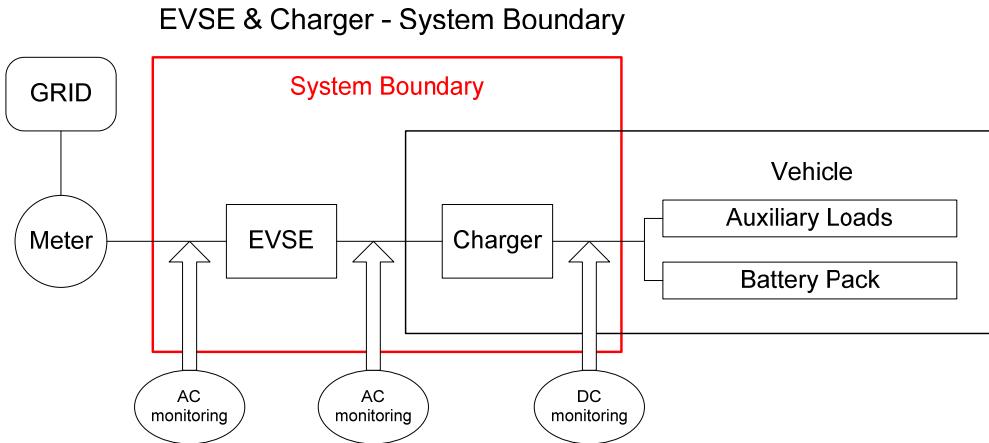


Figure 1: System Boundary Diagram

Research Institute's Infrastructure Working Council (EPRI IWC) documents; IEEE standards; CEC charging test procedures; and SCE internal documents.

### 2.3 Test Criteria

The next step was to identify the aspects of the researched codes and standards that applied within our defined system boundary and the scope of the evaluation goals.

SCE devised several groups of tests incorporating safety, functionality, grid events, power quality, and ergonomics. For each of these categories a number of tests were created.

The Nationally Recognized Testing Laboratories (NRTL) perform safety and function testing on commercial products. There was not a need to duplicate all of the testing that had been performed by them. Some testing was designated to be important enough that a similar test was developed to be performed at SCE; these were mostly tests that involved safety. Once the tests were designated, specific procedures were developed for each using the specific parameters identified in the researched codes and standards.

### 2.4 Designing Tests

After the specific aspects of each test were selected, acceptable limits were determined from the researched materials. Test procedures were created and revised. Data sheets were created to record the results of the tests. Good data sheets are vital to an effective procedure, as they guide the test technician through the process of properly executing the procedure.

For each procedure the steps were determined with the specific results expected and safety of

the technician in mind. After the procedure was initially completed an initial test was performed to review and validate the procedure and to discover any errors or areas for improvement.

### 2.5 Review

The individual procedures for each attribute were combined and organized into a cohesive test procedure. The completed procedure was then reviewed with engineers and managers. A few tests were added after the initial completion of the procedure. It was determined by SCE engineers that certain aspects of the charging system were not being fully represented by the current results. This model of continuous improvement is a key aspect of SCE.

After the procedure was reviewed and approved, SCE began using it for testing.

## 3 Executing the Procedures

SCE began using the procedure for testing with six EVSEs, one off-board charger, and seven vehicles. The PEVs and EVSEs used the SAE J1772 connector and the off-board charger used the CHAdeMO DC connector. The components were tested individually and in various combinations. The procedure includes testing of both individual components and whole systems since the results would be affected if one component of a system were changed.

As the testing progressed through the various EVSEs and PEVs, it was found that one test or another could not be performed as it was written either because of the EVSEs' design or the directions of the test. The specific test was then reviewed and possibly revised to improve the test's

clarity and ease of use. The sequence of the tests was reordered when a setup was torn down and a new setup built only to then go back to the first setup for a second test. It was also found that several tests could be performed with a single charging event if ordered properly. During all testing this procedure was continuously reviewed and sometimes revised to create a more complete and safe test procedure, include more detailed instruction, and to add needed tests.

Several pieces of equipment were designed and fabricated to facilitate the testing; including a test stand, a force test apparatus (Figure 2) and a displacement test apparatus. There were also specialty instruments acquired for the testing, such as a current leakage tester.

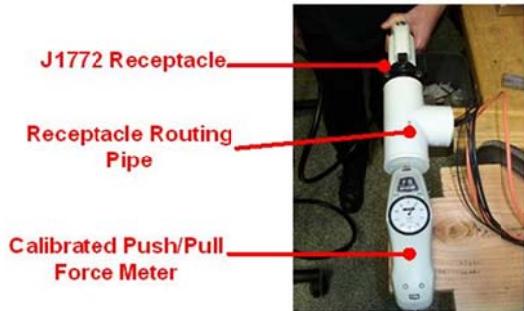


Figure 2: Force gauge test apparatus

### 3.1 Documenting Results

We evaluated the EVSE, PEV, charger and other battery charger system components and collected results (Table 1). The results are divided into two groups: compliance and characterization.

#### 3.1.1 Compliance

The compliance tests evaluate whether the component meets the requirements of the associated codes and standards. For instance the EVSEs were compared to SAE J1772, NEC 625, and various UL standards. SCE discovered through this testing:

- EVSEs that were not compliant with SAE J1772
- Vehicles that did not comply with SAE J1772
- EVSEs that allowed charges in excess of their current rating
- EVSEs that did not have strain protection (i.e. a means to de-energize the coupler before the wire broke from strain and thereby exposing live wires to users)

These discovered issues were then resolved by working with the manufacturer to make corrections.

#### 3.1.2 Characterization

The characterization tests evaluate the component to determine the effect on the electrical grid (“grid tests”) the safety or protection measures in place, the user interface, and the overall functionality. SCE discovered through this testing:

- EVSEs that did not respond to outages in a favourable manner
- Combinations of components that worked with no issues
- Combinations of components that did not work at all
- EVSEs with higher than expected no-battery mode power levels

Any problems were resolved by working with the manufacturer to make corrections.

## 4 Results

### 4.1 Analysis

An EVSE’s ability to restart after an outage is a critical functional check. Many EVSEs have cold load pickup features to help the utility system in recovery from power outages. The currently recognized way of performing this is to delay two minutes and then ramp up to full power at a rate of one amp per second. The older way of performing cold load pickup is to have a random delay between two minutes and twelve minutes and then charge at full power. This feature is important because introducing a large load on the grid directly following the restoration of power after an outage could cause additional stress to the grid infrastructure, resulting in a secondary outage.

During the long duration outage test it was found that the EVSEs which had implemented the older cold load pickup method could cause the vehicle not to charge. This was due to the availability or “awake” time of the vehicle, combined with the cold load start features of the EVSE that delay the start of the charge after a power outage. One test unit, Unit 5, did not charge the vehicle after the outage and had a startup time of approximately 5.5 minutes. This vehicle shut down or “slept” sometime between 3.5 and 7 minutes if the EVSE did not allow the charge. Testing with other vehicles with different wake periods would strengthen the understanding of the parameters.

Table1: Selected Test Results

Test Performed	4	5	6
Ground Integrity Test	Pass	Pass	Pass
Pilot Signal	Fail	Pass	Pass
De-Energized Contactors	Pass	Pass	Pass
Safe Contactor Operation	Pass	Pass	Pass
Automatic De-Energized Contactors	None	None	None
Strain Relief	Friction fitting	Friction fitting	Friction fitting
Strain Protection (weight test)	N/A	Cord slipped through friction fitting causing displacement.	No Displacement (Pass)
Long Duration Outage	Vehicle always charged	Vehicle did not charge	Vehicle timed out between 3.5 and 7 minutes
Momentary Outage	Fail	Pass	Fail
Voltage Range	Pass	Pass	Pass
Response to Voltage Sag	Pass	Pass	Pass
Response to Voltage Swell	Pass	Pass	Pass
Response to Frequency Variation	Pass	Pass	Pass
Voltage Distortion	Pass	Pass	Pass
Insertion Force (lbs.)	5.5	8.1	5.3
Removal Force (lbs.)	5.8	6.3	4.6
1-Hr Energy Consumption (Wh)	2.4	14.1	6.1

All of the grid tests except for the long duration outage do not use a vehicle for the tests, but rather, use a device called a grid simulator. One test, the momentary outage test, applies a short power loss. Charging systems should be able to recover unaided from such events. Two units failed the momentary outage test because they required user intervention to restart the charge. All EVSEs passed the other grid event tests, and were able to start a charge after each of the tests performed.

The insertion and removal force test showed all of the EVSE connectors' force effort levels to be within acceptable limits. Figure 3 shows the results of the force test. Unit 5 used a different connector manufacturer than the others and showed a higher required force.

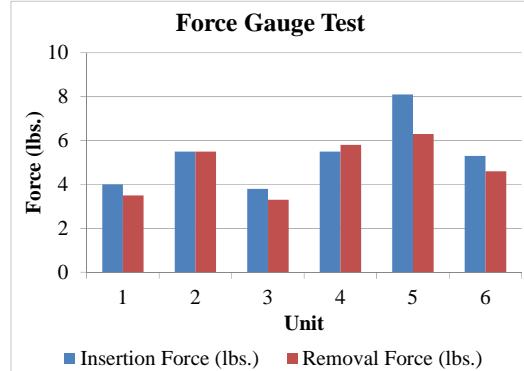


Figure 3: Force gauge test result

As a part of the testing the no-battery mode, sometimes called "idle" or "stand-by" mode, energy consumption was measured for each unit. Figure 4 shows the results of the one-hour no-battery mode energy consumption test. The results varied widely with the features included with each system (such as displays), from 2 W up to 14 W. This wide variation points toward the need for a standard for energy consumption in these devices when they are in no-battery mode.

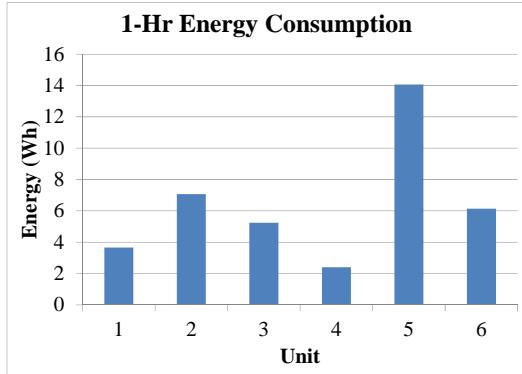


Figure 4: No-battery mode energy consumption

The vehicle and charging system was also tested. One of the characterization tests involves the recording of the unit's demand curve while charging. Figure 5 shows the demand curve of a vehicle while charging connected to the off-board charger evaluated (DC connection, 50 kW).

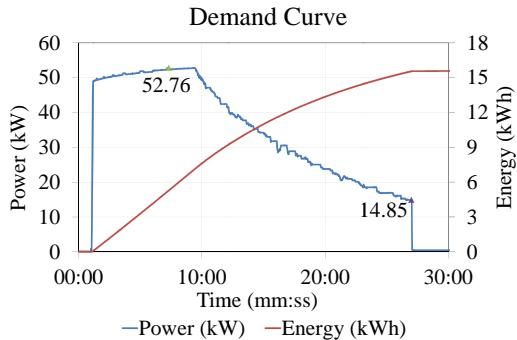


Figure 5: DC charger demand curve

## 4.2 Conclusion

SCE communicates all product performance for a particular device with the manufacturer of that device to improve product functionality. When SCE identified a component failure, noncompliance with code, interaction problem, or an opportunity to improve the product it was communicated to the manufacturer. SCE then worked with that manufacturer - or when it was an interaction with a vehicle - to work with both suppliers to determine the source of the issue and resolve it, retesting when a solution was implemented. In one case an interaction was found and SCE was able to connect the manufacturers to each other to resolve the problem.

This interactive testing relationship can work both ways. In a different case an EVSE failed a

test, and SCE worked with the manufacturer to determine that it was not actually a failure but that the test was not fully representative of the standard. That specific test was revised and expanded in order to correctly assess the EVSE. The unit was retested and passed the revised test. SCE used the results of this process to develop recommendations for the SCE fleet on charge infrastructure acquisitions. The recommendations helped to ensure that new technology is functional, effective, safe, reliable, and efficient when it is introduced into the SCE fleet.

## References

- [1] *Energy Star*, [http://www.energystar.gov/index.cfm?c=about\\_history](http://www.energystar.gov/index.cfm?c=about_history) accessed on 2012-01-25
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## Authors

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