System-Cost-Optimized Smart EVSE for Residential Application:

Final Technical Report

including Manufacturing Plan

DOE Award Number DE-OE0000590

Prime Contractor: Delta Products

Principal Investigator: Dr. Charles Zhu

Report Date: June 15, 2015

Table of Contents

Executive Summary

In the 2nd quarter of 2012, a program was formally initiated at Delta Products to develop smart-grid-enabled Electric Vehicle Supply Equipment (EVSE) product for residential use. The project was funded in part by the U.S. Department of Energy (DOE), under award DE-OE0000590. Delta products was the prime contractor to DOE during the three year duration of the project. In addition to Delta Products, several additional supplier-partners were engaged in this research and development (R&D) program, including Detroit Edison DTE, Mercedes Benz Research and Development North America, and kVA.

This report summarizes the program and describes the key research outcomes of the program. A technical history of the project activities is provided, which describes the key steps taken in the research and the findings made at successive stages in the multi-stage work. The evolution of an EVSE prototype system is described in detail, culminating in prototypes shipped to Department of Energy Laboratories for final qualification. After the program history is reviewed, the key attributes of the resulting EVSE are described in terms of functionality, performance, and cost. The results clearly demonstrate the ability of this EVSE to meet or exceed DOE's targets for this program, including:

- construction of a working product-intent prototype of a smart-grid-enabled EVSE, with suitable connectivity to grid management and home-energy management systems, revenue-grade metering, and related technical functions;

  and

- cost reduction of 50% or more compared to typical market priced EVSEs at the time of DOE's funding opportunity announcement (FOA), which was released in mid 2011.

In addition to meeting all the program goals, the program was completed within the original budget and timeline established at the time of the award. The summary program budget and timeline, comparing plan versus actual values, is provided for reference, along with several supporting explanatory notes. Technical information relating to the product design and test results are contained in the appendices to this report.

I. Project Overview

This report summarizes activities and accomplishments during the project *"System-Cost Optimized Smart-Grid Enabled EVSE for Residential Application,"* (DOE Award Number DE-OE0000590). The project is led by Principal Investigator (PI) Charles Zhu of Delta Products. Delta Products is the prime contractor, and oversees subcontractor-partners *Mercedes-Benz R&D North America, DTE – Detroit Edison,* and *kVA*.

The project is divided into two phases. Phase one was kicked off on May 15, 2012 and completed on October 15, 2014. Phase 1 activity was devoted to an iterative design and development process for the smart-grid-enabled EVSE, with designs, prototypes, and testing on each prototype phase. At the conclusion of phase 1, verified prototype samples were delivered to DOE National Laboratories. Then in Phase 2, DOE labs will tested and verified the EVSEs against performance and functional requirements.

According to the Statement of Project Objectives (SOPO), the specific project objectives for the overall project were:

> *"1. To design and build working prototypes of a system-cost-optimized smart-EVSE which will meet the technical requirements as set forth in DE-FOA-000054;*
>
> *2. To demonstrate that the system-cost-optimized EVSE represents a major cost reduction compared to existing EVSE products on the market, including:*
>
>> *a. Demonstration that the system-cost-optimized smart EVSE is at least 50% cheaper than competing EVSE's on the marketplace, in accordance with the targets as set forth in DE-FOA- 00054.*
>>
>> *b. Demonstration that the system-cost optimized smart EVSE can be mass-produced in large volumes at less than $500 per unit. "*

The project overall has proceeded according to the original project plan, and has passed all identified milestones at or before the original milestone timing. The only updates to the timing plan were made late in phase 1 to add a field installation of 24 EVSE units at a *DTE-Detroit Edison* workplace. This successful evaluation of workplace charging concept was completed according to the updated schedule, without any overall increase in program budget or timeline requirements. Phase 2 was also completed within time and budget constraints, with final confirmation of Phase 2 completed on April 15, 2015.

II. Review of Program Development Activities

A. Background and History

This project, "System-Cost-Optimized Smart EVSE for Residential Application" was envisioned in early 2011. In that timeframe, the Department of Energy was seeking innovative proposals for R&D activities to advance the state-of-the-art in electric vehicle supply equipment (EVSE). EVSE deficiencies have historically been viewed as a barrier to electric vehicle adoption. The barriers posed by EVSEs come in two different forms. To consumers, the already-high cost of an electric vehicle is made even higher when factoring in the need for EVSE infrastructure purchases. To electric utilities, the increase use of EVs held the potential downside of increased grid loads and peak-power demand.

Overcoming the consumer's problem would mean cost reduction. To overcome the electric utilities' problem, a smarter EVSE would be needed. These two ideas were jointly the topic of DOE Funding Opportunity Announcement (FOA) 000054. A team led by Delta Products submitted a proposal in response to this FOA, and was selected for funding by DOE. Work on the program began in May 2012.

The overall development schedule was 3 years. Most of the development activity was contained in Phase 1 of the program, which lasted for 2.5 years, from April 15 2012 until October 15 2014. Phase 1 was comprised of the overall product development process for the EVSE prototype. This included several successive phases of development activities, including the definition of requirements, architectural layouts, detailed designs, prototype evaluations, and verification in test. At the end of Phase 1, the verified prototype was shipped to the DOE National Laboratories for testing in the next phase. Argonne National Laboratory and Idaho National Laboratories both received prototypes for testing.

A shorter Phase 2 of the program lasted for 6 months, starting on October 15, 2015 and continuing through April 15 2015. Phase 2 activity was led by the DOE National Laboratories, who tested the EVSE prototypes according to several test protocols. The results of phase 2 are documented in test data by the National Laboratories.

B. Phase 1 Activities

i. Generation-0 "Yellow Board" prototypes

Early in the program, delta designed the Generation-0 “Yellow-Board” prototype of the intelligent EVSE. Three prototypes were built. Various Zigbee modules and Power line Communication (PLC) modules can be plugged in at Ethernet and USB ports. Software functions can quickly tested and modified, using the attached Personal Computer (PC). The yellow boards provide a flexible platform for experiments due to the ruggedized container and modular nature of the device. The system architecture, demand response function and metering concept were verified using the Gen-0 yellow board prototype plug-in vehicles. The Gen-0 prototypes, and associated target architecture, are shown in Figures 1 and 2 below.

Figure 1: Generation-Zero "Yellow-Board" Prototype, circa 2012.
Left – unit encased in travel enclosure. Right - internal main hardware under test

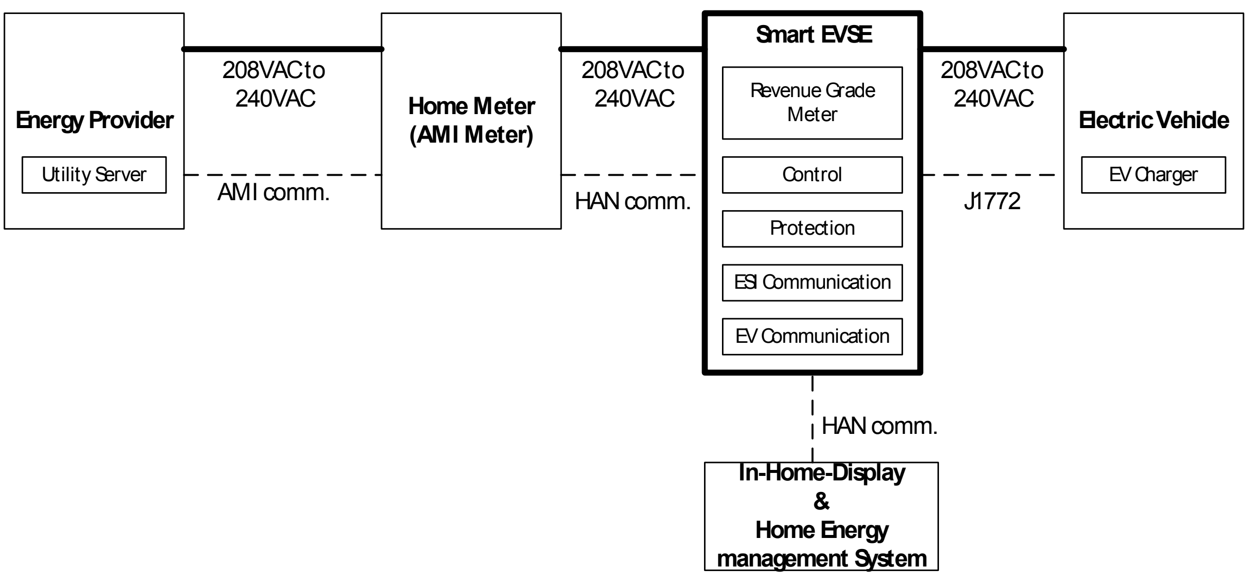


Figure 2: Updated system architecture, circa 2012

ii. 1st Generation Prototypes

Based on learnings and experience from the Generation-Zero prototypes, the first generation of prototypes were developed. This development continued from approximately mid-2012 through mid-2013.

The EVSE first generation design featured several new features that extended the capability of the EVSE. It used two main micro-controller, which are referred to as "Primary Side" and "Secondary Side" microcontrollers. The primary-side microcontroller unit (MCU) manages the basic charging functions, while the secondary-side MCU manages the smart functions and the pilot signal. Galvanic isolation was employed between the primary-side circuit and secondary-side circuit, to protect the user safety. This prototype also employed two communication channels to external systems beyond the EVSE boundary. One communication line is used for Zigbee communications, and the other is used for Ethernet connectivity. The metering Integrated Circuit (IC) communicates with the secondary-side MCU through an isolated serial port.

To successfully complete the Phase 1 design, software needed to be developed to enable the EVSE components to work with each other and provide overall functionality. Software components were developed for four micro-controllers: the primary-side MCU, the secondary-side MCU, the Zigbee MCU and the metering MCU.

While referred to as a 1^{st} generation prototype, this design is already suitable as a potential production level design. The dimensions are 350mm (H) x 400mm (W) x 126mm (D), representing a major improvement over typical EVSEs at the time of the 1st generation prototype's construction. The first-generation prototype is shown in Figure 3

While the first generation was considered a success, it led to several new realizations for the design team. Despite major advances in size, it was clear that more improvement could be obtained in size and cost with a re-design effort. Software upload capability was also viewed as a weakness in generation 1, because it contained no USB interface for software updates. Finally, the installation cost of the unit was viewed as higher than optimal due to the cable access and connection mechanism. These constraints in the 1st generation design were considered carefully by the team as the 2nd generation was planned.

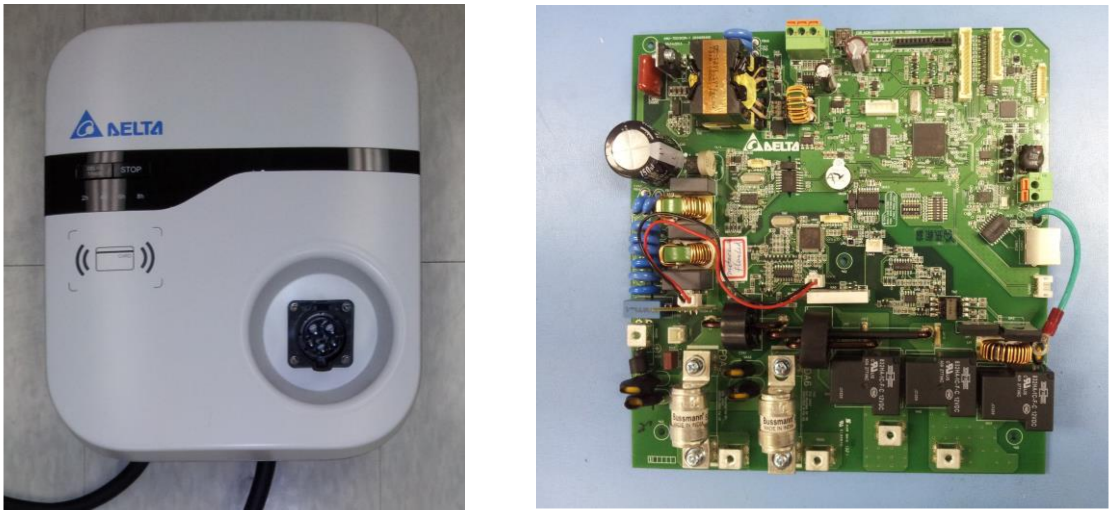


Figure 3: 1st-Generation Prototype, built in early 2013 and used for extensive testing in late 2013
Left - external view. Right – close-up view of main PCB inside prototype.

iii. 2nd Generation Prototypes

Between mid-2013 and mid-2014, the 2nd generation EVSE prototype was designed and prototyped. This 2nd-generation prototypes were ultimately verified and shipped to the Department of Energy for testing during the project's second phase. The prototype is shown in Figure 4.

While keeping the 1st-generation electrical and communication architecture, the 2nd generation EVSE hardware design achieves the following improvements and meets the design goals:

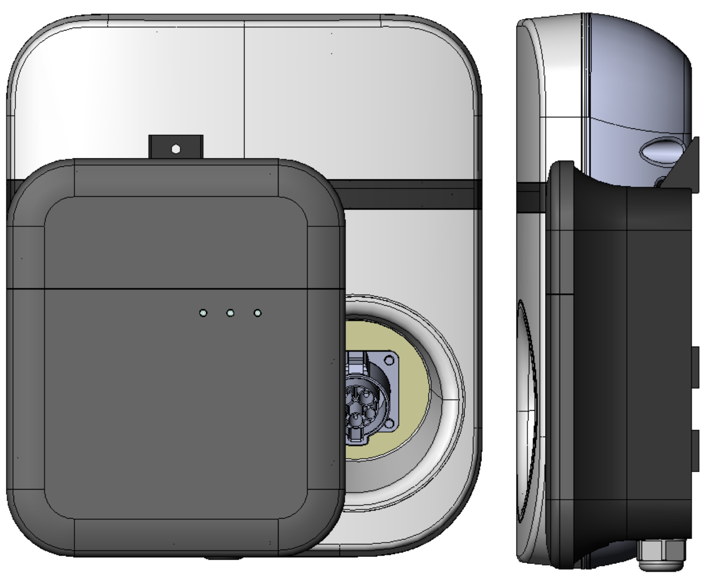
- The overall package is updated to a much smaller size, with 55% volume reduction compared to the previous generation design. The dimensions are 12.6 x 10.3 x 4.5 in (320 x 260 x 115 mm), excluding charging cable, mounting plate and cable holder. This brings extra benefit of lower cost and higher degree of waterproofing. Figure 5 shows the smaller size of the updated design, compared to the first generation design.

- The cable access and connection mechanism is improved in the 2nd generation design. This reduces the installation time to less than 10 minutes, reducing the overall system installation cost.

- The software service interface is greatly enhanced in the updated design. For example, the 2nd generation design is now fitted with a USB port to facilitate fast and easy software upgrades. The port also simplifies extraction of data from the EVSE device.

All the SOPO defined functions and features are once again successfully tested and demonstrated on the 2nd generation prototype. The unit was also tested and certified to meet UL specifications. An extensive summary of test results is contained in this report in Appendix 1.

Figure 4: 2nd-Generation Prototype, verified and shipped to DOE National Labs in October 2014.
Left - external view. Right – close-up view of main PCB inside prototype



a) front view   *b) side view*

Figure 5: Dimensional comparison of GEN 1 and GEN 2 Grid Smart EVSE
(Note: GEN 1 is the bigger unit in light color. GEN 2 is the smaller unit in dark color)

iv. Workplace Charging Demonstration

The program plan was updated to include a 24-unit workplace installation at DTE's Detroit site. This activity was successfully kicked off in May 2014 and completed in September 2014. These EVSEs have been successfully used by DTE employees commuting to and from work, providing an opportunity to monitor and test the EVSE prototypes in a real-world environment. This extension of the program was accomplished without any overall increase in program budget or timeline. To fully evaluate the EVSEs in practice, the EVSE hardware was installed at the parking garage used by DTE employees in downtown Detroit, MI. Additionally, charge control software was developed and installed to monitor and control the charge levels of these vehicles. This successful addition to the program served to build confidence in the EVSE design, build understanding of workplace Electric Vehicle (EV) charging and charge management, and to build awareness of EVSE capabilities in real-world environments. Figure 6 shows the final installation site, with multiple EVs plugged into multiple EVSEs. A screen shot showing the site management system interface is shown in Figure 7.

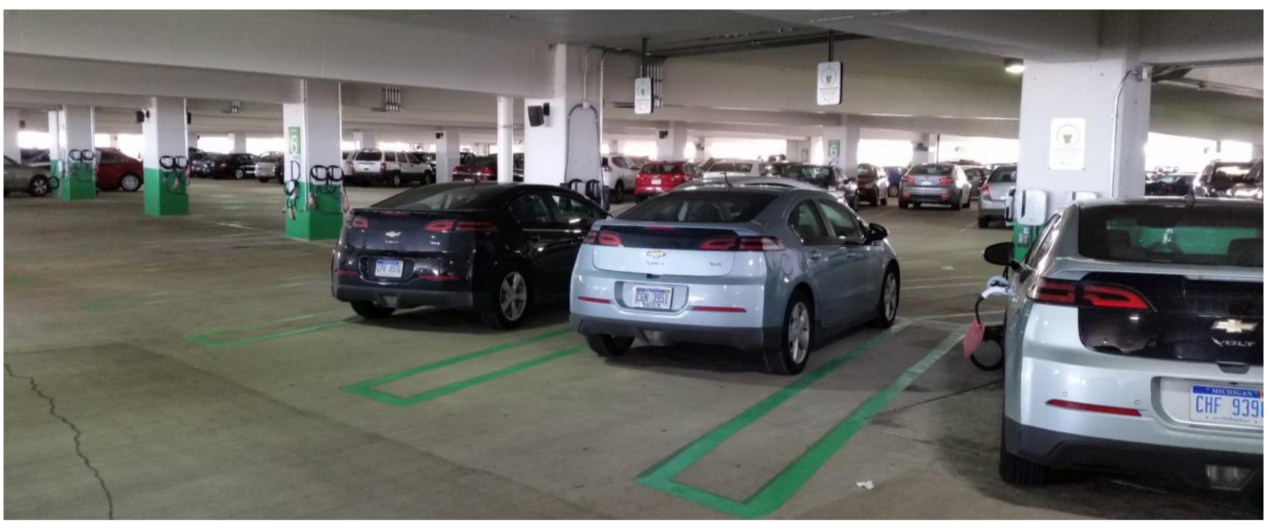


Figure 6: Photograph of the DTE Workplace Charging Site

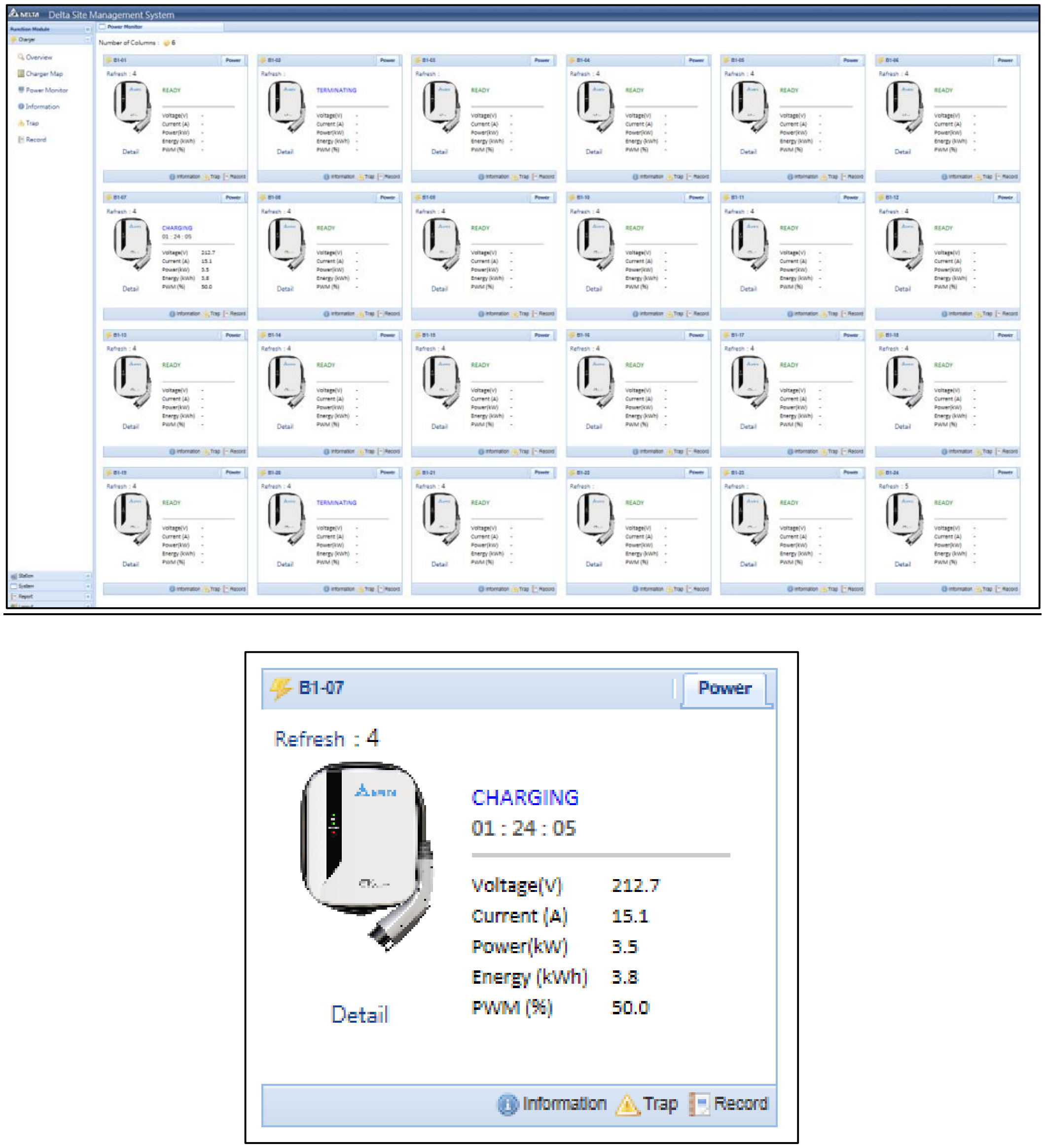


Figure 7: Screen Shot of Site Management System (SMS).
Top view is of overall site management; lower view is of a specific EVSE monitoring screen

B. Phase 2 Activities

Argonne National Lab and Idaho National Lab each received a 2nd Generation prototype EVSE unit at the beginning of Phase 2. The two labs conducted tests with Delta's on-site support. Delta also provided remote support when necessary to help achieve the test programs. Each lab conducted test independently in the following three categories:

1. J1772 functional test. This is conducted with a vehicle emulator at Idaho National Laboratory (INL). A GridTest tester was also employed. All results demonstrated full compliance with the J1772 standard.

2. Metering accuracy test. Accuracy of the meter was evaluated at both National Laboratory sites, to determine whether revenue-grade metering was achieved by the EVSE prototype. The target metering accuracy of ±0.5% was surpassed in the tests performed by both labs.

3. Smart grid connection use case test. The test was conducted with and ITron Advanced Metering Infrastructure (AMI) meter and a Delta developed Home Energy Management System (HEMS). Time synchronization, demand response and TOU communication were successfully verified in test.

Short form test reports from ANL and INL are included in Appendix X. Full reports are sent to NETL separately.

Besides the tests toward the technical deliverables, Idaho National Lab also conducted an assessment of cyber security. The assessment result was sent to Delta for review. Idaho National Lab determined that *"the ZigBee radio is secure enough that it is too difficult for us to continue trying to break into the ZigBee network".* This provides confidence in the future ability of the EVSE to provide data security in the face of cyber-security threats.

III. Program Results

A. Technical System Development

The ultimate goal of the program is to develop a working EVSE prototype with the performance characteristics, features and functions, and cost. This objective has been accomplished. The tables contained in *Appendix A - Technical Specifications* comprise a preliminary specification based on test data indicating the key technical characteristics of the EVSE prototypes delivered under this program. Related test certifications are also provided in this appendix. Cost-related parameters are described in the next section (***III-B - EVSE Cost Reduction***).

The tables and figures below show examples of the interfaces to the developed EVSE. Table 1 shows a summary of the EVSE performance in a variety of tests as documented at the conclusion of Phase 1 activity. This table summarizes broad technical performance areas such as Alternating Current (AC) input, AC output, start-up time, safety and protections, and integration behaviors. Overall the EVSE successfully performed all the tasks it was required to perform.

Figures 8 and 9 are screen-capture images meant to display the user interfaces to the EVSE systems. Figure 8 shows the interface to the HEMS. Demand response and pricing functionality are clearly indicated, along with real-time current draw and power usage. Figure 9 shows the interface from the utility side. Again, the demand response and pricing functions are clear, along with various energy network management capabilities available to the utility.

Table 1: Preliminary Result of EVSE Functional Tests

ITEM	PT2 RESULT	note
AC Input:		
AC Input Voltage	**PASS**	
AC Input Frequency	**PASS**	
AC Input Current	**PASS**	
Power Consumption	**PASS**	
Leakage Current	**PASS**	
AC Output		
AC Output Voltage	**PASS**	
AC Output Frequency	**PASS**	
AC Output Current	**PASS**	
Start Up Behavior:		
Start up time	**PASS**	
Cold-Load Pickup	**PASS**	EVT1 verification (FW upgrade)
Thermal Performance	**PASS**	
Protections:		
Upstream Breaker		
Input Fuse	-	240V 50A fuse on L1, 30A on L2
Over/Under Voltage Protection	**PASS**	
Over Current Protection	**PASS**	
Over Temperature Protection	**PASS**	
Charging Circuit interrupting Device(CCID)	**PASS**	
Ground Monitor/Interrupter(GM/I)	**PASS**	EVT1 verification (FW upgrade)
Wielding Detection	**PASS**	PT2 has the hardware bug EVT1 verification
Integration:		
ZigBee Module	**PASS**	
Pilot Circuit Requirement	**PASS**	
Pilot State Voltage Range	**PASS**	
EVSE Response Time	**PASS**	

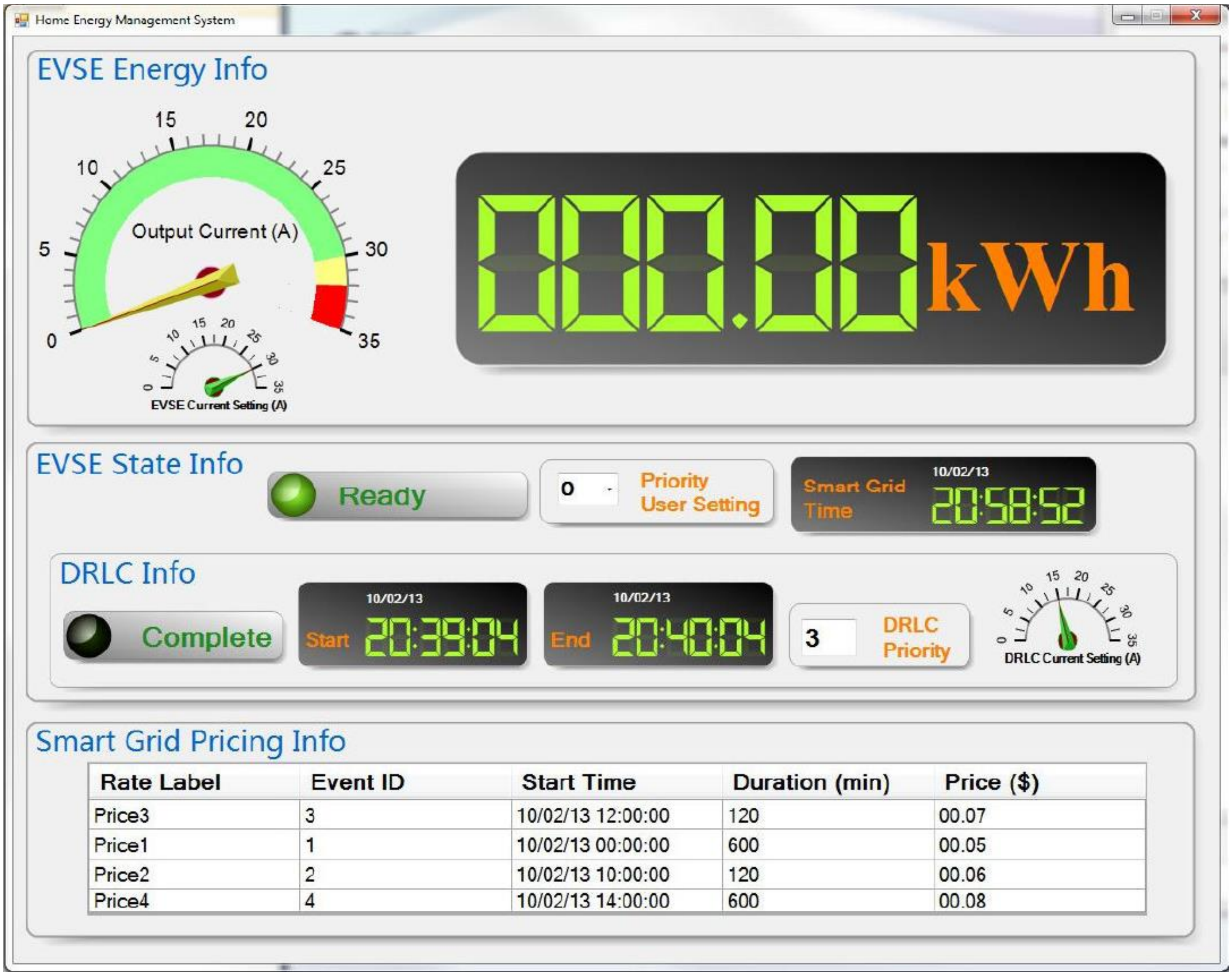


Figure 8: HEMS screen capture showing Demand response and Pricing functions test results

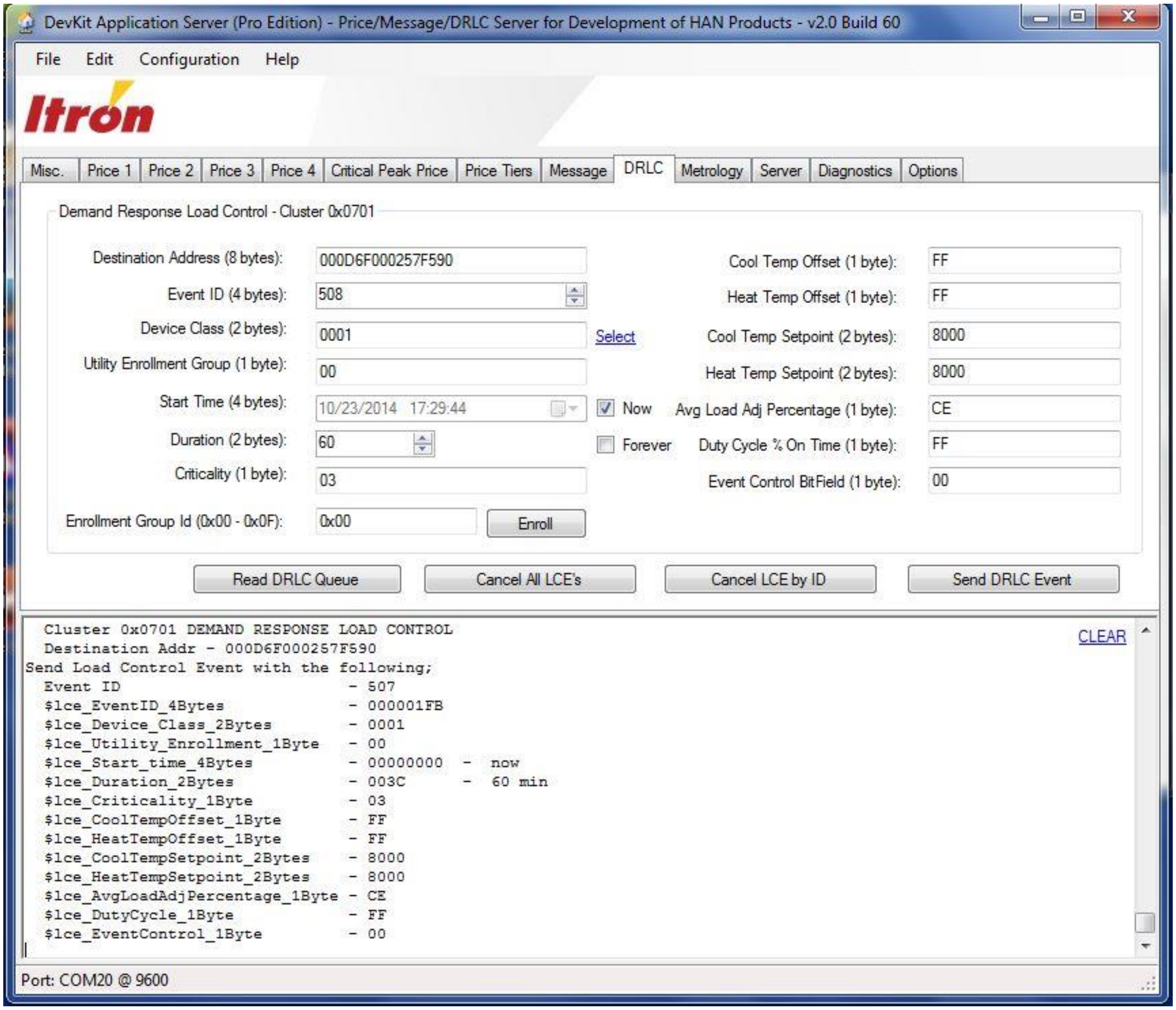


Figure 9: Utility server screen capture showing demand response and Pricing functions test result

B. EVSE Cost Reduction

A main objective stated by DOE is the reduction of EVSE costs. This is a primary objective of the project, supporting a higher-level objective of reducing the cost of ownership of plug-in vehicles. The original goal stated by DOE was a 50% cost reduction compared to currently available products. In the proposal submitted by the Delta team, this was expanded to clarify and end cost of $500 or less, which represents an aggressive goal.

In the original proposal, a component-by-component cost comparison was provided, clarifying some of the key potential sources of cost savings. Now, after the successive prototype development stages noted in a previous section, this table can be updated with more accurate estimates based on real working hardware. This comparison is made in Table 2 below. Table 2 compares three different potential costs of each component within the EVSE:

- The cost of components in a typical hypothetical EVSE produced in 2011, referred to as “Brand X”, is shown in the first cost column;
- The initially projected cost of the cost-optimized Delta EVSE, *as estimated in the original proposal to DOE*, is shown in the 2nd column;
- The current best estimate of the actual cost-optimized Delta EVSE, *based on the most recent hardware developed in Phase 1*, is shown in the 3rd column.

This analysis shows that the cost-reduction objectives of the program have not only been met, but surpassed. Costs were reduced from $1,020 in the hypothetical “Brand X” 2011 EVSE, to $400 for the cost-optimized Delta EVSE developed in Phase 1.

As noted in Figure 4, the cost reduction concept relies on several overlapping improvements in the EVSE design, which were developed in Phase 1. These improvements include the following:

1. elimination of duplicate circuitry within the EVSE;
2. reduction of unused communication options; so that costs are only incurred for the communication paths chosen in the system architecture;
3. a shift toward replacing expensive hardware components with software algorithms. This shift is enabled by the more powerful processing unit used in the updated designs, which can perform more software tasks in a faster time;
4. reduction of overall system size, number of components, and complexity.

The initial belief of the project team is borne out by the program results: a smarter EVSE can ultimately be cheaper to build than previous less-smart implementations. Note also that these cost reductions are all made with identical volume assumptions. It may be possible for additional cost reductions if economies of scale are improved. These economies of scale are in turn improved by reduce cost of Plug-in Electric Vehicle (PEV) ownership, in principle creating a kind of virtuous cycle of cost reduction and sales volume increase. While estimating these scale-up impacts is beyond the scope of this program, the basic trend is clear, and indicates a successful outcome of Phase 1.

Table 2: Cost Comparison for EVSE components.

The first two columns (for "Brand X" 2011 EVSE and 2014 Delta EVSE) are identical to the proposal to DOE for this project, written in 2011. The third column is an estimate of actual component costs for the cost-optimized smart EVSE that has been developed in Phase 1.

	Typical 'Brand X' 2011 EVSE	*Delta 2014 EVSE -PLAN-*	Delta 2014 EVSE -ACTUAL-	Cost Reduction Methods
AMI:				
Packaging	$30.00	*$55.00*	**$30.00**	Only one package; system cost reduction
Energy Meter	$180.00	*$80.00*	**$25.00**	Utillize low cost sensors with EOL and correction algorithm
Control Board	$0.00	*$80.00*	**$80.00**	Add much more features, however, utilize low cost up and remove expensive digital logic gates; system cost
Protection Hardware	$35.00	*$45.00*	**$20.00**	traditional EVSE, however, overall system costs greatly reduced
Display	$20.00	*$8.00*	**$6.00**	Simpler display
Communication: 802.15.4	$50.00	*$35.00*	**$35.00**	Technology cost reductions
Misc. Hardware	$60.00	*$20.00*	**$15.00**	Lighter and smaller package
Mounting Hardware	$10.00	*$15.00*	**$15.00**	Reduced hardware mounting due to single package con
Misc. Electronics	$5.00	*$35.00*	**$30.00**	traditional EVSE, however, overall system costs greatly reduced
J1772 Connector	$0.00	*$110.00*	**$124.00**	Reduced future prices of J1772 connectors
Cables	$0.00	*$20.00*	**$20.00**	No price impact
EVSE:				
Packaging	$40.00	*$0.00*	**$0.00**	Included already in smart EVSE
Mounting Hardware	$20.00	*$0.00*	**$0.00**	Included already in smart EVSE
Misc. Hardware	$40.00	*$0.00*	**$0.00**	Included already in smart EVSE
Misc. Electronics	$30.00	*$0.00*	**$0.00**	Included already in smart EVSE
J1772 Connector	$180.00	*$0.00*	**$0.00**	Included already in smart EVSE
Cables	$20.00	*$0.00*	**$0.00**	Included already in smart EVSE
Controller:				
Packaging	$20.00	*$0.00*	**$0.00**	Included already in smart EVSE
Control Board	$150.00	*$0.00*	**$0.00**	Included already in smart EVSE
Communication: GPRS	$100.00	*$0.00*	**$0.00**	Not required in smart EVSE
Misc. Hardware	$30.00	*$0.00*	**$0.00**	Included already in smart EVSE
Totals	**$1,020.00**	*$503.00*	**$400.00**	**Cost reduction of 50%, not including improved economies of of scale**

C. Preliminary Manufacturing Plan

A preliminary manufacturing plan was established for the new smart-grid-enabled EVSE. The smart EVSE final assembly and end-of-line test utilizing one production lines within a larger Delta production facility to be determined. The throughput is planned to be 2000 units per month initially and can be ramped up to 6000 units per month by adding more shifts. A variety of production technologies will be employed including

- Winding automation;
- injection molding;
- stamping;
- SMT (Surface Mount Technology)
- PWB assembly, and
- System assembly.

The production line will be comprised of three Assembly workstations, one Hi-pot test workstation, four ATS test workstations, one leakage test workstation, five packing workstation, and one pelleting workstation. A conceptual schematic is shown below in Figure 10.

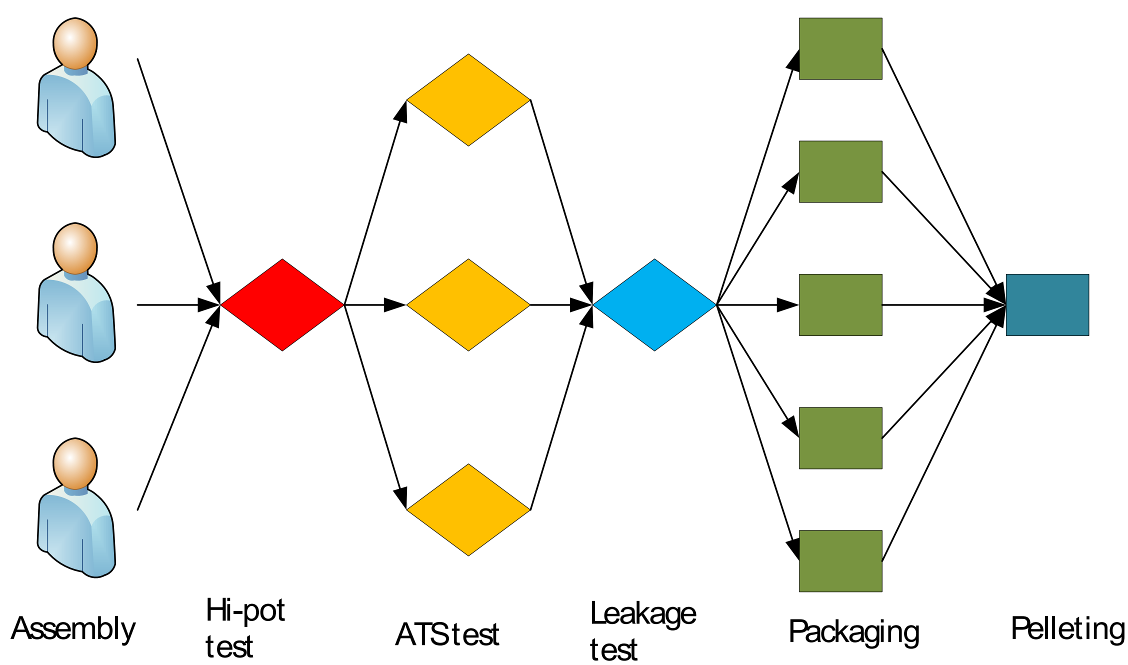


Figure 10: Assembly line layout diagram

The assembly line will require fixed asset investment. The following table lists the main equipment investment based on the results of the preliminary analysis:

Table 3: Fixed Investment Estimates for Manufacturing Line

Function	**Item**	**Quantity**	**Unit price (USD)**	**Sub total (USD)**
Assembly	X-PAQ precision fastening system	3	2000	6000
	Shop floor information system	1	120	120
Test	Hi-Pot	1	800	800
	ATS	1	35000	35000
	B/I	1	3000	3000
	IPX5 leakage detector	1	2000	2000
Packing	Shop floor information system	2	120	240
	Label printer	2	600	1200
Misc	Desk, ESD			2000
	Total			**50360**

As a part of the manufacturing plan, key component suppliers have been contacted for quotation and supplier qualification. Table 4 is a list of key components along with the status of supplier engagement for each. Based on this preliminary analysis, no major hurdles are foreseen for mass-production manufacture of all required components.

Table 4: Component and Supplier Preliminary Analysis

Component name	Main Supplier	Price meet target?	Quality Qualified?	Backup supplier
Charging coupler	A	Y	Y	B, C, D
Case	E	Y	Y	
ZigBee module	F	Y	Y	G, H
WiFi module	I	Y	Y	J
Fuse	K	Y	Y	L
Relay	M	Y	Y	N
MCU	O	Y	Y	
Current transformer	P	Y	Y	Q
Metering IC	R	Y	Y	
Terminal block	S	Y	Y	T

D. Budget and Schedule Results

i. Budget

Federal Cash (To report multiple grants, also use FFR Attachment):	
a. Cash Receipts	$0.00
b. Cash Disbursements	$0.00
c. Cash on Hand (line a minus b)	$0.00
(Use lines d-o for single grant reporting)	
Federal Expenditures and Unobligated Balance:	
d. Total Federal funds authorized	$1,997,450.00
e. Federal share of expenditures	$1,694,906.00
f. Federal share of unliquidated obligations	
g. Total Federal share (sum of lines e and f)	$1,694,906.00
h. Unobligated balance of Federal funds (line d minus g)	$302,544.00
Recipient Share:	
i. Total recipient share required	$1,583,765.00
j. Recipient share of expenditures	$1,415,925.00
k. Remaining recipient share to be provided (line i minus j)	$167,840.00

The overall budget result is healthy. The federal share is underspent by $302,544.00, or 15.1% of the budget. The recipient share is underspent by $167,840.00, or 10.6% of the budget.

In April 2014, a project update was proposed to DOE in writing by the PI and supplier-partner DTE – Detroit Edison. The proposal was to augment the program by installing multiple workplace charging units at DTE's Detroit site. This installation will be valuable as a test and evaluation platform for various workplace charging management strategies, and is aligned with the overall mission of the project. This change was justified in writing by the team, and approved by DOE during q2 2014. The effect of this change was to pull forward $33,000 of budget for DTE forward, into Phase 1 and out of Phase 2. The net budget for the project overall is unchanged.

ii. Schedule

The timeline originally established at program start was followed throughout. The completed timeline is shown below in Figure 11. Generally speaking, there were no deviations to the original schedule. Two tasks were added to the latter portion of Phase 1, when the opportunity arose for a workplace charging field demonstration. This additional activity incurrent no cost increases and no schedule extensions, compared to the original timeframe and budget.

Figure 11: Overall Project Timeline

E. Technology Transfer

Technology transfer activities in the project were focused largely on industry awareness of the availability of the new features available with the smart-grid-enabled EVSE. Several demonstrations were made to industry and government representatives, to show and explain the smart EVSE capabilities. A demonstration event was held on October 9, 2013 at DTE's downtown Detroit site. The team members presented their technology to a broad assembly of automakers, suppliers, and EV industry representatives. A final demonstration was held on October 30 2014, for a wider audience of industry representatives. There the full features of the smart-grid-enabled EVSE were presented, and a live charging demonstration of the management software was conducted. The invitees also got to see the phase 1 prototypes installed and operational in the parking lot, where the crowd lingered for several hours after the event was over to discuss the EVSE technology and trends in EV charging generally. These events helped move the industry forward and realize the potential of smart-grid-enabled EV charging strategies. Photos from each demonstration event are shown in Figures 12, 13, and 14 below.

Additionally, throughout the course of the program, team members participated in ongoing standards developments with IEEE and SAE. The prototype experiences helped shape these discussions. In the end the findings and experience of the project helped to shape future standards for smart-grid EVSEs

Figure 12: Engineering staff from Delta's Livonia offices demonstrate the SMART EVSE Capabilities to the demo attendees, assembled outside at the EVSE demo site at DTE's downtown Detroit headquarters. (Photo taken 10/9/2013)

Figure 13: Photo of the 2nd generation EVSE Prototype installed and under field trial at DTE's parking garage in downtown Detroit, MI. (Photo taken October 30, 2014)

Figure 14: Guests viewing charging of Daimler Smart EV at the October 2014 demonstration event

Appendix A: Smart-Grid Enabled EVSE Technical Specification

Table A-1: AC Input Specification

Parameter	Default value	Remark
Uin_{nom}	208Vrms/240Vrms	Nominal input operation voltage
Uin_{nom_min}	208 Vrms	North America
Uin_{nom_max}	240 Vrms	North America
Nominal line frequency	60 Hz	
Line frequency range	45 to 65 Hz	
Iin_{max}	30A	

Parameter	Value	Conditions
Pin(No Load)	≤ 5 W	Input 240Vac/60Hz, 25℃, No load, network Version(ZigBee)

Table A-2: Power Consumption Specification

Parameter	Value	Conditions
Leakage current	≤ 5 mA	Input 208Vac/240Vac/60Hz, 25℃, No load, network Version(ZigBee)

Table A-3: Start Up Time Specification

Parameter	Default value	Remark
T_{start}	50s Max.	Input 240Vac/60Hz, no load 25℃, non-network version (ZigBee)

Parameter	**Default value**	**Remark**
T_{start}	50~100 seconds	Typical value at 240Vac/60Hz, 25℃, 30A

Table A-4: OVP UVP Specification

Protection	**Default value**	**Remark**
OVP	$Uin_{high-off}$: 290 Vrms	Over voltage protection Tolerance of +/- 5V, trip time: 0.5~2.5s
OVP Recover	$Uin_{high-on}$: 280 Vrms	Over voltage protection recovery Tolerance of +/- 5V, trip time: 0.5~2.5s
UVP	$Uin_{low-off}$: 160 Vrms	Under voltage protection Tolerance of +/- 5V, trip time: 0.5~2.5s
UVP Recover	Uin_{low-on} : 170 Vrms	Under voltage protection recovery Tolerance of +/- 5V, trip time: 0.5~2.5s
OVP & UVP Hysteresis	10Vrms	Minimum hysteresis between Uin_{low-on} and Uin_{low-on} respectively $Uin_{high-on}$ and $Uin_{high-off}$ Tolerance of +/- 1Vrms

Table A-5: Output Current Limit Specification

Parameter	Default value	Remark
$Iout_{limit}$	$Iout_{max}$+6A	Factory default setting 46A. Tolerance+/-0.5A, trip time: 0.5~1.5s
$Iout_{limit-configure}$	$Iout_{configure}$+6A (20~40A) $Iout_{configure}$+3A (0~20A)	OCP is configured by system command. $Iout_{configure}$ is configured form $Iout_{min}$ to $Iout_{max}$. Tolerance+/-0.5A, trip time: 0.5~1.5s

Table A-6: OTP Specification

Parameter	Value	Remark
T_{OTP}	55℃	Over temperature protection Tolerance of +/- 1℃
OTP Recover	T_{OTP}-5℃	EVSE will resume to the normal operating Tolerance of +/- 1℃

Table A-7: CCID Specification

CCID 20 Trip threshold	15~20mA	Input voltage range: $Uin_{low-off}$~$Uin_{high-off}$ Output current range: 0~$Iout_{limit}$
CCID 20 Trip times	<25ms	Trip current 264mA

Table A-8: Ground Monitor/Interrupter

The ground monitor/interrupter is intended to monitor equipment ground continuity in a charging system. The equipment shall interrupt the circuit under conditions where the grounding is lost during operation.

Line Side GM/I	$Rin_{high\text{-}off}$ > 50Kohm	Input Ground Open protection, Trip time > 0.5s
Line Side GM/I Recover	$Rin_{Low\text{-}on}$ < 50Kohm	Input Ground Open protection recovery Trip time > 0.5s
Load Side GM/I	$Rout_{high\text{-}on}$ > 1Kohm	Output Ground Open protection, From State F to stop output time: Max. 100ms
Load Side GM/I Recover	$Rout_{high\text{-}off}$ < 1Kohm	Output Ground Open protection, Change to State X1 time: No requirement

Wielding Detection Note: The wielding detection intended to monitor the contact can't be closed before charging and shall be opened after charing.

Tables A-9 / A-10: Energy Management

Embedded non-revenue grade meter with 0.5% accuracy at nominal load will measure voltage, current, and energy for internal reference. The EVSE will also transmit this information to the Site Management System when available.

Parameter	Tolerance	Remark
Input Voltage	+/-0.5%	Uin_{nom}, $Iout_{nom}$
Input Current	+/-0.5%	$Iout_{nom}$
Input Reactive Power	+/-0.5%	Uin_{nom}, $Iout_{nom}$
Input Energy	+/-0.5%	Uin_{nom}, $Iout_{nom}$

Condition	Current (A)	Maximum Deviation from Reference Performance (%)
1	0.2	±1
2	0.3	±0.5
3	0.5	±0.5
4	1	±0.5
5	2	±0.5
6	3	±0.5
7	5	±0.5
8	10	±0.5
9	20	±0.5
10	30	±0.5

Table A-11: ANL Test Report

Test Report Electric Vehicle Supply Equipment (EVSE)

Test Suite	SAE J1772
Standard	SAE J1772™ JAN2010
EVSE Identity	DELTA FOA554
Customer Identity	ANL
Date of Validation	16JAN2015 13:47
Electrician/Engineer	

Test Item	Measured	Results
Available Current	30.01 A	Pass
Charge Voltage	210.83 V	Pass
EVSE Type	AC Level 2	Pass
GFI TRIP CURRENT	20.0 mA	Pass
GFI TRIP TIME	20.9 ms	Pass
Safety & Functionality per SAE J1772™ JAN2010		Pass

WARNING SUMMARY		
Test Name	**Test Point**	**Measured**
J1772 State B	Pilot Voltage Low	-13.41 V
J1772 State C	Pilot Voltage Low	-13.25 V

Test Passed - Ready to Charge Certified

Tested by Gridtest® EVE-100S Standards Test Unit, Serial #L0124100501, Firmware Version 1.20.0.048/28.Copyright © 2011-2013 Gridtest Systems, Inc. Permission to copy granted providing the report is copied in its entirety and no data is altered. All other rights reserved. Gridtest® is a registered Trademark of Gridtest Systems, Inc. Contact Gridtest Systems, Inc. at 818.600-2370 or email sales@gridtest.com (www.gridtest.com).

Advanced Vehicle Testing Activity

Idaho National Laboratory

Electric Vehicle Supply Equipment (EVSE) Test Report: Delta Smart Grid Capable EVSE

EVSE Features

LED Power Indicator	LED Charge Indicator
LED Fault Indicator	HEMS User App
Zigbee Wireless Modem	

EVSE Tested

Delta Smart Grid EVSE
AC Level 2
Model No. unknown

EVSE Specifications

Grid connection	Single NEMA 14-50P Cordset
Connector type	J1772
Approximate size (H x W x D inches)	12 x 10 x 5
Charge level	AC Level 2
Input voltage	208 / 240 VAC
Maximum input current	32 Amp
Circuit breaker rating	40 Amp

Test Conditions[1]

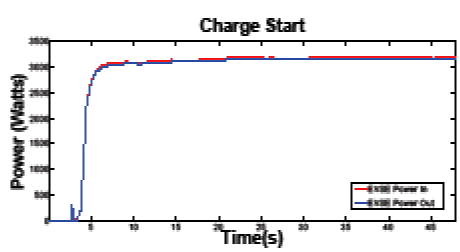
Test date	1/6/2015
Nominal supply voltage (Vrms)	209.8
Supply frequency (Hz)	60.00
Initial ambient temperature (°F)	70

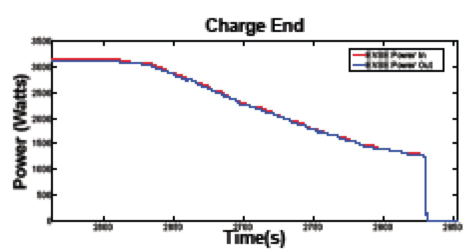
Test Vehicle[1,3]

Make and model	2012 Chevrolet Volt
Battery type	Li-ion
Steady state charge power (AC kW)	3.16
Maximum charge power (AC kW)	3.28

EVSE Test Results[1, 2, 4]

EVSE consumption prior to charge (AC W)	4.1
EVSE consumption during steady state charge (AC W)	30.2
EVSE consumption post charge (AC W)	4.1
Efficiency during steady state charge	99.04%





NOTE: Charge start and charge end power demand curves are dependent upon the vehicle

1. Hioki 3390 Power Meter used for all current and voltage measurements
2. Measurements were taken at EVSE grid connection and J1772 connection
3. Steady state charge power is the most common power level dictated by the vehicle during the charge
4. Steady state charge refers to the portion of the charge when power was greater than or equal to steady state charge power

For more information, visit avt.inl.gov

INL/EXT-11-23986

Figure A-1: Idaho National Laboratory Test Report

CERTIFICATE OF COMPLIANCE

Certificate Number	20140926-E354307
Report Reference	E354307-20140925
Issue Date	2014-SEPTEMBER-26

Issued to: DELTA ELECTRONICS INC
39 SEC 2 HUANDONG RD
SHANHUA DISTRICT
TAINAN ,741 TAIWAN

This is to certify that representative samples of ELECTRIC VEHICLE SUPPLY EQUIPMENT
EVMU401xxxxxx, EVMU301xxxxxx, EVMU161xxxxxx, where the 1st x can be 3 or 5 or 6 or 7; the 2nd x can be H or P; the 3rd x can be N or W or Z; the 4th x can be S or N; the 5th and 6th x can be dash, 0-9, A-Z or blank.

Have been investigated by UL in accordance with the Standard(s) indicated on this Certificate.

Standard(s) for Safety: UL 2594 and CSA C22.2 No. 280-13 - Standard of Safety for Electric Vehicle Supply Equipment

Additional Information: See the UL Online Certifications Directory at www.ul.com/database for additional information

Only those products bearing the UL Listing Mark for the US and Canada should be considered as being covered by UL's Listing and Follow-Up Service meeting the appropriate requirements for US and Canada.
The UL Listing Mark for the US and Canada generally includes: the UL in a circle symbol with "C" and "US" identifiers: cULus the word "LISTED"; a control number (may be alphanumeric) assigned by UL; and the product category name (product identifier) as indicated in the appropriate UL Directory.

Look for the UL Listing Mark on the product.

William R. Carney, Director, North American Certification Programs
UL LLC

Any information and documentation involving UL Mark services are provided on behalf of UL LLC (UL) or any authorized licensee of UL. For questions, please contact a local UL Customer Service Representative at www.ul.com/contactus

Page 1 of 1
Created by UL Document Assembler 2014-10-05 23:17:52 -05:00

Figure A-2: UL Certificate of Compliance