

EVS27 Symposium
Barcelona, Spain, November 17-20, 2013

US-EU Joint EV-Smart Grid Interoperability Centers

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Abstract

The US Department of Energy (DOE) and European Commission (EC) signed a Letter of Intent (LoI) in November 2011 to establish cooperative Electric Vehicle-Smart Grid Interoperability Centers at Argonne National Laboratory (ANL) and the EC's Joint Research Centre - Institute for Energy & Transport (JRC-IET). The intent is to facilitate harmonization of EV-grid connectivity and communication standards, technologies and test procedures between the US and EU.

Since the agreement, the laboratories have reviewed each other's test facilities and procedures, enhanced their testing capabilities (facilities and equipment), consulted with industry, initiated comparative test activities and proposed cooperative activities to DOE and the EC for the next two years. This paper reviews the background as well as the status and capabilities of the centers in addition to the accomplishments and future plans.

Keywords: charging, communication, smart grid, standardization, wireless charging

1 Introduction

The ultimate benefits of electric vehicles (EVs, including battery electric and plug-in hybrid vehicles), will be realized through smart charging and intelligent energy management in smart grids. This requires vehicles, charge stations, communications and networking systems to work in unison. Harmonizing EV-grid connectivity and communication standards will reduce the barriers for global manufacturers of EVs and EV supply equipment (EVSE), lower development costs, promote interoperability and increase consumer confidence ... all in support of US and EU goals to increase vehicle electrification and the adoption of new vehicle technologies.

The DOE-EC agreement targets three key areas of technical harmonization – interoperability, vehicle

test procedures and battery test procedures. Most of the activity has focused on the enhancement of the centers to support interoperability standards development and verification. However, some activities already underway in the laboratories have been leveraged to initiate cooperation in other areas such as vehicle testing. This paper addresses the status and plans in each of these areas.

A practical definition of EV-grid interoperability is the ability to charge conveniently, safely and securely – anywhere, anytime – and enabling smooth integration of functions offered by energy service providers. This simple explanation implies some not-so-simple technical challenges (listed below) will be addressed.

- *EV-EVSE compatibility*; Technology and standards must comprehend mobile and non-

exclusive customers; EVs will charge at single-family or multi-unit residences as well as workplace and public stations, using EVSE from a variety of manufacturers.

- *Harmonized EV-grid communication systems*; EVs will cross borders of utilities, municipalities and nations; necessitating ‘roaming’ capability for identification, billing and load management.
- *Co-existing legacy and advanced systems*; Tens of thousands of EVs and EVSE have been deployed widely in the US and abroad before connectivity and communication standards were widely adopted. And utilities are installing millions of smart meters as well as sensing and control systems to enable smart grids, but the technologies and rates of deployment vary by country and utility.
- *Availability of enabling technologies*; proposed regulations require EV identification, energy measurement and communication during charging, necessitating new technologies. Future functions to exploit the benefits of dispersed populations of electric energy storage in local, or even supra-regional EV fleets will call for ever more sophisticated communication and management solutions.

2 Background

2.1 The Establishment of US and EU EV-Smart Grid Interoperability Centers

The EU-US Energy Council and the Transatlantic Economic Council (TEC), co-chaired by the US government executive branch and European Commission, recognized e-mobility as a common growth sector and the TEC released the ‘Work plan for Advancing Transatlantic E-mobility Cooperation’ in November, 2011. The plan supported collaboration to harmonize regulation and EV-smart grid interoperability, including goals and recommended actions [1]:

- Common/compatible standards for EVs and smart grids
- Strengthening cooperation among regulators
- Joint research initiatives on charging and energy storage, including safety
- Compatible EV-grid communication methods in the US and EU markets

The work plan also included specific expectations of the US and EU interoperability centers:

- Similar/complementary test capabilities including common test fixtures, procedures and protocols.
- Direct support of joint standardization activities, research initiatives and smart grid communication methods.
- Support development of (ideally globally) applicable standards.
- Conduct pre-normative research.
- Exchange test protocols, participate in each other’s inter-laboratory comparisons (“round robins”), exchange of staff, and joint publications.
- Collaborate with industry organisations.

2.1.1 Argonne National Laboratory

The Center for Transportation Research at Argonne has directly supported the DOE Vehicle Technologies Program/Office for over a decade, resulting in substantial expertise and state-of-the-art facilities to support analysis, development and testing of EVs, e.g., the Advanced Powertrain Research Facility (APRF) [2]. In addition, Argonne has directly supported the development of electric and hybrid vehicle standards for many years with technical expertise and utilization of the laboratory facilities as required; including development of standard test procedures for EVs, HVs and PHEVs as well as EV-grid connectivity and communication. Laboratory resources are combined as needed to support tasks of the Interoperability Center.

To meet the needs of the Center, lab space and equipment were added to accommodate EV-EVSE-grid communication testing (AC and DC), high power DC charging and/or discharging, electromagnetic emission/compatibility testing, and network communication for load management studies (Figure 1).

The focus is on helping bridge the gaps in standards, communication technologies, messaging protocols and verification procedures that support EV-grid connectivity, including:

- Charging systems – AC, DC, and non-conductive (“wireless”) EVSE; requirements and test procedures to assess EV-EVSE-grid compatibility.



Figure 1: Vehicle connectivity and charging communication development at ANL

- Communications – Software and embedded systems to support identification, billing and load management; development and verification of proof-of-concept hardware and/or software systems, communication protocols and standards.
- Networks – Infrastructure-related systems to support a reliable vehicle-to-grid network.

To adequately address these issues and support the adoption of data-driven standards and/or methodologies, Argonne has developed enabling technologies, including compact metrology (i.e., sub-metering), communication controllers (i.e., EV-EVSE and EVSE-grid) and embedded software.

DOE officially launched the EV-Smart Grid Interoperability Center at Argonne on July 18, 2013. In addition to opening the center, there were technical demonstrations of EV-grid connectivity, with examples of charging load management (real PEV and EVSE in a simulated workplace charging environment) and vehicle-to-grid power supplied by the Dodge Ram PHEV.

In addition to Argonne, the DOE Vehicle Technologies Office intends to utilize the expertise of other DOE labs to address specific EV-grid connectivity issues such as cyber security, renewables integration and smart grid compatibility.

2.1.2 Joint Research Centre - Institute for Energy & Transport

The Joint Research Centre is the European Commission's research arm. JRC-IET has

substantial expertise in supporting developments in regulation, codes and standards through the validation of test procedures and measurement methodologies as well as performance assessment [3]. As a result of the DOE-JRC LoI, JRC-IET established the 'Reference Laboratories for EV/Smart Grid Interoperability', utilizing laboratory capabilities in Ispra, IT and Petten, NL.

The Ispra location of JRC-IET is recognized for testing vehicles and engine emissions in its VeLA-labs; this will be the site for EV efficiency and performance testing as well as evaluating EV-EVSE compatibility and, from 2014 onward, electromagnetic compatibility (EMC, both emissions and immunity) (Figure 2). The Petten location is expanding its Fuel Cell Test Facility to test EV batteries and the Smart Grid Simulation Centre to evaluate EV-grid interactions (e.g., the smart grid education tool shown in Figure 3).



Figure 2: JRC-IET Vehicle Emissions Laboratory (VeLA)



Figure 3: JRC-IET Smart Grid Education Tool

In summary, JRC-IET is addressing:

- EV-EVSE compatibility – Connectivity and functionality under all use-cases and environmental conditions, to ensure safety and code compliance.
- Smart grid simulation – Offline and real time simulation; component/system testing.
- Vehicle testing - Legislative and realistic operating conditions.

Since the signing of the LoI, JRC-IET has been updating its facilities and equipment, including:

- Build-up of new EV/HEV Laboratories:
 - Anechoic chamber (VeLA-9) – Electromagnetic emission and immunity tests.
 - Smart grid simulation – Lab with space for mounting ICT equipment in cars with smart grid simulation container.
 - Cold/warm Cell (VeLA-8) – Full exhaust gas analysis; for energy efficiency and HVAC issues in EVs.
 - HIL test system in Heavy Duty Vehicle motor test stand lab (VeLA-5) – Supports international cooperation on the development of test procedures for

hybrid HDV drive trains, which incorporates battery parameters in the hybrid simulation.

JRC-IET has been equipping its laboratories at Petten (NL) with test stands and x-ray tomography devices for batteries, enabling investigations of performance and safety validation of EV energy storage devices under typical and abusive operating conditions.

In addition, representatives of the automotive, supply, utility and battery industries have been solicited with the aid of the Transatlantic Business Council to provide their input on the role of the center.

The official launch of the European Reference Laboratory for EV/Smart Grid Interoperability is expected in the spring of 2014 when the facility modifications are completed. Until that time, joint participation in projects will be limited to planning, technology exchange and/or those utilizing its current facilities, e.g., vehicle testing or analysis/requirements of EV-smart grid integration.

3 Projects and Accomplishments

The technical staff of the interoperability center was already involved in SAE EV standards committees and the development of enabling technologies for EV-grid connectivity when the agreement between the DOE and JRC was finalized in 2011. As such, many of the activities were aligned with the objectives of the center and were the basis of the current projects (Figure 3).

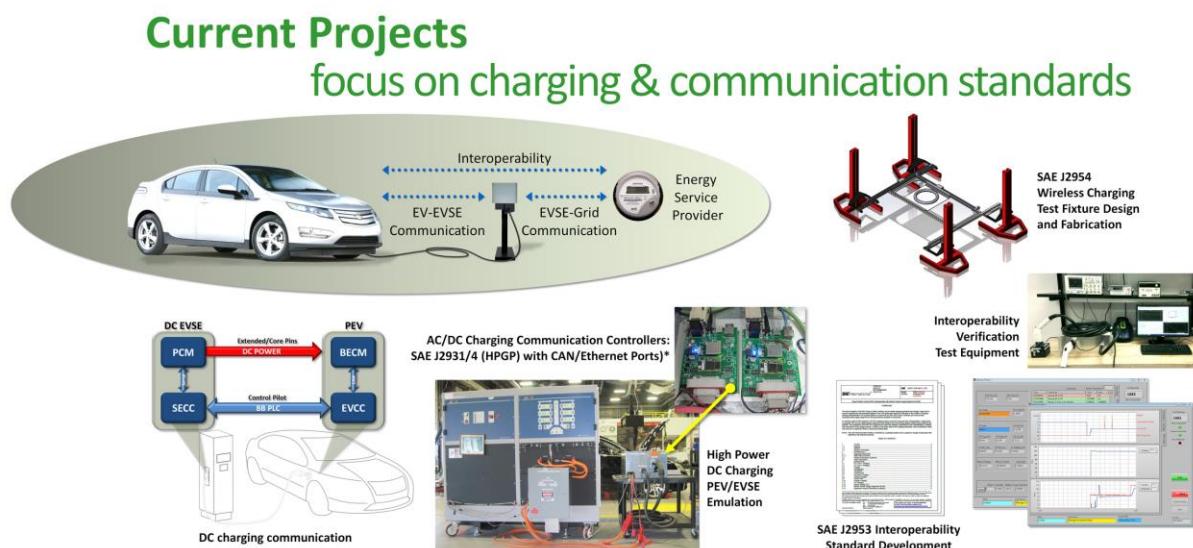


Figure 3: Projects at the Argonne EV-Smart Grid Interoperability Center

The following reflects accomplishments in 2012 and 2013 to date.

3.1 Interoperability

3.1.1 Codes and Standards

Argonne technical staff and laboratory resources are helping develop and refine EV standards to enable smart, convenient and safe interface with the grid, including the charge coupler (SAE J1772), communications (SAE J2836, J2847, J2931), interoperability (SAE J2953 chair/ISO 15118 sub-task chair) and non-conductive (“wireless”) charging (SAE J2954 chair).

SAE J1772 DC combo coupler and HPGP communication – Argonne supported UL testing of the combo coupler and bench testing of the proposed communication method together with the chip manufacturer; the data was provided to the SAE committee prior to balloting.

SAE J2953 interoperability – Prototype equipment and data analysis software were developed to monitor EV-EVSE messaging to assess compliance with the proposed standard. The next generation of this toolset will be made available to other DOE activities and, since it is intended to be applicable to the EU as well, will be jointly assessed by Argonne and JRC-IET for that purpose.

SAE J2954 non-conductive (“wireless”) charging – A prototype test fixture is being developed to support testing of wireless charging systems in accordance with the standard. The basic hardware (shown in Figure 4) will be equipped to automatically position charging system components (or an entire vehicle) at pre-determined locations and acquire a full data scan.

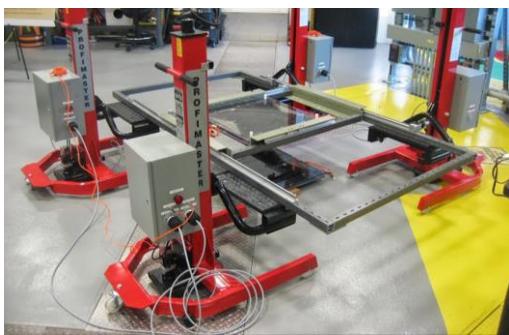


Figure 4: ‘Wireless’ Charging Test Fixture Hardware

3.1.2 Enabling Technology Development

3.1.2.1 Compact Metrology System

Argonne has developed four generations of proof-of-concept End-Use Measurement Devices

(EUMDs) to facilitate sub-metering of EV energy use, utilizing different current sensing technologies, processors and communication technologies. The current configuration is quite compact and inexpensive relative to conventional meters (Figure 5). The next version will utilize system-on-chip technology to reduce the size even further, making it possible to be packaged and installed in various locations, e.g., the vehicle, charge cord, EVSE, integrated with a typical meter or neighbourhood transformer to facilitate local grid management.

3.1.2.2 Electric Vehicle Communication Controller

Argonne has also developed a communication controller to evaluate power line communication (PLC) technologies that enable messaging between EVs, EVSE and the grid (Figure 5). The controllers are being used in AC and DC charging communication development (shown previously in Figure 3) and as the basis for developing a gateway to bridge existing utility messaging infrastructure (SEP 1.1) to SEP 2.0 [4].



Figure 5: End-Use Measurement Device (EUMD) and Electric Vehicle Communication Controller (EVCC)

3.2 Vehicle Testing

3.2.1 Electric and Hybrid Vehicle Test Procedures

JRC-IET and Argonne staff visited each other’s facilities to gain first-hand knowledge of the differences in test procedures and analytical processes employed for vehicle dynamometer testing. Argonne performs Level 1 vehicle benchmarking and Level 2 vehicle, component, and controls characterization in support of the US DOE (non-regulatory) – primarily in accordance with SAE test standards. JRC-IET defines pre-certification test procedures and performs vehicle/component characterization; it is involved in the UNECE GRPE round robin tests for definition of international test procedures. It thus supports the European Commission regulatory developments – currently with a focus on the world light-duty test procedures (WLTP) development.

3.3 Battery Testing

3.3.1 Cell, Module and Battery Test Procedures

JRC-IET and Argonne staff visited each other's facilities to understand the differences in test procedures and analytical processes employed for battery/fuel cell testing. Argonne performs cell and module testing in the Center for Electrochemical Energy Storage and integrated battery pack testing at the APRF.

JRC-IET has launched its EV component and battery testing, by equipping its laboratories at Petten (NL) with test stands and x-ray tomography devices for batteries, enabling investigations of performance and safety validation of EV energy storage devices under typical and abusive operating conditions. Collaborative activities together with Argonne will start soon, when the new battery laboratories are fully operational.

JRC-IET has contracted the build-up of a Hardware-in-the-Loop testing system in its HDV-motor test stand laboratory VELA-5 in Ispra (IT), in order to support the international work on test procedures for Hybridised Heavy Duty drive trains. It will be able to take battery parameters into the Hybridisation simulation during engine tests, which opens further opportunities for collaboration.

The capabilities and accomplishments to date of the Argonne and JRC laboratories have been compiled for public release in a brochure [5].

4 Future Plans

4.1 EV-Smart Grid Interoperability Center

The Argonne center will continue to focus on the SAE vehicle electrification standards associated with AC and DC charging communication, wireless charging and interoperability:

- Suite of DC charging coupler/communication standards (SAE J1772-v5, J2847/1-2, J2931)
- Interoperability (SAE J2953)
- Wireless Charging (SAE J2954)
- Wireless Charging Communication (SAE J2847/6)
- Charger power quality and charging systems efficiency (SAE J2894/2)

In addition, the APRF will continue vehicle (Level 1) and component (Level 2, in-vehicle with in situ sensors) benchmarking with vehicles of interest to the DOE and industry partners; the JRC will be invited to participate in the testing and analysis of selected vehicles.

Argonne will continue to participate in collaborative activities supporting the EU-US Energy Council, Transatlantic Economic Council, and the US Departments of State/Commerce represented by the US Mission to the EU. Efforts to work with individual EU Member States will continue as well; in particular with Germany due to the involvement of shared, multinational automotive manufacturers and suppliers.

Support for the US-China EV Initiative to assess the feasibility of an interoperability center in China will continue; it offers the opportunity to facilitate joint/harmonized activities in the US, Europe and Asia that could contribute to global EV-grid connectivity standards.

4.2 Integrated European EV/Smart Grid Reference Laboratory

JRC-IET will continue its technical support to:

- European standardization through participation in the CEN-CENELEC e-Mobility Coordination Group
- Resolving EV/SG interoperability issues in cooperation with EU-funded research projects and consortia
- EU initiatives such as the Clean Power for Transport Strategy COM(2013)17 and the proposed "Directive on the Deployment of Alternative Fuels Infrastructure, including Charging Infrastructure" (COM(2013)18 final)
- Cooperation with the automotive industry on grid connectivity; focusing on transatlantic interoperable/compatible DC charging.

4.3 Joint Activities

JRC-IET personnel will be briefed at Argonne on the equipment and data acquisition protocols in use; and Argonne personnel will be briefed on the component test procedures and smart grid activities at JRC-IET in Petten, The Netherlands, as well as the vehicle testing and EV-EVSE activities in Ispra, Italy.

Vehicle/component testing coordination – Argonne's APRF has been directly involved in the development of standard test procedures for electric, hybrid and plug-in hybrid vehicles. Since the equivalent fuel economy of an electric vehicle ('e-mpg' as quoted by EPA) is highly dependent on the test procedure and not as intuitive to the consumer (as compared to mpg or fuel consumption), it is critical that a consistent procedure is used globally to assess electrified vehicles. Hence, technical staff of the JRC-IET will be briefed on the HEV, PHEV and EV test procedures at Argonne and witness the testing of selected vehicles at the APRF:

- Level 2 in-depth data collection and analysis – Honda Accord PHEV (example)
- Level 1 testing of OEM fuel cell vehicle – Vehicle TBD

JRC-IET continues its participation in the development of international harmonized testing procedures at UNECE GRPE, for the testing and environmental performance of HEV, PHEV and EV, as well as participating in the UNECE GRSP Informal Group preparing the GTR on EV Safety. Regular update of the developments will be given during the status and quarterly coordination meetings.

Testing of EV, PHEV, HEV and their interplay with charging stations of different makes in the existing JRC-IET VELA facilities will continue. Test data, from both roller-bench and on-road testing, will be compared with those obtained from Argonne's APRF tests to – amongst others – quantify the impact of testing procedures on results.

Interoperability assessment coordination – The equipment being developed to assess EV-EVSE compatibility and EV-EVSE-grid interoperability is intended to be applicable to both the US and Europe. Therefore, Argonne and JRC-IET will cooperate on the adaptions/modifications and participate in testing in both locations to ensure that it is applicable to SAE and IEC standards.

Acknowledgments

The activity at Argonne is part of the U.S. Department of Energy Vehicle Technologies Office direct research expenditure for ANL.

The activity at JRC-IET is part of the European Commission's direct research expenditure for JRC, included in the EU's Seventh Framework Programme for Research (FP7).

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Authors

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Theodore Bohn is the principal investigator at the EV-Smart Grid Interoperability Center at Argonne. He is very active in PHEV-related standards committees, including chairing the SAE J2953 (interoperability) and the ISO15118-PT6 sub-committee (physical layer communication interoperability). He has over 25 years' experience with advanced technology and alternative energy fueled vehicle R&D and has worked for each of the US based automobile OEMs and many Tier I automotive suppliers.

Lee Slezak manages Vehicle Systems activities in the Vehicle Technologies Office of the US DOE, overseeing Transportation Electrification Recovery Act Funding of \$400M. Lee is also responsible for modeling and simulation, lab and field testing of advanced components and vehicles, vehicle systems optimization research, and EV standards activities, including the Interoperability Center at Argonne. Lee has been with DOE for more than 18 years.



Alois Krasenbrink is the Head of the Sustainable Transport Unit at the JRC - Institute for Energy and Transport in Ispra, Italy. His unit operates the Vehicle and Engine Emission Laboratories (VELA), providing scientific support to European Commission transport



polices; the unit is expanding to include EV testing and EV-grid interoperability. Alois studied Geophysics and received his Ph.D. from the University of Hanover, Germany, for his work on particle emissions from diesel vehicles. He joined JRC in 2002 as permanent staff.

Harald Scholz is a Senior Scientist in the Sustainable Transport Unit at the JRC-Institute for Energy and Transport in Ispra, Italy. Since 2011 he has coordinated the development of the electromobility laboratories and is a member of the Electromobility



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