PNNL-20913

U.S. DEPARTMENT OF ENERGY

Prepared for the U. S. Department of Energy
under Contract DE-AC05-76RL01830

Electric Vehicle Communication Standards Testing and Validation – Phase I: SAE J2847/1

R Pratt
F Tuffner
K Gowri

September 2011

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062; ph: (865) 576-8401 fax: (865) 576-5728 email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847 fax: (703) 605-6900
email: orders@ntis.fedworld.gov online ordering: http://www.ntis.gov/ordering.htm

This document was printed on recycled paper.
(9/2003

PNNL-20913

Electric Vehicle Communication Standards Testing and Validation – Phase I: SAE J2847/1

R Pratt
F Tuffner
K Gowri

September 2011

Prepared for
the U. S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

Vehicle to grid communication standards are critical to the charge management and interoperability among vehicles, charging stations and utility providers. Several standards initiatives by the Society of Automobile Engineers (SAE), International Standards Organization and International Electrotechnical Commission (ISO/IEC), and ZigBee / HomePlug Alliance are developing requirements for communication messages and protocols. While the standard development is in progress for more than two years, no definitive communication design guidelines are available for the automobile manufacturers, charging station manufacturers and utility backhaul network systems. At present, there is a wide range of proprietary communication options developed and supported in the industry. Recent work by the Electric Power Research Institute (EPRI) in collaboration with SAE and automobile manufacturers has identified performance requirements and a test plan based on possible communication pathways using power line communication over the control pilot and mains of the standard J1772 connector. The EPRI test plan facilitates the communication pathway and PLC technology selection. System level communication testing between EV and EVSE is needed to evaluate the field performance.

PNNL developed a system level test plan to include test cases, validation criteria, and certification requirements to verify reliability, robustness, repeatability, maximum communication distance, authentication, and security features of communication modules at the application layer level. The communications signals were subjected to varying conditions on the power line, similar to those expected in an actual vehicle battery charging application. These conditions included using a representative commercial vehicle battery charger (A123 / Hymotion L5), a commercial charging station (Coulomb Technologies CT2100) with J1772 connector and cable, changing the length of 240VAC cable for power line communications, charging at different charge rates, and observing the immunity of the communications to in-band signal sources.

For initial testing, two power line communication technologies from Echelon and Maxim were used based on availability of hardware and development support. Both the Echelon PL3170 and the MAX2990 Power Line Carrier modules provided reliable communications between the EVSE and PEV Charger using the AC mains.

Key findings:

1) Application layer data rate measurements represent actual system data throughput between EVSE and EV. The application layer testing measured lower data rates than indicated by vendors.

2) Testing showed both PLC technologies were unaffected by variable and constant charging rates, charging cable lengths, and voltage sources (Level 1 or Level 2).

3) The MAX 2990 Power Line Carrier module data rate ranges between 3.5 kbps and 4.8 kbps to demonstrate robust communication performance during noise injection testing.

4) The Echelon PL3170 data rate is 1.9 kbps and demonstrated robust communication performance.

5) Only a limited number of SAE J2847/1 messages need to be communicated between the PEV and EVSE during the highest data rate period.

DOE investment during FY2011 resulted in a communication test facility at PNNL that meets SAE's current and future communication testing and validation needs. The test plan developed provides all the required components for interoperability testing of communication over the mains. Further development is underway to test communications over control pilot and DC charging in collaboration with SAE and EPRI.

Acronyms

ANL	Argonne National Laboratory
BER	bit error rate
EPRI	Electric Power Research Institute
EMC	Electro Magnetic Compatibility
GITT	Grid Interaction Tech Team
HMI	Human Machine Interface
PNNL	Pacific Northwest National Laboratory
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicles
PLC	power line communication
SAE	Society of Automotive Engineers
TOU	Time-Of-Use
V2G	vehicle to utility grid

Acknowledgement

The authors wish to thank Mr. Vijay Dhingra, Rob Guzikowski and Michael Morrison of Echelon and Jim LeClare, Konrad Scheuer and Kaveh Razazian of Maxim for providing the evaluation kits and assistance during communication module development and testing.

The authors would also like to thank Mr. Lee Slezak of the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Program and Mr. Dan Ton of the DOE, Office of Electricity Delivery and Energy Reliability for funding this work.

Contents

Figures

1.0 Introduction

The SAE Hybrid Committee is developing Standards J2836/1[1] and J2847/1[2] for enabling electric vehicle to utility grid (V2G) communication. These standards include specifications for V2G communication data and messages to support charging based on time-of-use, demand response, real-time pricing, critical peak pricing and optimized energy transfer. The SAE J2931 Task Force is also evaluating available communication protocols and technologies, and is expected to make a recommendation on PLC selection criteria to enable communication between the vehicle and electric vehicle supply equipment (EVSE). Automobile manufacturers and EVSE manufacturers will soon begin the development of communication modules and expressed the need for testing and validation of the standards during the Nov/Dec 2009 Grid Interaction Tech Team (GITT) meetings. DOE challenged the GITT team to address barriers and pinch points that might impede the commercialization and broad market acceptance of PHEVs/EVs with particular focus on the "fuel" supply. Stakeholders from the automobile industry, electric utilities, and communication technology vendors and researchers meet on a regular basis to address any technical and standards issues. The outcome of this task will be to initiate the discussion about test protocols that can be used to verify that the communication modules present in the vehicle and EVSE meet the requirements of J2836/1 for Use Cases U1-U5.

PNNL worked with ANL and the GITT participants to develop a communication standard verification and interoperability testing project. As part of this effort, two power line communication (PLC) technologies were identified for developing prototype modules to test the J2847/1 messages. A V2G Communication Functional Test Bed was assembled and an HMI prototype was developed to demonstrate and test J2836/1 Use Cases.

The Communications Testing evaluated three SAE Standards working together in an operational scenario. These SAE Standards were:

- **SAE Recommended Practice J2836/1** – Use Cases for Communication between Plug-In Vehicles and the Utility Grid - provides a set of communication requirements for use with various load management and rate programs established by utility companies related to the charging of plug-in electric vehicles.

- **SAE Recommended Practice J2847/1** – Communication between plug-in vehicles and utility grid - establishes requirements and specifications for communication messages between plug-in electric vehicles and the electric power grid, for energy transfer and other related applications.

- **SAE Surface Vehicle Recommended Practice J1772[3] -** Electric Vehicle Conductive Charge Coupler - covers the general physical, electrical, communication protocol, and performance requirements for the electric vehicle conductive charge system and coupler. This standard specifies a common electric vehicle conductive charging system architecture including operational requirements and the functional and dimensional requirements for the vehicle inlet and mating connector (as shown in Figure 1).

[1] SAE2836-1. Use Cases for Communication between Plug-in Vehicles and the Utility Grid. (Surface Vehicle Recommended Practice). SAE International, Warrendale, PA.
[2] SAE J2847-1. Communication between Plug-in Vehicles and the Utility Grid. (Surface Vehicle Recommended Practice). SAE International, Warrendale, PA.
[3] SAE J1772 SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler. (Surface Vehicle Recommended Practice). SAE International, Warrendale, PA.

Figure 1. Yazaki SAE J1772 Connector.

The J2836/1 and J2847/1 communication standards are designed to allow the development of utility programs to enable consumers to charge their vehicles at the lowest cost during off-peak hours, and help the utilities reduce grid impacts by minimizing electric vehicle charging during peak periods. The SAE J2836/1 document establishes Use Cases for communication between plug-in electric vehicles and the electric power grid, for energy transfer and other applications. The SAE J2847/1 document establishes requirements and specification for communication between plug-in electric vehicles and the electric power grid, for energy transfer and other applications. Where relevant, this document notes, but does not formally specify, interactions between the vehicle and vehicle operator. A test protocol was developed to be compliant to the requirements and specifications of V2G communication requirements of J2931 for Use Cases U1-U5.

2.0 Scope and Objective

In January 2010, SAE conducted a competition among PLC communication hardware manufacturers to evaluate and select a technology that vehicle manufacturers could use to develop communication modules. Though the Electro Magnetic Compatibility (EMC) requirements were readily available to test the PLC technologies, there were no standard methods to test the application layer level communication of J2847/1 messages. Five PLC technologies (HomePlug, G.hn, GreenPHY, G3 and Echelon) passed the EMC testing, but no further evaluation could be undertaken without significant development work. SAE task force originally decided not to consider the low frequency, narrow band technologies because of the potentially lower data rate. However, the technology vendors expressed a concern that the data rate will be adequate and that the reliability will be higher. In discussion with the GITT, ANL and other interested partners, PNNL proposed the development of communication module prototypes to implement the J2847/1 messages for testing the low-frequency, narrowband technologies, with the following objectives:

1. Identify SAE J2836/1 Use Case(s) or portion of a Use Case that would be representative of the most critical portion of the charging communication process.
2. Use SAE J1772 compliant electrical connections, cables, and control signals for the testing.
3. Identify SAE J2847/1 messages to test PLC communication modules.
4. Develop a Human Machine Interface (HMI) to implement and test J2847/1 messages.
5. Build a functional test bed for PLC communications testing including battery charger, Level 2 EVSE, and PLC modules.
6. Test two PLC communication module preselected by SAE

The test plan, HMI software and laboratory infrastructure have been developed with the objective of testing currently available low frequency, narrowband PLC technologies. The hardware and test procedures are adaptable for future testing of other PLC technologies, communication options and related standards.

3.0 Use Case Summary

SAE J2836/1 Use Cases are based on the four functional requirements for consumer to charge, discharge, diagnose and exchange information with the vehicle, as identified by PR1, 2, 3 and 4 in the Use Case summary diagram shown in Figure 2. For each of these functions, there are four distinct steps, each with one or more options as described below:

1. **Enrollment:** This enables the utility to provide services to a specific plug-in electric vehicle (PEV) customer. These services include the ability to enroll, register, and initially setup the utility programs (one-time setup) and the customer provides the utility with customer account and PEV ID information.
2. **Utility Programs:** These are designed to entice PEV customers to consume energy during time of lower grid load. The programs include: U1: Time-Of-Use (TOU), U2: Direct Load Control (Demand Response), U3: Real Time Pricing, U4: Critical Peak Pricing, and U5: Optimized Energy Transfer (Regulation Services, etc.).
3. **Binding/Rebinding:** The PEV Connection and Energy Transfer has three methods for the customer to connect the PEV to the utility. S1: Cordset EVSE (120VAC), S2: Premise EVSE (240VAC), S3: Premise EVSE (DC).
4. **Connection Location:** The location alternatives for the customer to connect the PEV to the utility are L1: Home: connects at premise; L2: Another's home inside the utility's service territory and A: premise pays tariff or B: customer pays tariff; L3: Another's home outside the utility's service territory; L4: Public: curbside, workplace, business, multi family dwelling.

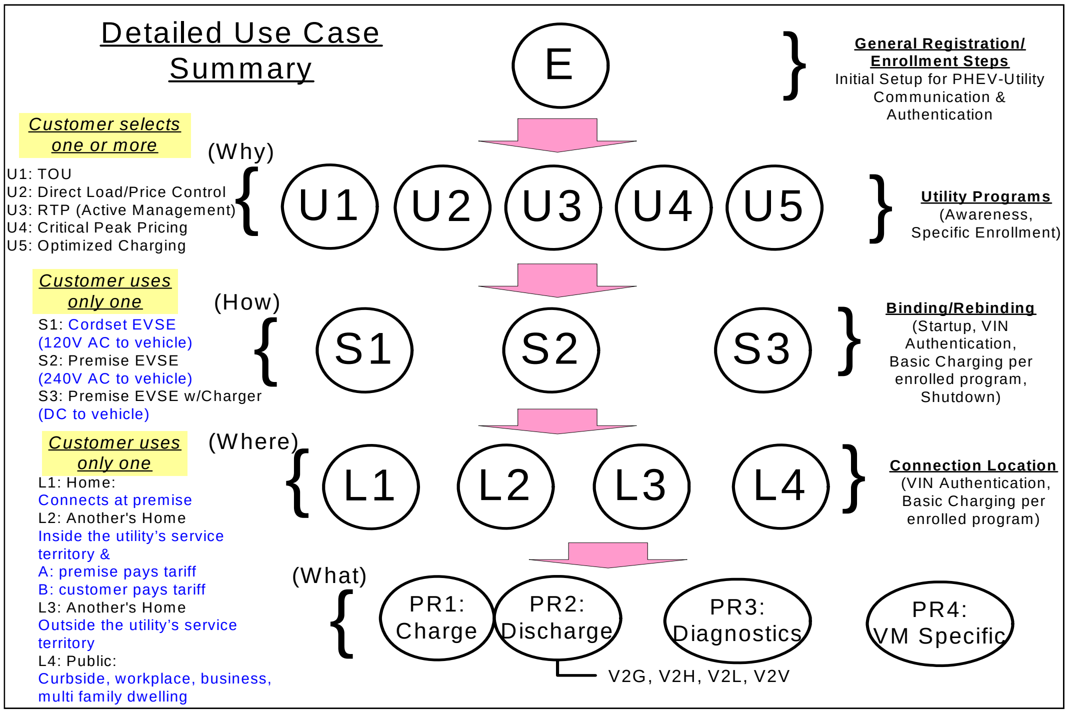


Figure 2. SAE J2836 Use Case Summary.

The SAE J2847/1 communications typically occur when the PEV is connected to the EVSE, prior to the start of the charging process. The communications necessary to support the Use Case throughout the energy transfer can be inferred in the sequence diagram shown in Figure 3 by counting all the dashed red arrows that connect on the PEV vertical line. During the Startup phase, the PEV ID must be sent. During the Charging Cycle, the customer settable preferences are sent (see Figure 2), the Energy Request, and the Energy Schedule, and Energy Delivered are communicated. Finally at Charge Complete, the Energy Consumed and Cost are communicated.

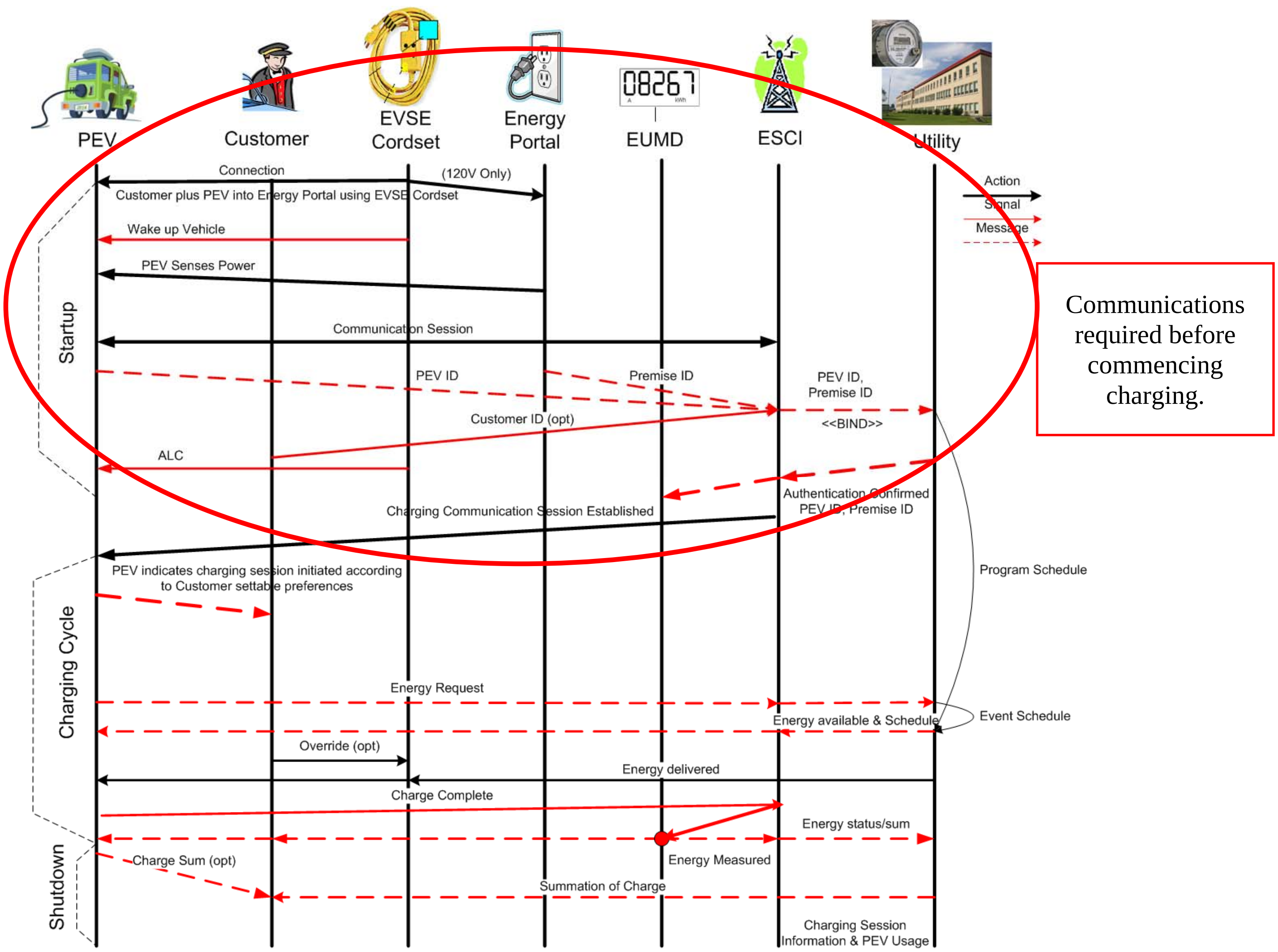


Figure 3. SAE J2836/1 Sequence Diagram.

From a customer perspective, the time from connecting until charging starts is critical. This would be the time when a customer needs to wait for association and authentication before charging starts. The red circle on Figure 3 encloses SAE J2836/1 Use Case communications necessary prior to commencing charging. But this is also the period when the most messages are sent. Therefore, the following three criteria are identified as critical for vehicle to grid communication:

1. Speed – a calculated value using the payload bits as the numerator and the latency as the denominator. Latency is the time from when a message was sent until received by the target. The

payload does not include encryption, error correction, or other overhead information communicated. The units for speed is kilobits / second (kbps).

2. Accuracy – the number of message bits in error. This is also known as bit error rate (BER).
3. Test conditions that would mimic operational conditions.

The SAE J2836/1 Use Case scenarios are categorized in three subsets: Startup, Charge Cycle, and Shutdown. When implementing the J2847/1 messages, it became apparent that more efficient software could be developed by using the nine-state state machine shown in Figure 4. This state machine represents the Use Cases described in SAE J2836/1 and implements SAE J2847/1 messages between the EVSE and the PEV.

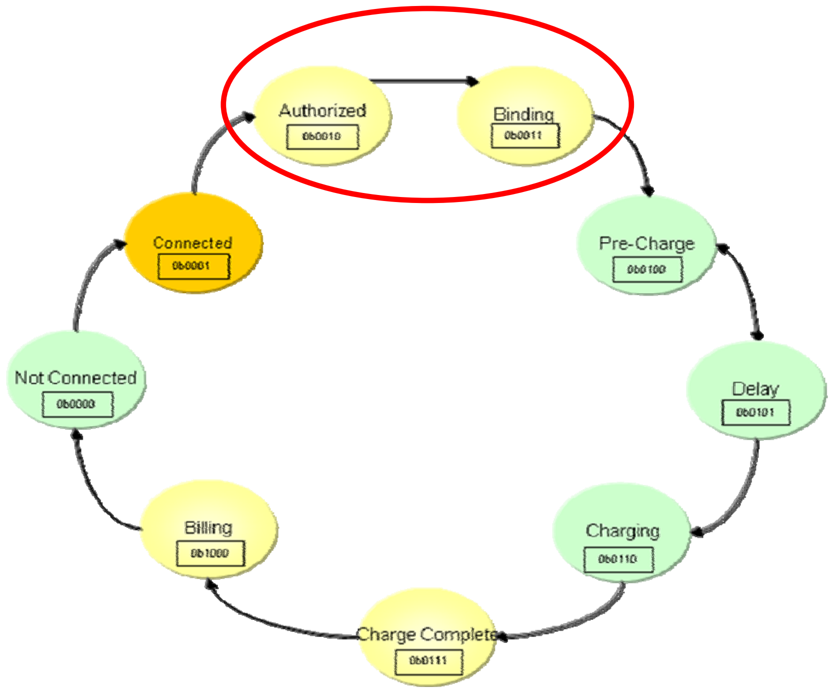


Figure 4. SAE J2847/1 Message Cycle.

An observation of the SAE J2836/1 Use Case scenarios is that the majority of messages communicated occur between the Authorized and Binding states shown within the red circle in Figure 4. A detailed list of messages and sequence implemented for testing each state is described in Appendix A. A mapping of SAE J2847/1 messages to the corresponding SEP2.0 messages and additional messages for smart charging that PNNL integrated in the testing are listed in Appendix G.

4.0 Human Machine Interface Prototype

A simple human machine interface (HMI) has been developed to obtain user input for charging preferences, and to display charging status, battery status, and any other utility communication information. Though the screen layout and interaction widgets in the HMI can be implemented in a variety of different ways, the basic input and display items necessary for standards testing are included in this prototype. All of the HMI display items are related to J2847/1 messages and can be either mapped directly or indirectly. The following are data items and their function as implemented in the prototype HMI:

Authentication Status	An indicator that shows whether or not the vehicle was identified and authenticated with the utility network.
Battery Capacity	The maximum amount of electricity that can be stored in the battery.
Battery State of Charge	The current amount of electricity stored in the battery. It is usually displayed as a percentage of the maximum battery capacity.
Charge By Time	The time by which the vehicle owner desires that the vehicle be charged.
Connection status	An indicator that shows whether or not the vehicle is connected to the utility AMI network or to the Utility back office.
Current Charge Rate	The rate at which the vehicle is currently drawing power.
Current Price of Electricity	The current price of electricity as given by the utility.
Demand Response Active	An indicator that displays when the vehicle is responding to a demand response request from the utility.
Demand Response Override	This is both an indicator and an input item. As an input item, it allows the vehicle owner to override the vehicles automated response to a demand response signal from the utility. As an indicator, it displays when the vehicle owner has selected to override that signal.
Estimated current cost of charge	The estimated cost of the current charge session based off the rate of power draw, and the current price of electricity.
Rate Plan	The plan for which the vehicle owner has subscribed. This should indicate any demand response programs, and rate incentives that the owner and utility have agreed upon.
Pricing Schedule	The price of electricity over a 24 hour period of time, allowing the vehicle and owner to make decisions on when the vehicle will charge.
Pricing Override	An indicator showing that the vehicle owner has chosen override the price based charging to begin charging immediately.

The primary method for user interaction with the vehicle charger is typically through a touch screen interface in the vehicle or the charging station. Due to the limited screen size, the information and interactions presented to the user is broken up into several tabbed screens.

The main HMI screen (Figure 5) provides information to the user on the status of their electric vehicle, and will display several basic elements to the user, display some additional items during vehicle charging, and may contain some user configurable optional information. Upon activation of the screen, the user will be presented with a visual representation of the battery state of charge. Once the vehicle is plugged in, and the handshaking with the utility has been accomplished, the connection, handshaking and authentication icons in the middle of the display will be enabled indicating that the process was successful. This handshaking mechanism will be accomplished via J2847 complaint messages that will authenticate the vehicle with the utility, and transmit the rate table from the utility back to the vehicle. The screen will display the time by which the vehicle will be charged and the current system state, the current price of electricity, and the cost of the current charge session (based on the previously mentioned data).

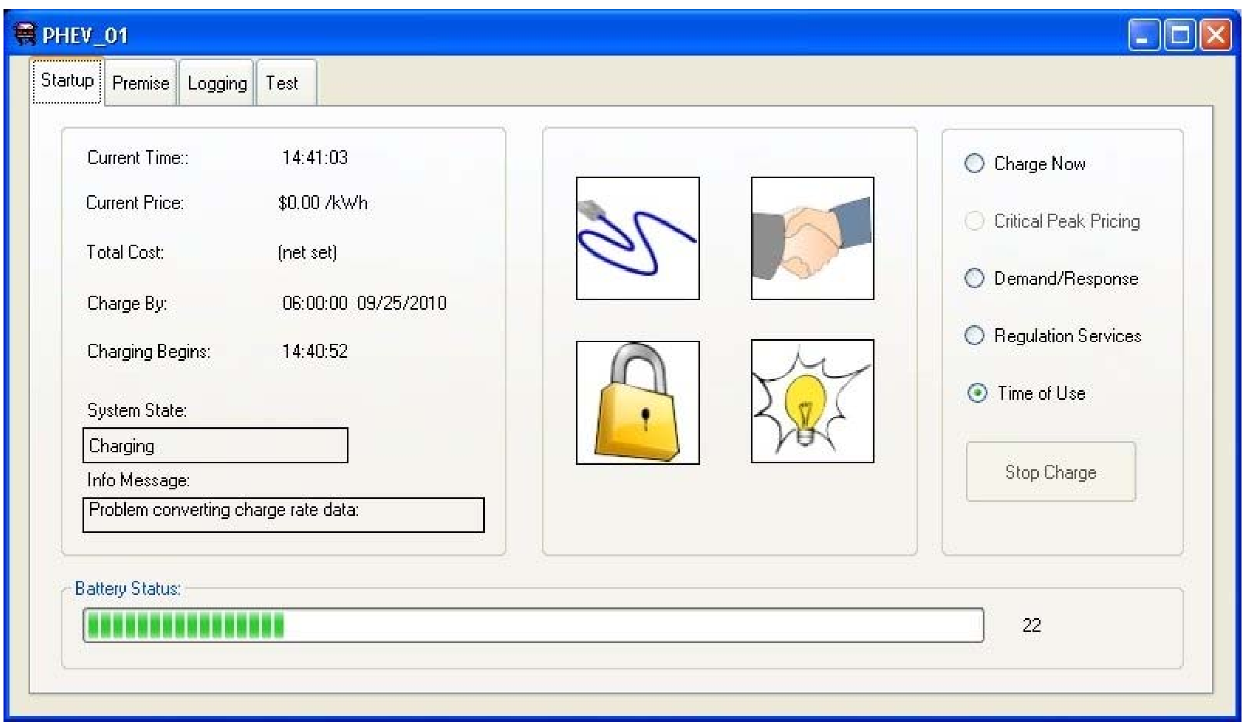


Figure 5. Sample HMI Screen.

When the vehicle is plugged in and the handshaking with the utility is completed, the vehicle will immediately begin a charge session using the optimal charge scenario based on the TOU rate schedule and the "charge by" time set in the preferences screen. The user will also have the option to override the scheduled charge and begin charging immediately. The user also has the option to temporarily override the selected rate plan (for example, temporarily opt out of demand response programs).

In addition to the main screen shown in the "Startup" tab, the user can also see additional information in the "Test" tab which is currently used to modify the test parameters. This tab provides information about the selected rate plan, such as the current and future price of electricity, the optional programs they may have enrolled in (Demand Response, etc…), and some statistical information on how often such signals have been received and responded to. Another purpose is to give the user control over the charge process and what is displayed.

5.0 Functional Test Bed

The V2G Communication Functional Test Bed consisted of A123 Systems' Hymotion L5 Plug-In Conversion Module, Coulomb Technologies' CT2100 (Level I and II) Charging Station, an HMI connected between the charger and the charging station, SAE J1772 Control Pilot and Proximity circuitry, and PLC communications modules. Primary considerations in selecting hardware in June 2010 were commercially available and UL certification. PNNL controlled the battery charge rate by sending CAN-bus commands to the Hymotion L5 charger. A system-level block diagram of the Functional Test Bed used to develop and test the SAE J2847 messages is shown in Figure 6.

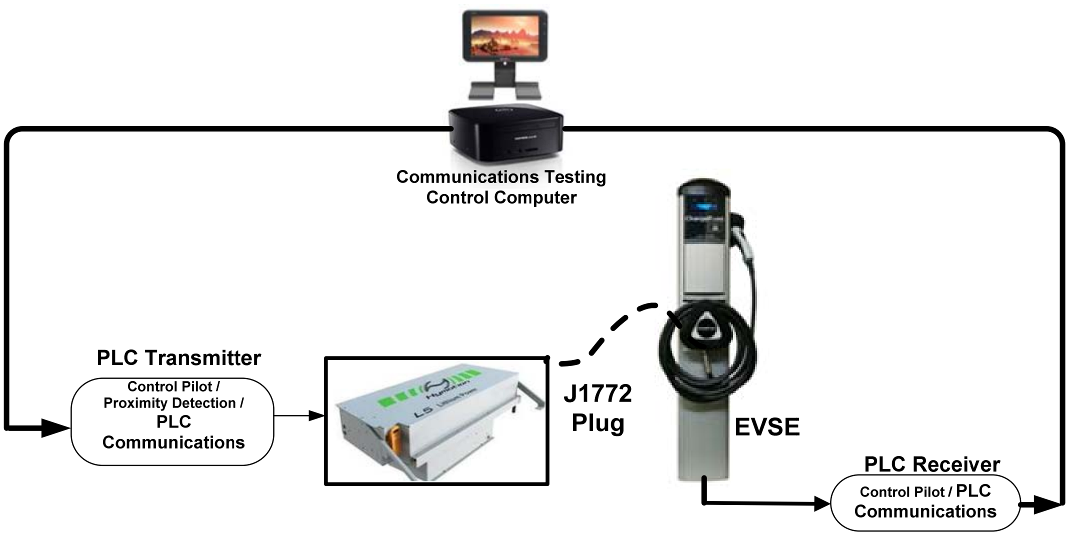


Figure 6. Functional Test Bed Components.

In order to implement and test the Use Cases in J2836/1, a hardware interface between the PEV and EVSE is needed to comply with the J1772 requirements. The Hymotion L5 Charger used for the testing was not supplied with the components located within the red circle on Figure 7 (D, R2, R3, and S2). These were implemented separately using component values contained in SAE J1772 Tables 4, 5, and 7.

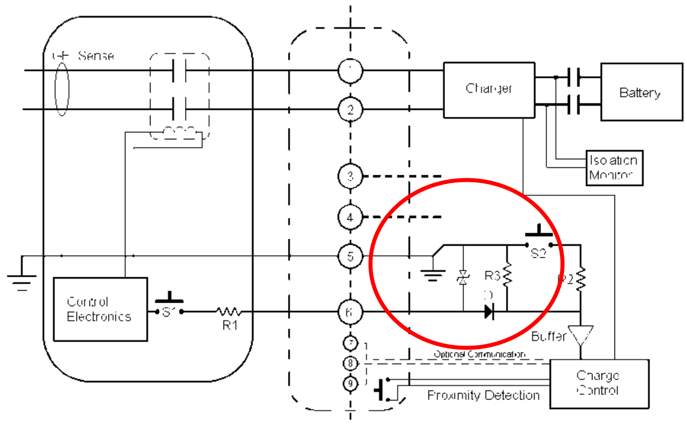


Figure 7. J1772 Schematic.

PNNL contacted two narrow band technology providers (Echelon[4] and Maxim[5]) to obtain evaluation kits to develop communication modules. Echelon provided PL 3170 transceivers and provided the development environment to implement the J2847/1 messages as network variables to test the communication characteristics. The PLC transceivers provide the physical layer communication protocols and these are developed by Echelon. Maxim provided G3 Lite MAX2990 evaluation kit which is integrated with the application layer microprocessor for testing.

---

[4] PL3120 / PL3150 Smart Transceiver Data Book. Echelon Corporation, San Jose, CA.
[5] MAX2990 Integrated PowerLine Digital Transceiver Evaluation Kit Operation Manual. Maxim Integrated Products, Sunnyvale, CA.

6.0 Test Plan

A test plan was developed to include test cases, validation criteria, and certification requirements to verify reliability, robustness, repeatability, maximum communication distance, authentication, and security features of V2G communication modules at the application layer level. The highest communication data rate necessary to implement SAE J2836/1 and J2847/1 V2G communications takes place when the vehicle connects to the charging station. Upon connection, the PEV ID, customer preferences, Energy Request, and Energy Schedule are communicated. Additional information such as rate schedule could also be communicated depending on the Use Case. Since the longest message (PEV ID) might be up to 20 characters and the shortest message could be five characters, the communication speed testing was done with these two message lengths.

6.1 Test Cases

The test cases were built upon experience gained developing SAE J2836/1 compatible communications architecture (Figure 8). This experience enabled the test team to select a subset of the required communications that would best allow reliability, robustness, repeatability, maximum communication distance to be quantitatively tested. The test cases selected were:

- Test Case 1: This test case verified PLC transceiver compatibility with the testing infrastructure and make configuration changes for each vendor's product. Transmit and receive PLC modules were plugged into the same 120VAC receptacle for this test case.
- Test Case 2: Evaluate operation on 240 VAC lines with the charger disconnected and operating at 0% charge rate (idle); 50% charge rate, 75% charge rate, 100% charge rate, and a variable charge rate.
- Test Case 3: Measure the effect of charging cable length on PLC communications performance.
- Test Case 4: Evaluate the effect of interfering signals on PLC communications performance.
- Test Case 5: Tests that highlight the strengths of particular PLC technology.

6.2 Communications Testing Approach

The testing approach focused on testing the reliability, robustness, repeatability, and maximum communication distance of the PLC equipment. In addition, the tests needed to be identical for the products tested. The method used to measure this time period was to transmit a message from a testing control computer to the power line carrier transmitter module, allow the PLC interface to communicate from its transmitter module to its receiver module, and wait until the same message is received by the control computer from the PLC "receiver" module. These messages were compared for accuracy and reliability. Measurements of these characteristics are collected under the terms latency (the delay term), data rate (bits/second), and error rate (error bits/transmitted bits x 10^6). The communications testing was controlled by the control computer shown in the V2G Test Bed, Figure 8.

The PLC connection to the mains was made between Line 1 and Line 2 for 220V configurations and between Line and Neutral for 120VAC configurations. Local restrictions may apply to the use of line-to-earth coupling. In general, line-to-earth coupling is only used in commercial applications in North America and non-EU countries where the associated 50/60Hz leakage current is allowed.

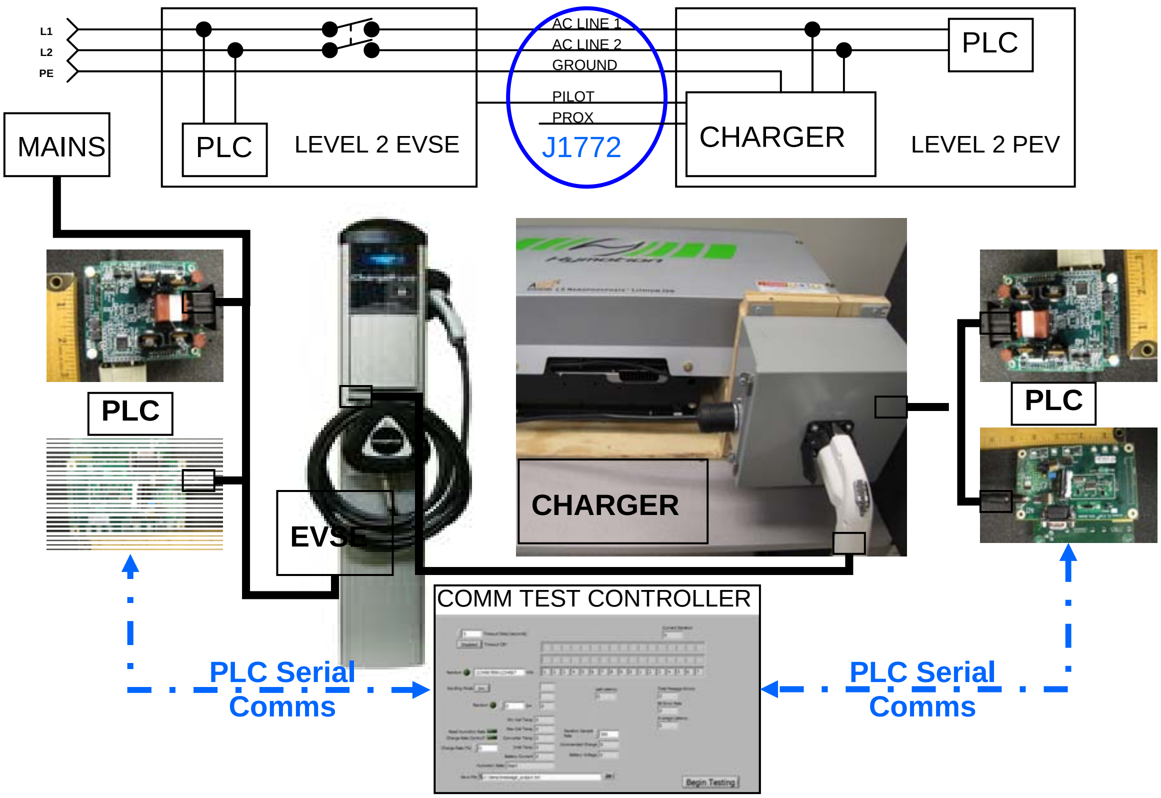


Figure 8. Functional Test Bed Architecture.

6.3 Communications Testing Overview

The communications signals were subjected to varying conditions on the power line, similar to those expected in an actual vehicle battery charging application. These conditions included using a representative commercial vehicle battery charger (A123/Hymotion L5), a commercial charging station (Coulomb Technologies CT2100) with J1772 connector and cable, changing the length of 240VAC cable for PLC communications, charging at different charge rates, and observing the immunity of the communications to in-band signal sources.

Data transmission rates and error rates for sample messages were obtained by repeated testing as described below:

1. A serial host was created to both send and receive serial data through the interface boards. The serial host utilized was based around a National Instruments PXI system, which off-loaded the testing to a dedicated device to reduce external influences on the timing. The dedicated serial host also enabled precision timing of the message latency to be observed.

2. The PXI system sent a command to one PLC device as if it were a selection a GUI, or other input panel. The system then waited to read a corresponding result from the receiving end, which could typically go into another GUI or input panel as a display item.
3. Testing began by sending the desired message to the sending device. As soon as the message successfully left the host serial buffer, a millisecond time is performed. This millisecond timer continues to increment until one of two things occurs. Either a message is received up to a carriage return character, or a pre-determined time out expires. If a time out condition occurs, the entire data pack is just flagged as an error. The system then clears the buffers and waits for the next message transmission. During this process, the average latency is continually updated, along with a rough estimate of the bit-error-rate (as estimated by mismatches in the VIN sent and the VIN received).

6.4 Communications Testing Configuration

1. Both the MAXIM2990 and Echelon PL3170 PLC modules were configured to act as a serial modems to the Control Computer.

- MAXIM 2990 – The testing team used the MAXIM 2990 configuration utility to set its mode for an RS-232 UART – 115,200 / 8/ N / 1 and setting a communications timeout delay to 4 milliseconds. The MAX2990 default state waits until a 4Kbyte buffer is full before it transmits.
- Echelon PL3170 – The Echelon engineers and the testing team developed an ARM7 application that controlled the PL3170 and allowed it to act as a serial modem. It also operated as a UART – 115,200 / 8 / N / 1.

2. Message Length – the 20-byte and 5-byte message lengths were necessary to support implementation of a measureable protocol common to both MAXIM and Echelon PLC communication methods. A 20-byte message corresponds to the Vehicle Identification Number (VIN). The 5-byte message corresponds to an Echelon message to turn ON / OFF a device and set the degree to which it is ON.
3. Latency – the time delay between when a message was sent to the transmitting PLC unit and the time in which the message was received by the receiving PC (Figure 9). The latency time recorded was corrected by subtracting the loopback packet transmission time of the non-PLC portion of the system.
4. Effective Data Rate – message length (in bits) divided by the latency.

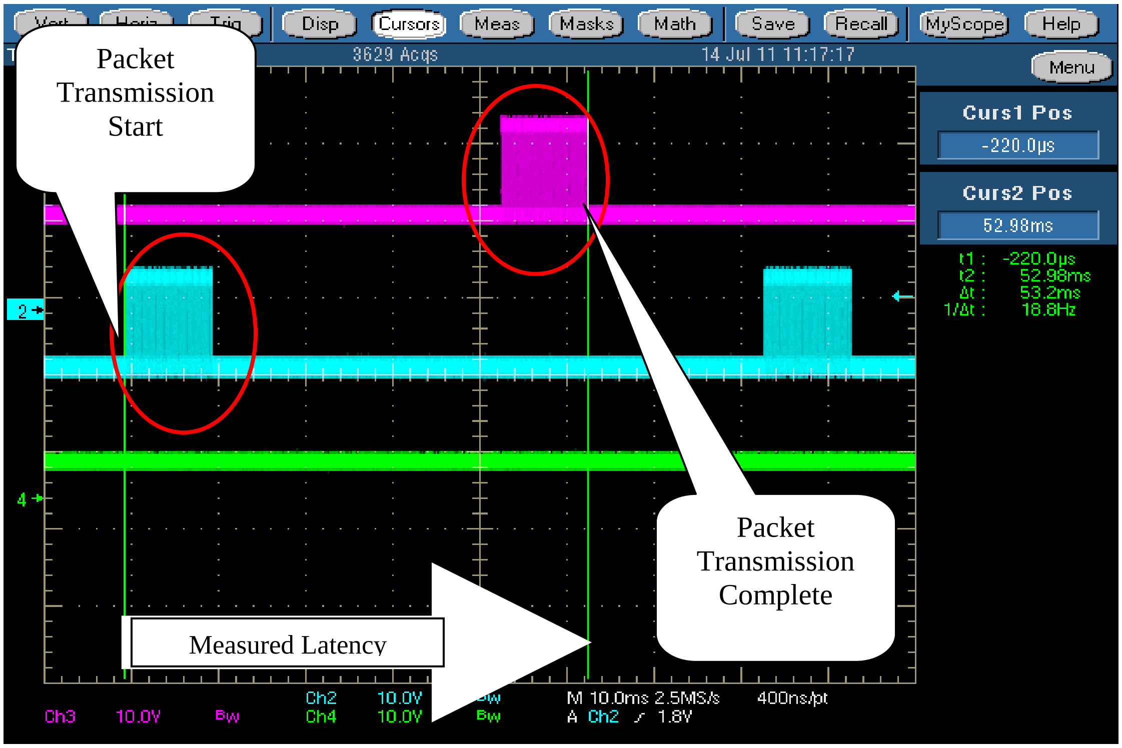


Figure 9. Latency Measurement.

6.5 Communications Testing Process

The following process was used during each communications test.

1. Discharge the Hymotion L5 battery using the 4.2kW Aurora Inverter to the grid as needed.
2. Plug the SAE J1772 plug into the charger's SAE J1772 receptacle.
3. Electrically connect the PLC modules to the AC lines supplying the EVSE or charger. The cable connecting to the PLC modules must have an IEC320-C7 plug rated for 240VAC. These electrical connections were made in two of three places:

- A custom box where the J1772 plug connected to the charger;
- Inside the Coulomb CT2100 Charging Station where the 240VAC supply connections were made to the charging station.
- In a distribution panel that supplied the Coulomb CT2100 Charging Station. A 30-foot power cable connected the charging station to the distribution panel.

4. Energize the distribution panel from the 208VAC, 3-phase building supply.
5. Power up the communications control computer (National Instruments) and start the custom application built for communications testing.
6. Connect the serial cables to the communications control computer and within the communications testing application, verify PLC communications.

- For the MAX2990 modules, hardware handshaking was required. In addition, the MAX2990 Control Panel was verified to be correctly configured: 150kHz – 490kHz FCC mode, 4 millisecond timeout, and NORMAL or ROBO mode selected.
- The Echelon PL3170 modules required no handshaking and were operated in a mode compliant with the FCC PLC communications regulations.

7. The Communications Control Computer Interface, shown in Figure 10, has options to send either 20-byte random messages or 5-byte random messages, count messages sent, count messages with errors, measure latency, and record message data to allow determination of bit error rate.
8. Data collection times varied based on the purpose of the test, but tests reporting bit error rates were performed to report measured error rates with accuracies below 1 x 10^{-6}.

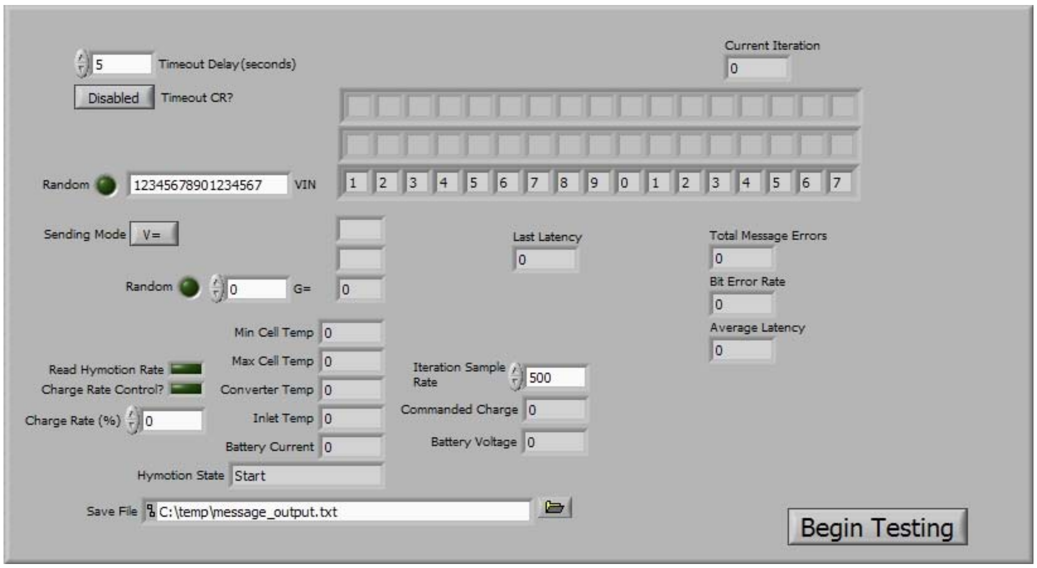


Figure 10. Communications Control Computer Interface.

7.0 PLC Prototype Testing Results

7.1 Echelon PL3170 Test Results:

1. 3.3 million messages transmitted and received with 58 errors (17.5×10^{-6} BER) and no system lockups. 322 thousand messages were communicated while charging.
2. 130 millisecond latency (135 milliseconds – 5 millisecond loopback time).
3. 1.91K bps effective data rate (20-byte basic message + 11 bytes other payload)
4. Communication error rates and latency were unaffected while using a 30 foot A.C. cable in addition to the 17 foot J1772 cable.
5. Echelon PL3170 test data is presented in Appendix E and typical oscilloscope signals are presented in Appendix F.
6. Noise injection:

- The Echelon communication signal was displayed on a spectrum analyzer line through an Echelon Power Line Coupling Circuit, Model 78200R. This coupling circuit was measured to insert no attenuation from 50kHz to 500kHz.
- An externally generated, equal amplitude FSK signal was added to the power line. The Agilent function generator output was set to 130kHz and 3.2 volts. The FSK controls were set to 20kHz FSK offset and 50kHz FSK rate.
- No errors observed. However, when the externally generated signal was within ~2dB of the Echelon power line signal, the latency would increase up to ~930 milliseconds and the secondary channel signal was visible on the spectrum analyzer.

7.2 MAXIM 2990 Test Results:

1. 25.1 million messages transmitted and received without any errors. 2.8 million messages communicated while charging.
2. Normal Mode Latency - 40 millisecond latency (42 milliseconds – 5 millisecond loopback time) for a 20-byte message.
3. ROBO Mode Latency - 50 millisecond latency (52 milliseconds – 2 millisecond loopback time) for a 20-byte message.
4. MAX 2990 test data is presented in Appendix B.
5. The MAXIM2990 effective data rate is a function of the message length and mode (NORMAL or ROBO) while using a 20 millisecond time out delay. The time out delay is a period of RS-232 inactivity.

- Normal Mode – 20 byte message effective data rate – 4.5 kbits/sec
- Normal Mode – 251 byte message effective data rate – 33.4 kbits/sec
- ROBO Mode – 20 byte message effective data rate – 3.6 kbits/sec

- ROBO Mode – 251 byte message effective data rate – 4.8 kbits/sec
- ROBO mode uses a 9-byte packet payload with ~15 milliseconds between 9-byte payload packets. The MAX2990 uses the RS-232 CTS line to delay payloads more than 9-bytes in ROBO mode.
- Normal mode uses a ~140-byte packet payload with ~20 milliseconds between 140-byte payload packets. The MAX2990 uses the RS-232 CTS line to delay payloads more than 140-bytes in Normal mode.

6. Communication error rates and latency were unaffected while using a 30 foot A.C. cable in addition to the 17 foot J1772 cable.
7. ROBO mode (high reliability mode) was not needed while no other transmitters were on the power line.
8. Noise injection:

- The MAXIM communication signal was displayed on a spectrum analyzer line through an Echelon Power Line Coupling Circuit, Model 78200R. This coupling circuit was measured to insert no attenuation from 50kHz to 500kHz.
- The same externally generated, FSK signal used for the Echelon PL3170 noise immunity testing was added to the power line. The Agilent function generator output was set to 130 kHz and 3.2 volts. The FSK controls were set to 20kHz FSK offset and 50 kHz FSK rate. The bit error rate on 882 messages was 136,054 x10-6. Roughly only 7 out of 8 messages successfully were received in NORMAL mode (Footnote 14 in Appendix B). In ROBO mode, the bit error rate returned to 0.
- When the function generator output was reduced to 2.4 volts (-3dB), the bit error rate returned to zero in NORMAL mode (Footnote 15 – Appendix C).
- When the function generator output was increased to 4 volts (+3dB), the bit error rate remained at zero in ROBO mode (Footnote 16 – Appendix D).

8.0 Conclusions and Future Work

Several SAE standards are emerging to aid in the integration of electric vehicles into the power system. During FY11, utility communication aspects of the J2836/1, J2847/1, and J1772 standards were tested on two narrow band, low-frequency PLC communication technologies. The differences in the MAXIM MAX2990 and Echelon PL3170 modules required developing a common test platform to evaluate the communication devices. PNNL met this need by developing a laboratory setup to test the PLC communications devices, as well as providing a platform for testing future electric vehicle communication methods.

The application layer communication test architecture, hardware, and measurement methods developed for the narrowband PLC products initially available are easily adapted to test other mains or control pilot PLC products, narrowband or wideband PLC products, or ZigBee products. DOE's investment in the development of the communication testing facility at PNNL is ready to meet current and future SAE's testing needs. The facility meets SAE J2931 standard requirements currently being developed by EPRI[6].

8.1 Future Work

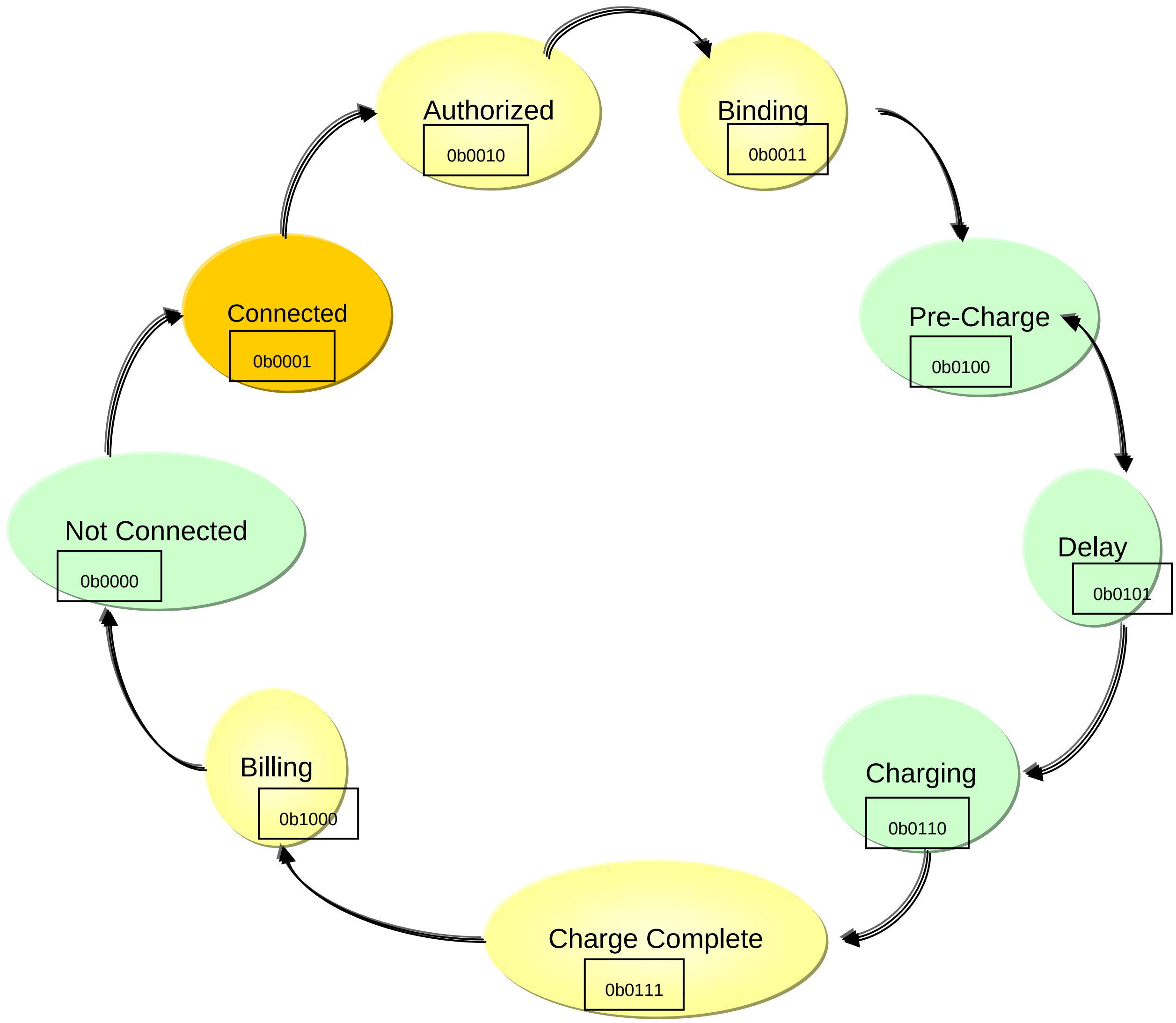
With the developed test platform and methodology, vehicle communications testing will be extended into other technologies and PHY/MAC options. This will include testing different electrical paths, such as the J1772 control pilot interface, as well as wireless communication methods. Future revisions and implementations of the J2836/1 Use Cases and J2847/1 standards will also be evaluated using the developed test platform.

In-band signaling for DC charging and reverse energy power flow messages are being finalized for publication, and these need to be tested during the near future before they can be incorporated in vehicles. In addition, SEP 2.0 application protocol is expected to be finalized in early 2011 and this needs to be tested for HomePlug, Wi-Fi and power line carrier communications. During FY12, PNNL will work closely with industry partners to implement and test the new SAE standards and SEP 2.0 protocols to accelerate the communication module development by vehicle and charging station manufacturers.

[6] J2931 PLC Communication Test Plan. Electric Power Research Institute. Palo Alto, CA. September 2011.

Appendix A: Use Case Implementation Details

A state machine was created that carries out the Uses Cases described in SAE J2836/1 and passes SAE J2847/1 messages between the EVSE and the PEV. The SAE J2836/1 Use Case scenarios are categorized in three subsets: Startup, Charge Cycle, and Shutdown. When implementing the J2847/1 messages, it became apparent that additional differentiation needed to occur for messages to be communicated effectively. The SAE J2836/1 communication state machine and notes showing the J1772 responses, owner interface, J2836/1 Use Cases, and J2847/1 messages are listed below.



<u>State = 0 (Not Connected)</u>

Source: PEV
Destination: EVSE
Notes: The Not Connected state begins with the J1772 plug and charging station not connected to the vehicle and it's PEV Controller. The EVSE Controller receives its power from the EVSE and is always

powered up. The EVSE Controller is monitoring for J1772 connector insertion. The following events occur when the J1772 plug is inserted into the vehicle.

1. The PEV Controller uses the +12VDC Control Pilot signal to signal the EVSE Controller that the J1772 plug is connected to the vehicle.
2. The EVSE Controller signals the Charging Station that a vehicle is connected.
3. The vehicle owner displays his ID card to the EVSE and if authorized, the Charging Station closes the contactor supplying 220VAC to the vehicle's charger and the PEV Controller.
4. The PEV sends the Vehicle ID at 2 second intervals (PNNL) to the EVSE Controller using Power Line Carrier (PLC) communications.
5. The EVSE Controller commands the PEV Controller to change to the CONNECTED state.

State = 1 (Connected)

Source: EVSE
Destination: PEV

Notes: The Connected state is indicated by the EVSE contactors being closed and the generation of a 1kHz square wave between -12V and +8V. The EVSE generates a 1kHz square wave for the PEV when the EVSE begins generating it. This indicates charging has been authorized by the EVSE.

It is important to note that the Coulomb access card actually causes the contactors to close which powers the Controller and allows the vehicle VID to be passed from the vehicle to the charging station. This approach minimizes exposure of personal identification.

The following communications occur during the CONNECTED state:

1. The EVSE's HMI "Connected" indicator turns ON when first Vehicle ID arrives.
2. The PEV Controller continues to send the Vehicle ID and also sends the User Information, Battery Data, and Battery Status information to the EVSE Controller.
3. The EVSE's HMI sends current clock time to the EVSE Controller.
4. The EVSE Controller sends Local Time to the PEV Controller (PNNL).
5. When the EVSE Controller has received User Information, Battery Data, Battery Status, and Local Time, the EVSE controller commands the PEV to change to the AUTHORIZED state.
6. The EVSE Controller informs the EVSE's HMI that it is in the AUTHORIZED state.
7. The EVSE's HMI "Authorized" indicator turns ON.

State = 2 (Authorized)

Source: PEV, EVSE
Destination: Utility

Notes: A combination of vehicle VID and access card information are presented to the utility to authenticate the user. The following responses occur when the information is sent.

1. The EVSE Controller begins sending a 50% duty cycle, 1 kHz, square wave to the PEV Controller using the J1772 Control Pilot signal line.
2. The PEV Controller continues to send Battery Status information to the EVSE Controller.

State = 3 (Binding)

Source: Utility (EVSE HMI)
Destination: PEV, EVSE

Notes: Binding is the connecting stage for the vehicle and utility. Once identification information has been verified (AUTHORIZED) and the communication is bound, that indicates that the two reside within the same network.

1. When the utility agrees to charge this vehicle, the EVSE HMI relays that the vehicle is BOUND to the EVSE Controller.
2. The EVSE's HMI "BOUND" indicator turns ON.
3. The EVSE controller commands the PEV to change to the BOUND state.

State = 4 (Pre-Charge)

Source: PEV
Destination: Utility (EVSE HMI)

Notes: In this state, the PEV sends an Energy Request to the utility based upon one or more of five Use Cases below. The utility then responds to the PEV's request with the Energy Available. The user also has the option to override the predetermined Use Case and be charge the pricing of energy at that current time.

- U1: Time-of-Use
- U2: Sends Request for discrete event information
- U3: Sends customer's predetermined pricing info to utility
- U4: Requests Critical Peak Pricing
- U5: Requests Active Load Management information

1. The PEV Controller continues to send Battery Status information to the EVSE Controller.
2. The EVSE controller commands the PEV to change to the PRE CHARGE state.
3. When the EVSE Controller has received Charge Complete Time from the EVSE HMI and Battery Status from the PEV Controller, the EVSE controller commands the PEV to change to the CHARGE DELAY state.

State = 5 (Charge Delay)

Notes: In this state and in the TOU Use Case, the charging process is delayed until the charging time agreed by the utility is reached.

1. The EVSE controller commands the PEV to change to the CHARGE DELAY state.
2. The PEV Controller sends Charging Status information to the EVSE Controller.
3. When the EVSE Controller is within the 15 minute interval for charging to start or is any other mode, the EVSE controller commands the PEV to change to the CHARGING state.
4. Note: In the event of a critical peak price event, the EVSE Controller commands the PEV Controller to the CHARGE DELAY state.

State = 6 (Charging)

Source: Utility, EVSE
Destination: PEV

Notes: During the charging state, energy is sent from the utility to the PEV based upon its energy request. The actual charge start time is sent from the EVSE to the Utility. The PEV sends periodic battery voltage updates to the EVSE using the BatteryStatus network variable.

1. The EVSE controller commands the PEV to change to the CHARGING state.
2. The PEV Controller uses the Hymotion CAN bus to monitor Battery State of Charge and battery charge current. This CAN bus is also used to adjust the battery charge rate. This data is sent to the EVSE Controller using PLC communications.
3. When the Battery SOC reaches 95%, the PEV Controller stops charging the battery.
4. Depending on the Use Case, the EVSE controller sends differing commands to the PEV Controller for charge rate using PLC communications.
5. Note: In the event of a Critical Peak Price event, the EVSE Controller commands the PEV Controller to the CHARGE DELAY state.

State = 7 (Charge Complete)

Source: EVSE
Destination: Utility (EVSE HMI)

Notes: At the end of a charging session, the EVSE transmits the date, time, duration and the energy delivered to the PEV and Utility. The EUMD also reports the amount of power transferred during a charging session.

1. The EVSE controller commands the PEV Controller to change to the CHARGE COMPLETE state.

2. The EVSE Controller displays the estimated total kWhrs used and cost to charge the battery.
3. The EVSE Controller sends the estimated total kWhrs used and cost to charge the battery to the EVSE HMI using PLC communications.

State = 8 (Billing)

Source: Utility
Destination: PEV/EVSE

Notes: Utility sends a summation of charge to the PEV.

Appendix B: MAXIM 2990 Test Data

Message	Mode	Voltage	Conditions	Latency (ms)[1]	Error Count	BER x 10^{-6}	Total Messages
20-byte	Normal	120 VAC	Idle[2]	39	0	0	1,868,920
20-byte	Robo	120 VAC	Idle[2]	51	0	0	2,803,876
20-byte	Normal	240 VAC	Idle[3]	40	0	0	2,173,438
20-byte	Robo	240 VAC	Idle[3]	50	0	0	2,954,267
20-byte	Normal	240 VAC	Idle - long[9]	22	0	0	1,625,978
20-byte	Normal	240 VAC	100%[4]	40	0	0	1,358,110 (523,500 charging)[5]
20-byte	Normal	240 VAC	100%[4]	40	0	0	2,141,876 (371,500 charging)[5]
20-byte	Normal	240 VAC	50%[6]	40	0	0	2,399,599 (514,500 charging)[5]
20-byte	Normal	240 VAC	75%[6]	40	0	0	1,613,748 (374,500 charging)[5]
20-byte	Normal	240 VAC	GFCC[8]	40	0	0	1,923,685 (1,079,500 charging)[5]
20-byte	N/A	Loopback[7]	N/A	5	0	0	5,225,237
20-byte	N/A	Loopback[10]	Dual[11]	5/5[12]	0	0	528,133/73,034[12]
20-byte	Normal	240 VAC	FSK Interfere[14]	946	120	136054	882
20-byte	Normal	240 VAC	FSK Interfere[15]	91	0	0	2,039
20-byte	Robo	240 VAC	FSK Interfere[14]	50	0	0	2,146
20-byte	Robo	240 VAC	FSK Interfere[15]	50	0	0	2,030
20-byte	Robo	240 VAC	FSK Interfere[16]	51	0	0	2,148
20-byte	Normal	240 VAC	Dual[11]	40 / 136[17]	281 / 10[17]	173 / 26[17]	1,261,852 / 385,894[17]
20-byte	Robo[18]	240 VAC	Dual[11]	51/74[17]	0/0[17]	0/0[17]	1,836,388/173,860[17]
251-byte	Normal	240 VAC	Idle - long[9]	65	0	0	3,552,804
244-byte	ROBO	240 VAC	Idle - long[9]	423	0	0	77,506

1. The Maxim boards require a 4 millisecond hardware delay before sending a packet. The Echelon boards and loopback mode required a testing-imposed delay before sending the next new message - is not included in latency value.
2. Idle is PLC communication over an otherwise unused 3 foot electric path (only the PLC units are running)
3. Idle is PLC communication over an otherwise unused 17 foot J1772 cable (only the PLC units are running)
4. Percentage is the limitation to the Hymotion charging rate, no other throttling or external charge rate control was used. PLC communication was over the 17 foot J1772 cable
5. Speed and error testing was run overnight - charging completed during that period, so the line was only under load part of the test
6. Percentage is the limitation to the Hymotion charging rate as controlled by CAN commands. PLC communication was over the 17 foot J1772 cable
7. Loopback tests are the serial cables connecting the PLC devices jumpered together through another 3 foot NULL modem cable.
8. GFCC charging rating is a PNNL-developed method of charging to provide regulation services to the grid. The charging rate varies over the charging period in response to grid stress.
9. Idle - long is PLC communication over an otherwise unused 17 foot J1772 cable with an additional 45 feet of cable (only the PLC units are running).
10. Loopback test are the serial cables connecting the PLC devices jumpered together through 25-foot long NULL modem cables - dual tests running simultaneously on the NI system.

11. Dual represents conditions where both the Echelon and Maxim PLC units were operating on the same 17-foot J1772 cord and 45 additional feet of cable. Tests were conducted simultaneously on the same NI PXI system.
12. Latency and message count values for Dual tests are ordered as Maxim/Echelon for the testing placeform - these numbers are under the loopback condition.
13. Noise FSK represents the addition of 3.8 Volts of FSK noise at 130 kHz on the 240 VAC power channel
14. FSK signal applied at 130 kHz with 10 kHz hop frequencies applied at 0 dB relative to the observed signal level at 130 kHz.
15. FSK signal applied at 130 kHz with 10 kHz hop frequencies applied at -3 dB relative to the observed signal level at 130 kHz.
16. FSK signal applied at 130 kHz with 10 kHz hop frequencies applied at 3 dB relative to the observed signal level at 130 kHz.
17. Latency, error count, BER, and message count values for Dual tests are ordered as Maxim/Echelon.
18. Robo mode during "both" or "dual" tests represents only the Maxim PLC device operating in Robo mode. Echelon devices do not have a secondary mode selection.

Appendix C: MAXIM 2990 Normal Mode Oscilloscope Measurements

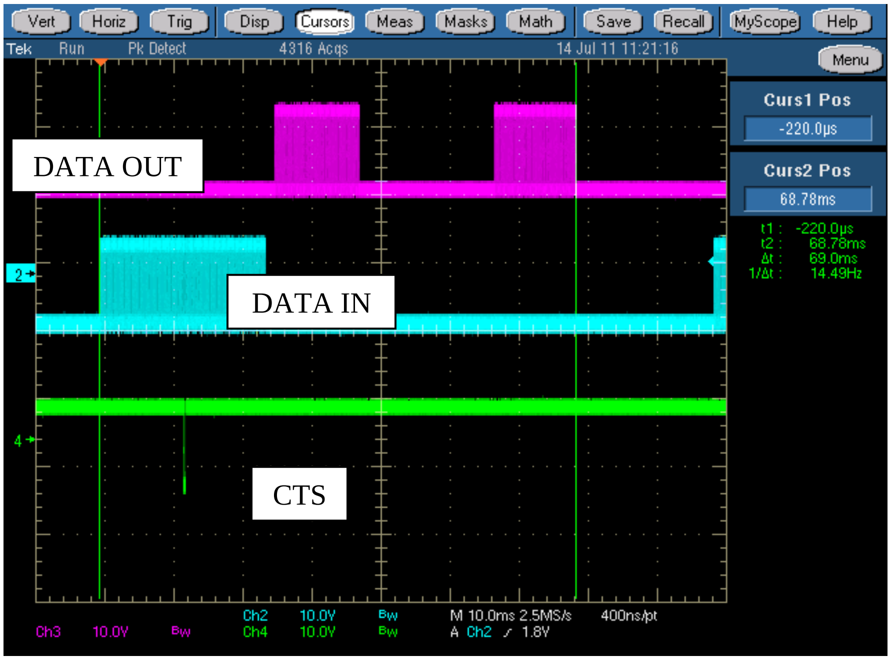


Figure 11. MAX 2990 Normal Mode 274 Byte Message - 69 millisecond latency.

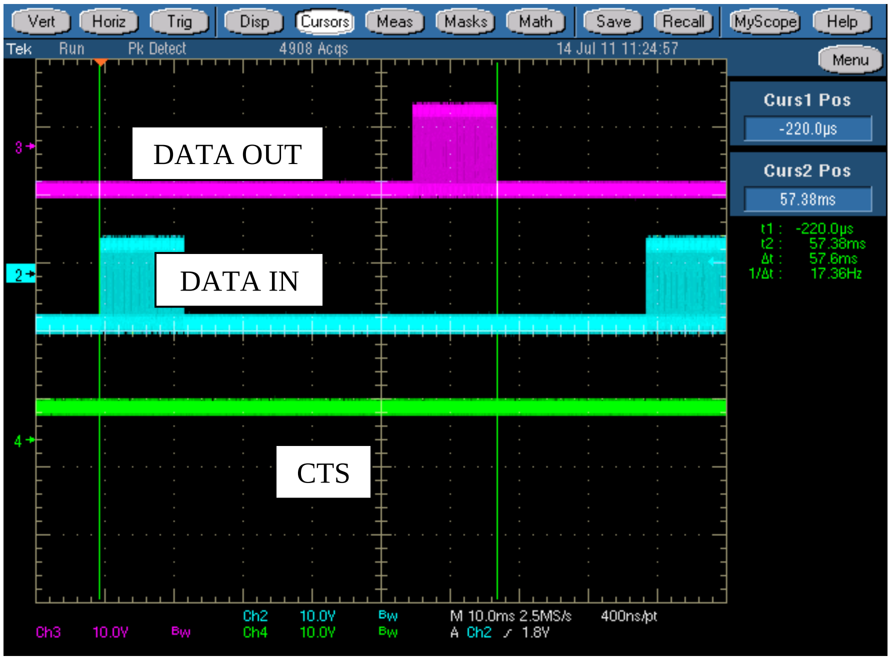


Figure 12. MAX 2990 Normal Mode 140 Byte Message - 57.6 millisecond latency.

Messages longer than 140 bytes are divided into packets smaller than 140 bytes in the MAX2990. Note that the CTS line briefly holds off the incoming RS-232 in Figure 13.

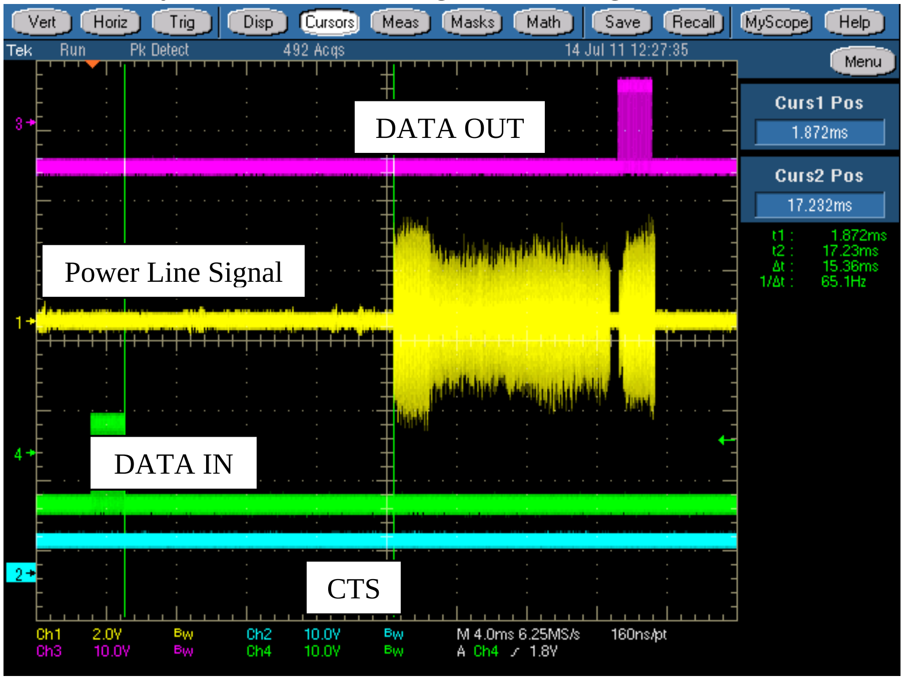


Figure 13. MAX 2990 Normal Mode - 20 Byte Message - with 15 millisecond time out delay

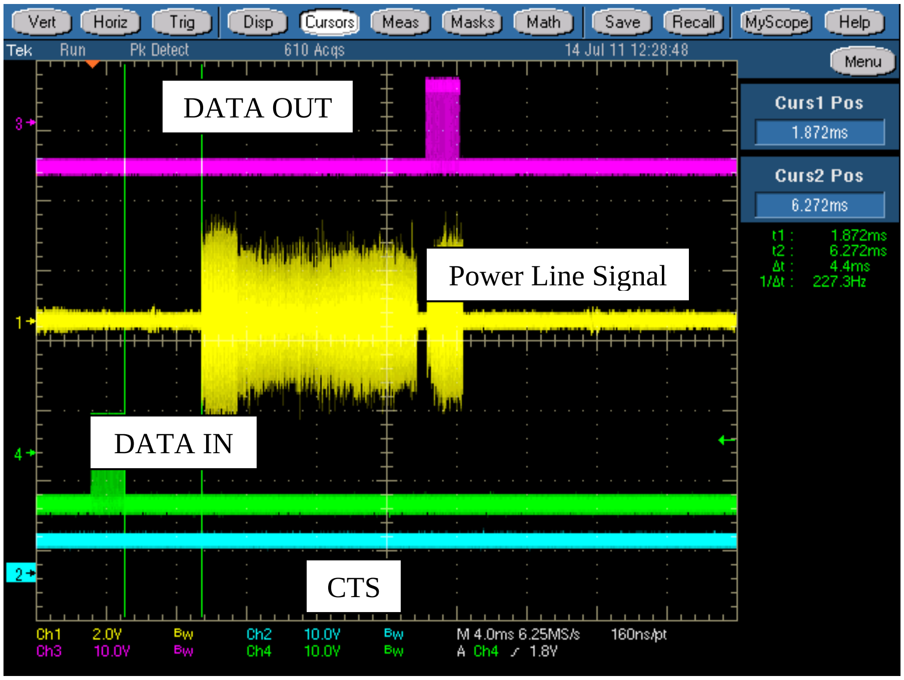


Figure 14. MAX 2990 Normal Mode - 20 Byte Message - with 4 millisecond time out delay.

The time out delay sets the period in which the MAX2990 waits for incoming RS-232 signals until it transmits a partially filled buffer. Therefore, this time out delay has a direct effect on latency and the effective data rate. The minimum time out delay was experimentally determined to be 4 milliseconds.

Appendix D: MAXIM 2990 ROBO Mode Oscilloscope Measurements

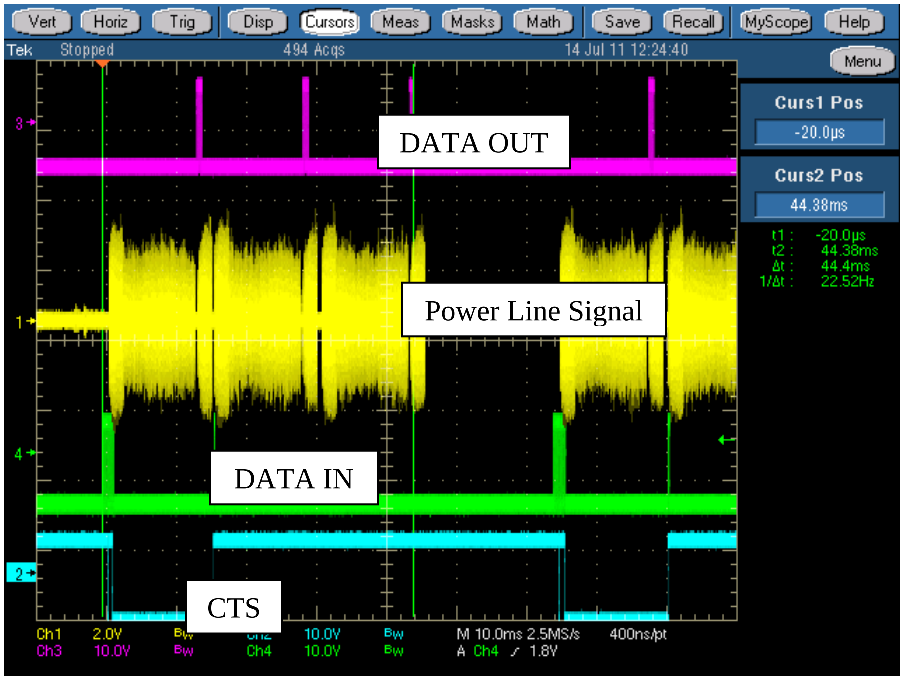


Figure 15. MAX 2990 ROBO Mode - 20 Byte Message - with 44 millisecond latency.

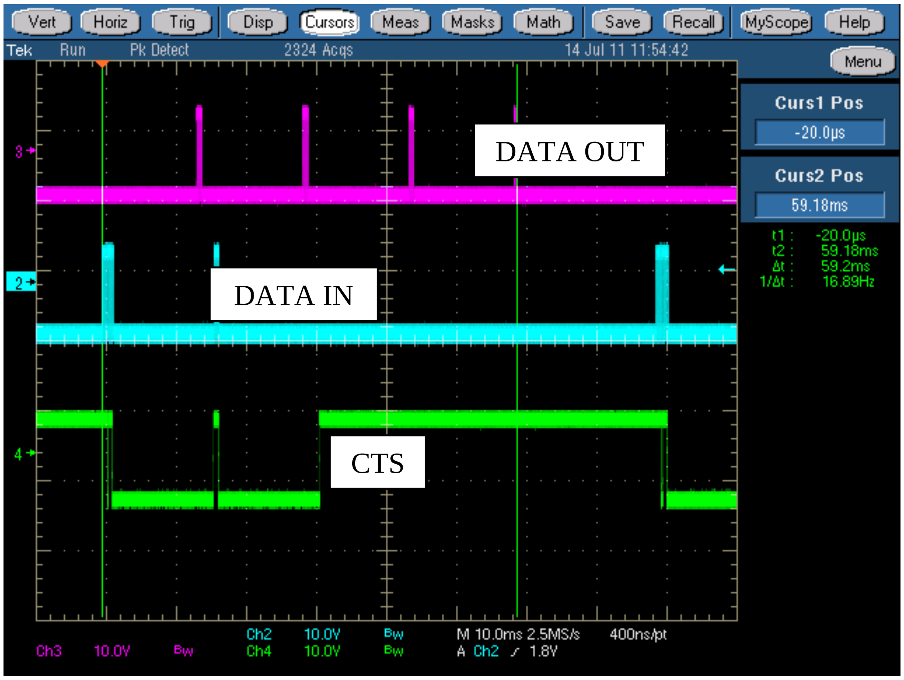


Figure 16. MAX 2990 ROBO Mode - 27 Byte Message - with 59 millisecond latency.

Messages longer than 9 bytes are divided into packets up to 9 bytes in the MAX2990. Note that the CTS line briefly holds off the incoming RS-232 in Figure 16. The power line signal in Figure 15 shows the power line communications signal.

Appendix E: Echelon PL3170 Test Data

Message	Voltage	Conditions	Latency (ms)[1]	Error Count	BER x 10^{-6}	Total Messages
20-byte	120 VAC	Idle[2]	135	28	28	985,104
20-byte	120 VAC	Idle[2]	135	0	0	387,533
5-byte	120 VAC	Idle[2]	70	0	0	217,864
20-byte	240 VAC	Idle[3]	135	8	20	393,424
20-byte	240 VAC	Idle - long[9]	135	25	23	1,103,398
20-byte	240 VAC	100%[4]	135	8	27	296,467 (50,500 charging)[5]
20-byte	240 VAC	50%[6]	135	4	14	287,883 (70,500 charging)[5]
20-byte	240 VAC	75%[6]	135	4	14	278,392 (53,000 charging)[5]
20-byte	240 VAC	GFCC[8]	135	6	24	252,009 (147,800 charging)[5]
5-byte	240 VAC	Idle[3]	69	0	0	229,049
20-byte	Loopback[7]	N/A	5	0	0	5,225,237
20-byte	Loopback[10]	Dual[11]	5/5[12]	0	0	528,133/73,034[12]
5-byte	Loopback[7]	N/A	2	0	0	3,397,520
5-byte	Loopback[10]	Dual[11]	3/2[12]	0	0	528,133/73,034[12]
20-byte	240 VAC	FSK Interfere[14]	288	1	5	198,998
5-byte	240 VAC	FSK Interfere[14]	69	0	0	1,028
20-byte	240 VAC	Dual[11]	40 / 136[17]	281 / 10[17]	173 / 26.2	1,261,852 / 385,894[17]
5-byte	240 VAC	Dual[11]	51/74[17]	0/0[17]	0/0[17]	1,836,388/173,860[17]

1. Timeout on Maxim boards is a hardware-set delay before sending a packet. Timeout on Echelon boards and loopback mode is a testing-imposed delay before sending the next new message.
2. Idle is PLC communication over an otherwise unused 3 foot electric path (only the PLC units are running)
3. Idle is PLC communication over an otherwise unused 17 foot J1772 cable (only the PLC units are running)
4. Percentage is the limitation to the Hymotion charging rate, no other throttling or external charge rate control was used. PLC communication was over the 17 foot J1772 cable
5. Speed and error testing was run overnight - charging completed during that period, so the line was only under load part of the test
6. Percentage is the limitation to the Hymotion charging rate as controlled by CAN commands. PLC communication was over the 17 foot J1772 cable
7. Loopback tests are the serial cables connecting the PLC devices jumpered together through another 3 foot NULL modem cable.
8. GFCC charging rating is a PNNL-developed method of charging to provide regulation services to the grid. The charging rate varies over the charging period in response to grid stress.
9. Idle - long is PLC communication over an otherwise unused 17 foot J1772 cable with an additional 45 feet of cable (only the PLC units are running).
10. Loopback test are the serial cables connecting the PLC devices jumpered together through 25-foot long NULL modem cables - dual tests running simultaneously on the NI system.
11. Dual represents conditions where both the Echelon and Maxim PLC units were operating on the same 17-foot J1772 cord and 45 additional feet of cable. Tests were conducted simultaneously on the same NI PXI system.
12. Latency and message count values for Dual tests are ordered as Maxim/Echelon for the testing placeform - these numbers are under the loopback condition.
13. Noise FSK represents the addition of 3.8 Volts of FSK noise at 130 kHz on the 240 VAC power channel
14. FSK signal applied at 130 kHz with 10 kHz hop frequencies applied at 0 dB relative to the observed signal level at 130 kHz.
15. FSK signal applied at 130 kHz with 10 kHz hop frequencies applied at -3 dB relative to the observed signal level at 130 kHz.
16. FSK signal applied at 130 kHz with 10 kHz hop frequencies applied at 3 dB relative to the observed signal level at 130 kHz.
17. Latency, error count, BER, and message count values for Dual tests are ordered as Maxim/Echelon.
18. Robo mode during "both" or "dual" tests represents only the Maxim PLC device operating in Robo mode. Echelon devices do not have a secondary mode selection.

Appendix F: Echelon PL3170 Oscilloscope Signals

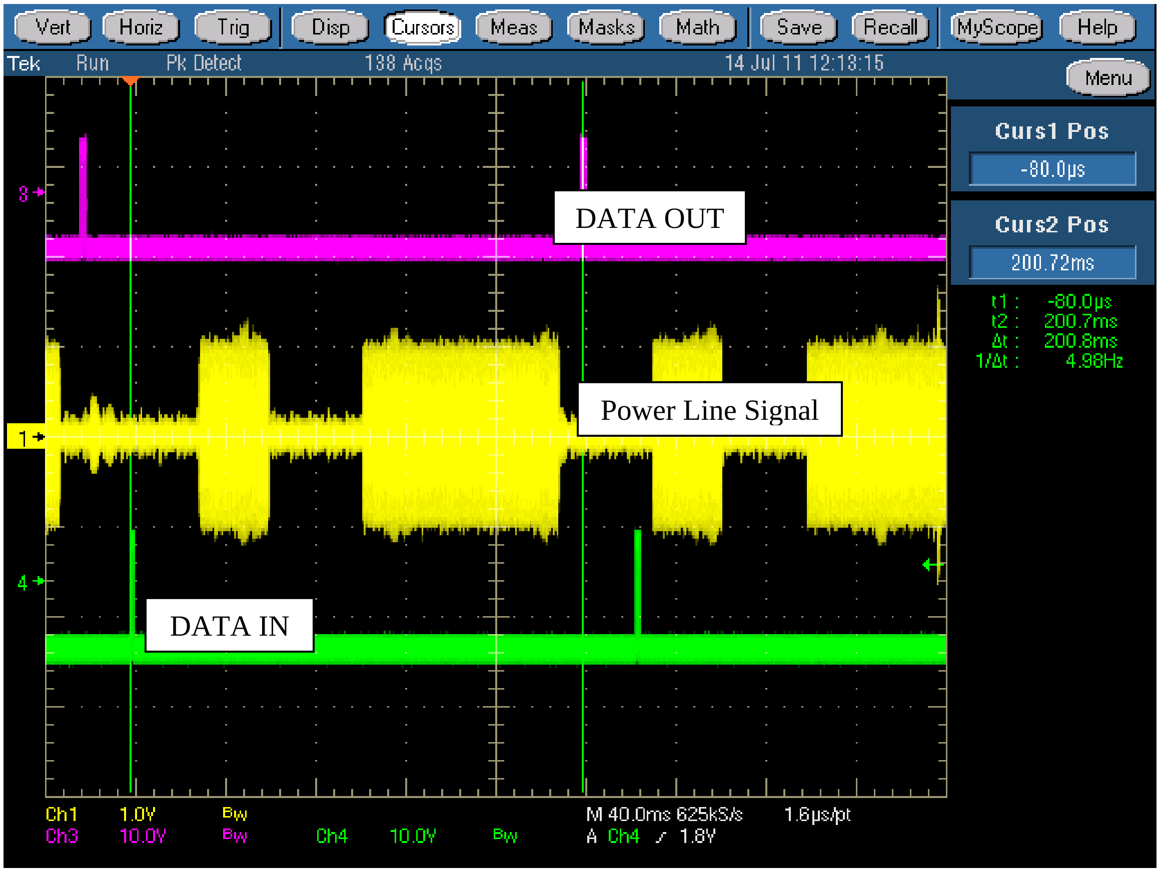


Figure 17. Echelon PL3170 - 40 Byte Message - with 200 millisecond latency.

The data transferred within the PL3170 is set by loading specific (PLC) network variables and allowing the PL3170 system to recognize data needs to be transferred. Figure 17 shows a network variable transfer with 40 byte payload. Figure 18 is a summary of data rate measurements made on the Echelon and MAX2290 PLC units.

Test	Mode	Distance	Latency (ms)	Length (bytes)	Raw Data Rate (kb/s)	Corrected Data Rate (kb/s)
Maxim - 110 VAC - VIN	Normal	3 FT	39	20	4.10	4.71
Maxim - 220 VAC - VIN	Normal	J1772	40	20	4.00	4.57
Maxim - 110 VAC - VIN	Robo	3 FT	51	20	3.14	3.48
Maxim - 220 VAC - VIN	Robo	J1772	50	20	3.20	3.56
Maxim - 220 VAC - VIN	Robo	J1772+25 FT	50	20	3.20	3.56
Maxim - 110 VAC - Long	Normal	3 FT	65	251	30.89	33.47
Maxim - 220 VAC - Long	Normal	J1772	65	251	30.89	33.47
Maxim - 110 VAC - Long	Robo	3 FT	423	251	4.75	4.80
Maxim - 220 VAC - Long	Robo	J1772	423	251	4.75	4.80
Maxim - 220 VAC - Long	Robo	J1772+25 FT	423	251	4.75	4.80
Echelon - 110 VAC - VIN	-	3 FT	194	20	0.82	0.85
Echelon - 220 VAC - VIN	-	J1772+25 FT	193	20	0.83	0.85

Figure 18. Summary of PLC Data Rate Measurements.

Appendix G: SEP 2.0 Data Variables Supporting SAE J2847/1

EV to EVSE Messaging (Bidirectional)

J2847 Messages	SEP 2.0 Variables	Function	Data Type(s)	PNNL Tested
Identifications				
Vehicle ID	\\PEVData\ElectricVehicle\ID	Object Identifier	string	**X**
Smart PEV Present				**X**
EVSE Override				**X**
Vehicle Info/Status				
Time at Connection				**X**
Battery SOC Start				**X**
Battery SOC End				**X**
Battery SOC Actual	\\PEVData\BatteryStatus\stateOfCharge	State of charge in percent	Float	**X**
Vehicle Type	\\PEVData\ElectricVehicle\EndDeviceGroup			
Usable Battery Energy	\\PEVData\BatteryStatus	Current battery status	String, Boolean, float	
Customer Mode Preference				
Other Messages included by PNNL				
Customer ID/PIN	\\Registration\CustomerAccount\ID	Object identifier for linkage to customer account	string	**X**
Battery Status	Voltage: \\PEVData\Battery\BatVnom Current: \\PEVData\CurrentFlow Capacity: \\PEVData\Battery\ahrRtg Power: \\PEVData\ActivePower	Nominal voltage of battery; electrical current; Amp-hour capacity rating; product of RMS values for the voltage and in-phase component of current.	Float	**X**
Charge Control	\\PEVData\ChargerStatus\batChaSt	Battery charger charging mode status	string	**X**
Charge Complete	\\PEVData\BatteryStatus\batSt	Battery System Status	Boolean	**X**
Charging Profile				**X**
Odometer Time	\\PEVData\ElectricVehicle\OdometerReadDateTime	Date and time to take an odometer reading	unsigned integer	
Odometer Reading	\\PEVData\ElectricVehicle\OdometerReading	Odometer Reading	string	

EV/EVSE to AMI Messaging (Bidirectional)

J2847 Messages	SEP 2.0 Variables	Function	Data Type(s)	PNNL Tested
Identification				
Communications Authenticated	\\MessageReceipt\Confirmation	Confirmation of a notification message	unsigned integer, string	**X**
EUMD ID	\\MeteringData\MeterAsset\ID	Object Identifier	string	
Energy Requests				
Energy Request (amount)	\\PEVData\Charger\batChgPwr	Battery charging power required	float	**X**
Power Request (rate)				
Energy Available (amount)	\\DRLCEvent\EndDeviceControl	Value of a type of float	float	**X**
Power Available (rate)				
Power Schedule				
Energy Delivered (kWh)	\\MeteringData\MeterReading	Set of values obtain from the meter	string, unsigned integer, float	**X**
Timing Information				
Time Charging to Start	\\PEVData\DateTimeInterval\start	Date and time that interval started	unsigned integer	**X**
Time Charging to End	\\PEVData\DateTimeInterval\end	Date and time that interval ended	unsigned integer	**X**
Time Charge is Needed				**X**
Actual Charge Start Time				**X**
Pricing				
Request Scheduled Prices				**X**
Publish Prices	\\PricingData\TariffProfile	A schedule of charges	string, unsigned integer	**X**
Define Rate Time Period				**X**
Rate Time Period Status Hash				
Request Rate Time Period Info				**X**
Price for Rate Time Period	\\PricingData\ConsumptionTariffInterval	Interval sequence defining service quantities consumed	integer	**X**
Load Control (U2 Only)				
Load Control				**X**
Cancel Load Control				
Report Event Status Request				**X**
Report Event Status Response				**X**
Request Scheduled Events				**X**

EV/EVSE to AMI Messages included by PNNL

Other PNNL Messages	SEP 2.0 Variables	Function	Data Type(s)	PNNL Tested
Premise ID	\\Registration\HANAsset\ID (Not sure if this is right)	Object identifier for the HAN	String	**X**
Billing Request (J2836 – Opt.)	\\BillingData\CustomerBillingInfo	The creation of the monthly customer billing statements is the method employed to notify Customers of charges, adjustments and credits applied to their account for Services and Products.	unsigned integer, string, float	**X**
Program	\\BillingData\TariffProfile	A schedule of charges	String, unsigned integer	**X**
Energy Schedule	\\PricingData\TariffProfile	A schedule of charges	String, unsigned integer	**X**
Anticipated Charge Duration				**X**
Premises Limits	\\Base\Mains\Voltage	Measured RMS or DC voltage currently applied	float	**X**
Power Used	\\BillingData\RealEnergy			**X**
Date / Time	\\Base\Time	Local Time	integer, string, unsigned integer, Boolean	**X**
Invoice Amount	\\BillingData\ErpInvoice\amount	Total amount due on this invoice based on line items and applicable adjustments.	float	**X**

Lee Slezak
United States Department of Energy,
Office of Vehicle Technologies
1000 Independence Ave, OE-10
Washington, DC 20585

Dan Ton
United States Department of Energy,
Office of Electricity
1000 Independence Ave, OE-10
Washington, DC 20585

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

U.S. DEPARTMENT OF
ENERGY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)
www.pnl.gov