Grid Interconnection and Performance Testing Procedures for Vehicle-To-Grid (V2G) Power Electronics

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GRID INTERCONNECTION AND PERFORMANCE TESTING PROCEDURES FOR VEHICLE-TO-GRID (V2G) POWER ELECTRONICS

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ABSTRACT

Bidirectional power electronics can add vehicle-to-grid (V2G) capability in a plug-in vehicle, which then allows the vehicle to operate as a distributed resource (DR). The uniqueness of the battery-based V2G power electronics requires a test procedure that will not only maintain IEEE interconnection standards, but can also evaluate the electrical performance of the vehicle working as a DR. The objective of this paper is to discuss a recently published NREL technical report that provides interim test procedures for V2G vehicles for their integration into the electrical distribution systems and for their performance in terms of continuous output power, efficiency, and losses. Additionally, some other test procedures are discussed that are applicable to a V2G vehicle that desires to provide power reserve functions. A few sample test results are provided based on testing of prototype V2G vehicles at NREL.

1. INTRODUCTION

Over the past 15 years, energy storage technologies for vehicle traction systems have improved dramatically and found their way into commercially viable hybrid, electric, and plug-in hybrid vehicles. Typical electric or plug-in hybrid vehicles use power electronics to charge the batteries directly from the utility, thus increasing the all-electric driving range for the electric or hybrid vehicles [1]. Power electronics can also be designed so that power can be fed back to the grid. A vehicle with this type of technology is defined as being vehicle-to-grid (V2G) capable. Possible uses of V2G vehicles for distributed energy applications are to provide power to utility/local loads, regulate voltage and frequency, offer spinning reserves, and enable electrical demand management. Electric, plug-in hybrid, and V2G vehicles will have the potential to absorb excess electricity produced by renewable energy sources (e.g., wind or photovoltaics) when the grid is operated at low load conditions [2].

V2G vehicles utilize a reliable, high-power, high-energy battery pack with bidirectional power electronics and controller. The controller module controls the power electronics to operate in charge, discharge, or standby modes. The first commercial V2G vehicles are expected to use either a nickel metal hydride or a lithium-ion battery pack to obtain high energy densities [2]. The block diagram of a fully electric vehicle with V2G capability is shown in Fig. 1. In this configuration, the utility connection is made using the same power electronics that are used for the traction motor/generator (M/G), thus eliminating the need for a separate battery charger.

Though V2G functionalities are expected to be the same for different vehicles, the specific V2G system configuration can be different depending on the details of the vehicle design, such as fully electric or hybrid; the power electronics topologies; and the type of power and control connections. Irrespective of their design, all vehicles with V2G capability must meet IEEE Std. 1547 (referred as IEEE 1547 hereafter) “Standard for Interconnecting Distributed Resources with Electric Power Systems,” which specifies the type, production, and commissioning tests that must be performed to demonstrate that the utility interconnection functions properly [3].

The objective of this paper is to discuss a recently published NREL technical report [4] that provides interim test procedures for V2G vehicles. The NREL test plan was designed to test and evaluate a vehicle's capability to provide power to the grid, and to evaluate the vehicle's ability to connect and disconnect from the utility according to a subset of the IEEE 1547 tests [4]. Some additional performance tests were included in the test plan to verify the V2G-capable vehicle's continuous output power, efficiency, and losses [4]. It is important to note that almost all the tests described in that report were for V2G modes only, not for modes in which the vehicle was charging its batteries from the grid [4]. Once validated, these procedures could become the basis for testing standards for V2G applications.

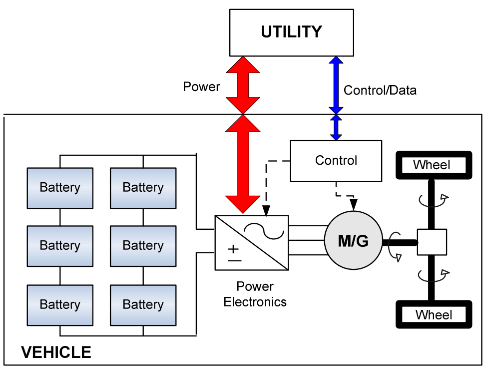

Fig. 1: Block diagram of an electric vehicle with V2G

2. TEST SETUP AND REQUIREMENTS

The manufacturers' specifications for the V2G-capable vehicle are important in designing the test plan and procedures. The required information includes: type of vehicle propulsion, power electronics topology, type and size of the battery, battery terminal voltage, utility connection voltage level(s) and frequency, output power, charging rate and time, type of power connectors, charge/discharge control methods, type of on-board data acquisition, and display and electrical safety systems [4].

An example of a test setup for a V2G-capable electric vehicle is shown in Fig. 2 [4]. This configuration has a single-phase connection to the utility grid. A programmable AC grid simulator is used to emulate the electric utility. This grid simulator is controlled by a computer and is capable of outputting voltage waveform sequences. As the grid simulator can not sink power, a variable load bank is used in parallel. In this particular vehicle under test, the charging/discharging is controlled using cellular signals. For safety reasons, a manual disconnect is included in the test system that can disconnect the batteries from the utility connection in case of emergency.

The general requirements for the test procedure are as follows: (1) Implementation of these test procedures shall be conducted in accordance with appropriate safety procedures, sequences and precautions. (2) The manufacturer shall specify the range of environmental conditions for the equipment under test. The tests shall be conducted in an environment that is within the manufacturer's specified environmental operating conditions. (3) Measurement equipment used to confirm performance shall have calibration traceability. The accuracy of the measuring equipment shall be suitable for the test being conducted. (4) The test results shall be documented in a test report. The test report shall include sufficient critical operating information to rerun the test and reproduce the results. (5) Each test method shall be specified, and engineering considerations, including range of operating conditions, shall be justified.

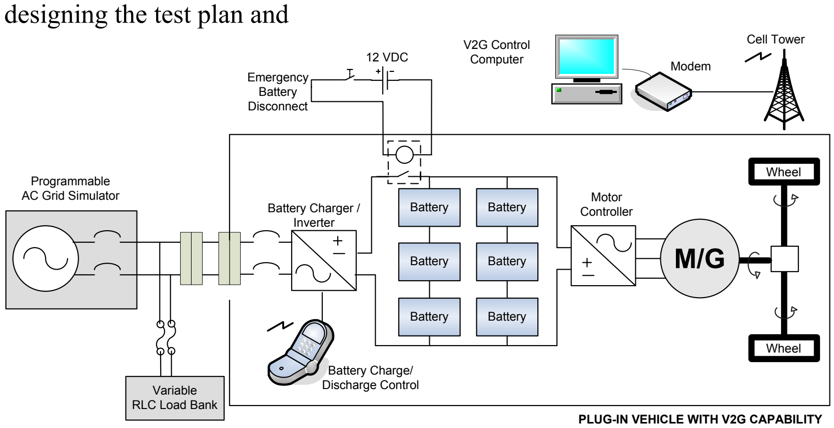

Fig. 2: Example of V2G test setup

3. GRID INTERCONNECTION TESTS

This section discusses various tests to determine the safe V2G interconnection to the utility grid. Most of these tests are described based on the IEEE Std. 1547.1-2005 (referred as IEEE 1547.1 hereafter) that gives the conformance test procedures for equipment that interconnects distributed resources with electric power systems [5]. Some of the IEEE 1547.1 tests are unfeasible or redundant for V2G power electronics and are discussed as additional tests at the end of this section. The tests described in this section are in the order in which they are suggested in IEEE 1547, Table 4. It is important to note that V2G vehicles may be capable of connecting to the utility at different voltage levels (e.g. 120 V, 240 VAC rms); therefore, all of the interconnection testing discussed in this report will need to be conducted for all practical utility connection voltages.

3.1 Response to Abnormal Voltages

This series of tests is used to ensure the V2G power electronics disconnect from the utility whenever voltage levels go out to the ranges specified in IEEE 1547. The V2G must not only disconnect from the utility when a voltage threshold is reached, but must also disconnect within the amount of time specified in Table 1 of IEEE 1547. This procedure uses the ramp and step functions defined in IEEE 1547.1, Annex A. This procedure should be repeated to test for both over and under voltage conditions. This procedure has two parts: 1) a magnitude test to determine the grid voltage magnitude at which the inverter disconnects, and 2) a time test to determine the time it takes the inverter to disconnect after the voltage range has been exceeded. The detailed test procedure can be found in IEEE 1547.1, section 5.2.

3.2 Response to Abnormal Frequencies

This series of tests is used to ensure the V2G power electronics disconnect from the utility whenever the frequency falls outside of the ranges specified in IEEE 1547. Again, the V2G vehicle must not only disconnect from the utility when a frequency threshold is reached, but must also disconnect within the amount of time specified in IEEE 1547, Table 2. This procedure uses the ramp and step functions defined in IEEE 1547.1, Annex A. This procedure should be repeated to test for both over and under frequency conditions. This procedure has two parts: 1) a magnitude test to determine the frequency threshold at which the inverter disconnects, and 2) a time test to determine the time it takes the inverter to disconnect after the frequency threshold has been exceeded. The detailed test procedure can be found in IEEE 1547.1, section 5.3.

3.3 Synchronization and Seamless Transfer

To properly interconnect with the utility, V2G converters must properly synchronize causing minimal system transients. If the unit can also supply a load independently of the utility status, the voltage and frequency supplied to the load must also be free of significant transients during the transfer process, regardless of the inverter's initial conditions and power exporting status prior to the shift. Two basic test methods are provided in IEEE 1547.1, section 5.4. If the V2G power electronics can generate a voltage independently of the utility and are thus capable of out-of-phase paralleling (e.g., operating in a stand-alone mode), the unit must be tested using Method 1 to verify its synchronizing capability. The V2G power electronics that are not able to supply power independent of the utility must be tested to determine the synchronization current using Method 2. The detailed test procedure can be found in IEEE 1547.1, section 5.4.

3.4 Unintentional Islanding

The purpose of this test is to verify that the V2G power electronics cease to energize the utility as specified in IEEE 1547 when an unintentional island condition is present. This test determines the trip time for the test conditions and confirms that the trip time is within two seconds of the formation of an island as specified in IEEE 1547. This test procedure is designed to be universally applicable to all distributed resources, regardless of output power factor. Any reactive power compensation by the V2G converter should remain on during the test. Where the V2G manufacturer requires an external or separate transformer, the transformer should be connected between the V2G and resistive-inductive-capacitive (RLC) load and should be considered part of the product being tested. The detailed test procedure can be found in IEEE 1547.1, section 5.7. It is important to note that steps 'n' and 'o' of the anti-islanding tests in IEEE 1547.1 cannot be performed for some V2G interconnection equipment because both the input power from the battery and the output power level are not adjustable. When this is the case, it should be noted clearly in the test report.

3.5 Open Phase

The purpose of this test is to verify that the V2G interconnection systems cease to energize the utility upon loss of an individual phase at the point-of-common-coupling (PCC) or at the point of V2G connection. After the phase disconnect is opened, the V2G shall cease to energize all output terminals connected to the simulated utility within the timing requirement of IEEE 1547 for unintentional islanding. The test details can be found in IEEE 1547.1, section 5.9.

3.6 Reconnect Following Abnormal-Condition Disconnect

The purpose of this test is to verify the functionality of the V2G interconnection component or system reconnect timer following an abnormal condition disconnect, so that no reconnection takes place until the utility voltage and frequency are in the range specified in IEEE 1547 for the specified time interval. This test may be performed in conjunction with the over voltage, under voltage, over frequency, and under frequency tests. The detailed test procedure can be found in IEEE 1547.1, section 5.10.

3.7 DC Current Injection

V2G converters that connect to the utility without the use of DC-isolation output transformers must comply with the DC current injection limit specified in IEEE 1547. The detailed test procedure can be found in IEEE 1547.1, section 5.6. This test may be conducted as part of the harmonics test. If a simulated electric utility grid is used, the output of the simulated grid should be connected to a dedicated isolation transformer. The V2G power electronics shall be considered in compliance if all calculated percent DC injection currents are within the limit specified in IEEE 1547.

3.8 Harmonics

The purpose of this test is to measure the individual current harmonics and total rated-current distortion (TRD) of the V2G converter under normal operating conditions. The detailed test procedure can be found in IEEE 1547.1, section 5.11. It is important to take steps to ensure that measured harmonics exceeding the allowable levels in IEEE 1547 are not caused by characteristics of the simulated electrical utility grid. The V2G power electronics shall be considered in compliance if the individual current harmonics and TRD do not exceed the limits specified in IEEE 1547. For a multiphase V2G test unit, each of the phases shall comply with the specified limits.

3.9 Additional IEEE Std. 1547 Tests (optional)

The temperature stability test verifies that the V2G power electronics maintain measurement accuracy of parameters over their specified temperature range. The manufacturer's protective, monitoring, and control function tests for the V2G power electronics at the specified temperature range can be accepted in lieu of further third-party or owner testing if a temperature-controlled testing environment is not available. The temperature stability test is discussed in IEEE Std. 1547.1, section 5.1.

The reverse power test is performed to characterize the accuracy of the reverse-power protection magnitude setting(s) of the V2G unit under test. This test is a variation of the unintentional islanding test and should only be required for V2G power electronics that use reverse or minimum import power-flow protection for disconnecting from the utility when an unintentional island condition is present. Details of the reverse power test procedure can be found in IEEE 1547.1, section 5.8.

Three tests are included under the interconnection integrity tests category: a test of protection from electromagnetic interference (EMI), a test of surge-withstand performance, and a dielectric test of the paralleling device. In the EMI protection test, V2G power electronics are tested to confirm that the influence of EMI does not result in a change in state or misoperation of the interconnection functions. The purpose of the surge withstand test is to verify the level of surge withstand protection specified by the manufacturer of the V2G vehicle. The dielectric test determines if the paralleling device (such as a contactor or circuit breaker) of the V2G vehicle, operating at the normal operating temperature, can withstand the application of an AC rms test potential of 1,000 V plus 220% of the nominal AC rms voltage for 1 minute without breakdown. The detailed test procedures and requirements can be found in IEEE 1547.1, section 5.5. It may be difficult to conduct these tests because of safety concerns, the requirement of special instruments, and the possibility that the V2G unit under test could be damaged. In some cases, certified factory test results (i.e., those performed by the manufacturer) may suffice in lieu of further third-party or owner testing.

4. V2G ELECTRICAL PERFORMANCE TESTS

This section discusses the performance tests to be conducted on the electronics to determine a vehicle's suitability for V2G applications. These performance tests are designed to verify or establish the relevant converter's operational characteristics. The test results may provide information not generally found on V2G vehicle's specification sheets, or on listing labels or other labels.

4.1 Continuous Output Power

The purpose of this test is to establish the continuous output power level that the V2G DUT can maintain for a specified period of time at the specified ambient operating temperature after reaching thermal equilibrium. This test procedure is developed from Sandia Inverter Test Protocol, section 5.4, which is designed for photovoltaic inverter testing [6]. Several modifications are required to apply it to the V2G testing. The detailed test procedure can be found in the NREL report [4]. V2G converters that can connect to utility at multiple nominal AC voltages shall be tested separately for each nominal voltage.

4.2 Conversion Efficiency

The purpose of this test is to establish the conversion efficiency of the inverter between the vehicle battery and the AC output as a function of output power level. This test procedure is developed based on Sandia Inverter Test Protocol, section 5.5 [6]. Again, several modifications are required to apply it to the V2G testing. The detailed test procedure can be found in the NREL report [4]. V2G converters that can connect to utility at multiple nominal AC voltages shall be tested separately for each nominal voltage.

5. ADVANCED GRID-SUPPORT TESTS (OPTIONAL)

Though V2G-capable vehicles can provide peak power demand-response, it may not be economical because such a service is needed for just a few hours each year. The most promising markets for V2G are for those services that the electric industry refers to as ancillary services, such as frequency regulation and spinning reserve. With today's battery technology, designing a V2G-capable vehicle that can provide reserve capability will be easier than designing a vehicle that provides regulation [7]. In this section, a general test procedure is given that is applicable to typical V2G vehicles that desire to provide reserve functions. Additionally another test procedure is developed that determines the charging time for the vehicle. This charging time test is important to understand how often one can use the V2G vehicle to support grid reserve [4]. In the future, other test procedures will be developed for additional V2G capabilities such as reactive power control, voltage regulation, and power quality control based on the manufacturer's/customer's request.

5.1 Active Power Reserve

The purpose of this test is to evaluate a V2G vehicle's capability to provide active power reserve to the utility using stored energy in vehicle's battery. This test is very similar to the test described in section 4.1 except that the duration for continuous output power at various power levels is measured. V2G converters that can connect to utility at multiple nominal AC voltages shall be tested separately for each nominal voltage. The detailed test procedure can be found in the NREL report [4].

5.2 Charging Time

The purpose of this test is to determine the time required to fully charge a V2G vehicle using the manufacturer-recommended charging method from a specified starting state-of-charge at a specified ambient operating temperature. V2G converters that can connect to utility at multiple nominal AC voltages shall be tested separately for each nominal voltage. The detailed test procedure can be found in the NREL report [4].

6. V2G SELF-PROTECTION TESTS (OPTIONAL)

This section describes tests that are meant to evaluate the V2G power electronics' ability to protect themselves under various abnormal conditions. These tests are obtained from UL Standard 1741 "Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources" [8]. If the V2G vehicle comes with power converters that are UL1741 certified, factory test results may suffice in lieu of further third-party or owner testing.

6.1 Output Overload

This procedure ensures the DUT will not become a hazard when subjected to load conditions in excess of its ratings. The details of the test can be found in UL 1741, section 47.2.

6.2 Short Circuit

The purpose of this test is to characterize the V2G converter's response when subjected to an output-faulted condition. The details of the test can be found in UL 1741, section 47.3.

6.3 Loss of Control Circuit

The protective utility connect functions become disabled when control power is lost. Under these conditions, a utility interactive converter must cease to export power to the utility upon loss of control circuit power. The details of the test can be found in UL1741, section 47.8.

7. SAMPLE TEST RESULTS

NREL is working with the industry to develop and test V2G vehicles. Various V2G-capable electric and plug-in hybrid vehicles were tested for interconnection and electrical performance at the NREL's Distributed Energy Resources Test Facility (DERTF).

In this paper some sample results from one such V2G vehicle testing are given. This particular vehicle was a gas-electric hybrid vehicle that was converted into a V2G-capable plug-in hybrid. The original storage battery was replaced with a 12 kWh Lithium-ion battery back. Two separate power electronics converter were used in this vehicle — a battery charger for charging and an inverter for sending power back to the grid. Charge and discharge commands were sent from a local computer using CAN signal. The charge rate was adjustable, but the discharge rate was not. The V2G inverter was connected to a grid simulator at split-phase 240 V rms. The test results, as shown in this section, were collected using a Yokogawa PZ4000 Power Analyzer.

7.1 Results from Abnormal Voltage Tests

Magnitude tests were first conducted to determine the grid voltage magnitudes at which the inverter disconnected due to over and under voltage. At the moment just before the vehicle ceased exporting current due to over voltage, the voltage magnitude was 261.0 VAC rms, 108.8% of nominal voltage. From IEEE 1547, the vehicle was required to trip at or below 110% of nominal voltage, so it is in compliance. The under voltage magnitude that caused the vehicle to cease exporting current was 212.1 VAC rms, or 88.4% of nominal. The required trip magnitude is 88%, so the vehicle is in compliance. Figs. 3 and 4 show the normalized voltage magnitude and the normalized current waveform recorded during the over voltage test and the under voltage test, respectively.

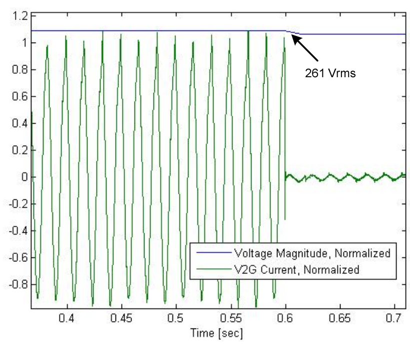

Fig. 3: Magnitude test for over voltage

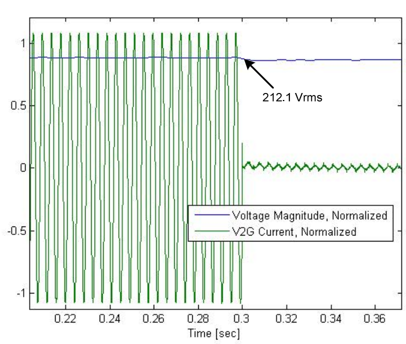

Fig. 4: Magnitude test for under voltage

Note that the small voltage drop of approximately 1% just after the inverter ceases to export current was a result of the grid simulator taking over the full load power; it was not a programmed voltage step. It did not affect the test results because it occurred after the end of test conditions.

The time tests were conducted next to determine the time it took the inverter to disconnect after the voltage range had been exceeded. The abnormal voltage time tests were conducted once for each time-magnitude pair specified in IEEE 1547. Figs. 5 and 6 show the normalized voltage magnitude and the normalized current waveform recorded during the over voltage test and the under voltage test, respectively. For the 120% over voltage test, the inverter tripped in 97 ms, well under the allowed time of 160 ms, and hence passes IEEE 1547 requirement. For the 50% under voltage test, the inverter tripped in 83 ms, about half of the allowed time, and hence passes the test. 110% over voltage and 88% under voltage tests were performed as well, and the V2G power electronics passed the tests.

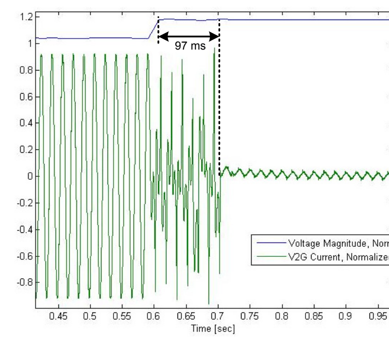

Fig. 5: Time test for over voltage

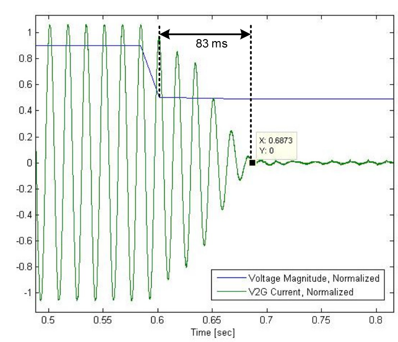

Fig. 6: Time test for under voltage

7.2 Result from Unintentional Islanding Test

The RLC load bank was tuned as described in the IEEE 1547.1, section 5.7, and the unintentional islanding test was run through several iterations. The inverter output power is not adjustable, so the test was run only at full power. Each time, the vehicle disconnected from the grid well within the allowed 2 seconds as specified in IEEE 1547.

Fig. 7 shows the grid current and load voltage during one of the test conditions. The grid current is not normalized in this figure, unlike most other waveforms shown in this paper. When the grid simulator output contactor was opened, the grid current dropped to zero. As expected, the inverter ceased to energize the RLC load a short time after that event, causing the load voltage to drop to zero.

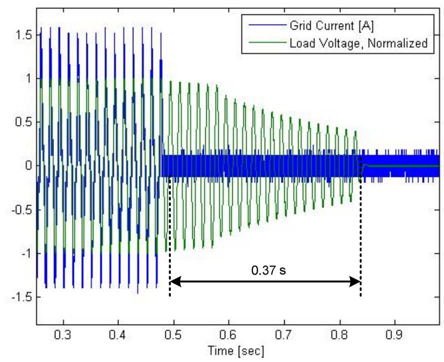

Fig. 7: Unintentional islanding test

7.3 Result from Harmonics Test

Using a Yokogawa PZ4000 power analyzer, the inverter output current waveform was captured for 100% of the rated output current. The first 40 harmonics of the output current were calculated. The results are shown below in Fig. 8, with even harmonics in (a) and the odd harmonics in (b). From the figures, it is clearly evident that all the harmonics are much smaller than the IEEE 1547 specified limits. The TRD was calculated as 0.8%, which was well below the 5% allowed by IEEE 1547. Therefore, the V2G power electronics passed the tests.

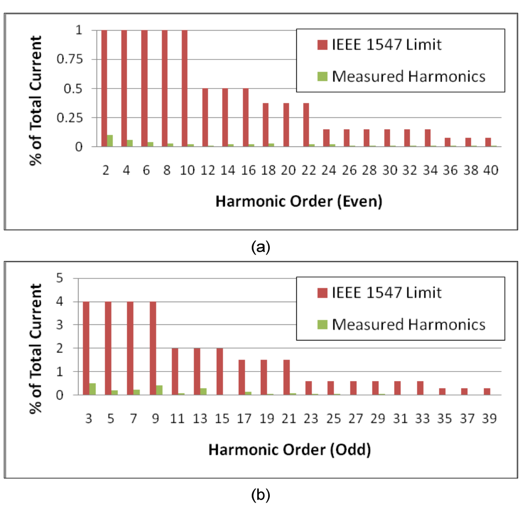

Fig. 8: Harmonics test results

7.4 Result from Continuous Output Power Test

This test was run for 85 minutes with the inverter set for 240 Vrms output voltage. During testing, the battery state of charge dropped from above 90% SOC down to 30% SOC, representative of a full discharge. The battery electronics automatically disabled discharging when SOC reached 30% to avoid battery damage. This test was run only at the nominal line voltage of 240 VAC rms. The test facility did not allow storage of the vehicle at a controlled temperature, nor did it allow for temperature regulation during testing, hence testing was conducted without temperature regulation. Fig. 9 shows that the output power was nearly constant over the test duration.

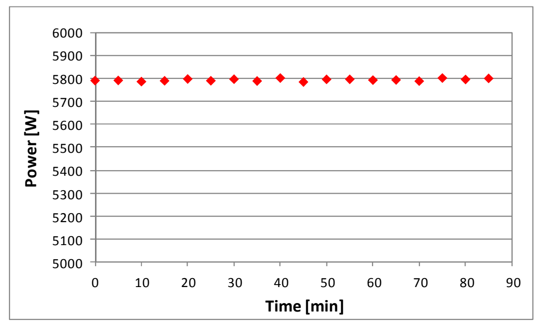

Fig. 9: V2G continuous output power

8. CONCLUSION

The advancement of power electronics and battery technology will lead to the next generation of plug-in vehicles that are V2G capable and can take power from the grid during charging and provide power to the grid during discharge. In this paper a recently published NREL technical report on interim test procedures for V2G vehicles was discussed, followed by some sample test results from a particular V2G-capable vehicle that was tested at NREL. NREL is continuing to perform these tests on V2G vehicles. Once testing is expanded to a larger variety of vehicles, these procedures could become the basis for testing standards for V2G applications.

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10. REFERENCES

(1) Emadi, A., Young, J.L., Rajashekara K., Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles, IEEE Transactions on Industrial Electronics, 2008

(2) Kramer, W., Chakraborty, S., Kroposki, B., A review of plug-in vehicles and vehicle-to-grid capability, 34th Annual Conference of IEEE Industrial Electronics Society (IECON), 2008

(3) IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE Standards Coordinating Committee, 2003 (R2008)

(4) Chakraborty, S., Kramer, W., Kroposki, B., Martin, G., McNutt, P., Kuss, M., Markel, T., Hoke, A., Interim Test Procedures for Evaluating Electrical Performance and Grid Integration of Vehicle-to-Grid Applications, National Renewable Energy Laboratory Report TP-5500-51001, 2011

(5) IEEE Std 1547.1, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE Standards Coordinating Committee, 2005

(6) Bower, W, Behnke, M., Erdman, W., Whitaker, C, Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems, http://www.bewengineering.com/docs/InvertrTestProto_041014.pdf, 2004 (accessed March 2012)

(7) Letendre, S., Denholm, P., Lilienthal, P., Electric and hybrid vehicles: new load or new resource?, Public Utilities Fortnightly, 2006

(8) UL 1741 Ed. 2, Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, Underwriters Laboratories, 2010