1999 Toyota RAV4 EV NiMH Charging Systems Study

Volume 1

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EPRI Project Manager
R. Swaroop

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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2244 Walnut Grove Avenue
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Principal Investigator
N. Pinsky

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REPORT SUMMARY

The testing discussed in this report seeks to provide information needed for evaluating energy consumption and charging impacts of various types of Original Equipment Manufacturer (OEM) EV charging systems. The report addresses these questions by studying the AC power quality and demand impact of three charging systems. All there were used with the Toyota RAV4 EV inductive and conductive versions.

Background

EV charging systems are expected to become a significant portion of the load on the utility system in the near future. The significant load that EVs would represent in the coming years and their presence in Southern California Edison's (SCE) vehicle fleet and service territory requires that SCE investigate the impact that these EV chargers would have on the utility.

Objective

To provide information for evaluating energy consumption and charging impacts of EV charging systems.

Approach

In order to evaluate the impact of EV charging, the selected OEM EVs were evaluated at several states of charge (SOC). To discharge the vehicles, they were driven on the Urban Pomona Loop at minimum payload and with no accessories to the specified SOCs as indicated by the vehicle's SOC gage. After discharge, the vehicles were placed on charge and monitored for power quality and demand. The power quality parameters monitored were:

- True Power Factor (TPF)
- Displacement Power Factor (dPF)
- Voltage Total Harmonic Distortion (V THD)
- Current Total Harmonic Distortion (I THD)
- Fundamental Current ($I_{fundamental}$)

In conjunction with power quality issues, the team analyzed the demand profiles of EV systems. By studying the demand of EV systems in conjunction with EV penetration and customer usage data, electric utilities can better prepare for the impact of this new technology. The data will also help the utilities with load management, planning service upgrades, and rate planning.

Results

Charger testing has been completed for both inductive and conductive versions of the Toyota RAV4 EV with good results. In terms of the power quality, data shows that on the circuit tested, all charging systems had excellent power quality characteristics. The power factor remained well above 0.95 throughout the normal operating range, and the total harmonic distortion (THD) for

current and voltage remained well below the limits set by the IEEE 519 standards and recommended by the National EV Infrastructure Working Council (IWC). The (IWC) recommends a maximum limit of 20% for current THD and also recommends a minimum limit of 0.95 for true power factor for level 2 chargers. IEEE 519 recommends a limit of 15% for current total demand distortion (TDD) for the particular circuit used for these tests.

In terms of demand, the data shows that both inductive Gen I and Gen II chargers had a peak charging power that ranged between 6.8 kW to 7.0 kW and had a charge duration of about 1.25 hours to 4.75 hours when charging from 80% and 10% SOC respectively. The peak charging power of 5.00 kW for the Toyota on-board conductive charger ranged between 1.5 hours to 5.75 hours for the same SOCs. The difference between the peak power duration and the total charge duration for the tested chargers were found to be very small. The small difference between the peak power duration and the total charge duration accounted for the charger's good utilization of the charging equipment (Utilization Factor), except for occasions when thermal management and/or pack equalizations were necessary.

The inductive and conductive versions of the RAV4 need to be tested one final time for performance at the Pomona Raceway. Range tests will also be performed after performance testing. These results will show what kind of performance drop-off these vehicles experienced with respect to the vehicle's final mileage and type of usage.

EPRI Perspective

There is a need to educate customers on the load impact and opportunities for load management of EVs. Concerns about EV charging impacts on the grid dictate that EPRI and the utility industry be involved in working closely with initial EV users to understand how to fully plan for EV load and take full advantage of the potential for EV load management.

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Keywords

Electric vehicles
EV testing/performance
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EV battery charger testing/performance

ABSTRACT

To support the safe and efficient use of electric vehicles (EV) and to minimize their potential utility system impacts, Southern California Edison (SCE) in cooperation with the Electric Power Research Institute (EPRI) has been involved in evaluating EVs and their corresponding chargers.

EV charging systems are expected to become a significant portion of the load on the utility system in the near future. The significant load that EVs would represent in the coming years and their presence in SCE's vehicle fleet and service territory requires that SCE investigate the impact that these EV chargers would have on the utility. The testing discussed in this study seeks to provide the information needed for analyzing the energy consumption and charging impacts of the 1999 Toyota RAV4 EV inductive and conductive versions. Additionally, the performances of both versions of the Toyota RAV4 EV were documented in the form of a Performance Characterization report (see *1999 Toyota RAV4 EV (NiMH) – Inductive Charging Performance Characterization Report (Task 1)* and the *1999 Toyota RAV4 EV (NiMH) – Conductive Charging Performance Characterization Report (Task 1)* dated November, 1999), which analyzes the vehicle's overall performance in terms of charger performance and on-road performance.

EXECUTIVE SUMMARY

The testing that was performed on the selected OEM vehicles seeks to provide the information needed for evaluating the energy consumption and charging impacts of the EV charging systems. This report addresses these questions by studying the AC power quality and demand impact of currently available inductive and conductive chargers for the Toyota RAV4 EV. Both inductive and conductive versions of the Toyota RAV4 EV are powered by Panasonic Nickel Metal Hydride (NiMH) batteries. All of the testing done with the inductive chargers was completed a 1999 Toyota RAV4 EV inductive version. The on-board conductive charger testing was completed using a 1998 Toyota RAV4 EV and a few data points obtained with a 1999 Toyota RAV4 EV conductive model for comparative purposes.

In order to evaluate the impact of EV charging, the selected OEM EVs were evaluated at several states of charge (SOC). To discharge the vehicles, they were driven on the Urban Pomona Loop (see Appendix C, page C-1) at minimum payload with no accessories to the specified SOCs as indicated by the vehicle's SOC gage (see Appendix E, page E-1). After discharge, the vehicles were placed on charge and monitored for power quality and demand.

Charger testing has been completed for both inductive and conductive versions of the Toyota RAV4 EV with good results. In terms of the power quality, data shows that on the circuit tested, all charging systems had excellent power quality characteristics. The power factor remained well above 0.95 throughout the normal operating range and the total harmonic distortion (THD) for current and voltage remained well below the limits recommended by the National EV Infrastructure Working Council (IWC) and set by the IEEE 519 standards. The National EV Infrastructure Working Council (IWC) recommends a maximum limit of 20% for current THD and also recommends a minimum limit of 0.95 for true power factor for level 2 chargers. IEEE 519 recommends a limit of 15% for current total demand distortion (TDD) for the particular circuit used for these tests.

In terms of demand, the data shows that both inductive Gen I and Gen II chargers had a peak charging power that ranged between 6.8 kW to 7.0 kW and had a charge duration of about 1.25 hours to 4.75 hours when charging from 80% and 10% SOC respectively. The peak charging power of 5.00 kW for the Toyota on-board conductive charger ranged between 1.5 hours to 5.75 hours for the same SOCs. The difference between the peak power duration and the total charge duration for the tested chargers were found to be very small. The small difference between the peak power duration and the total charge duration would accounted for the charger's good utilization of the charging equipment (Utilization Factor), except for occasions when thermal management and/or pack equalizations were necessary.

The AC kWh per kilometer efficiency for both of the inductive charging systems displayed an almost direct proportionality with the SOC charge at which charging was started. The on-board Toyota conductive charger on the other hand had an AC kWh per kilometer efficiency that was constant for the entire range of starting SOCs tested.

Testing is still underway on the life cycle and performance testing of the two RAV4s and will be completed and reported on very shortly in an addendum report.

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1
INTRODUCTION

Electric Vehicle (EV) charging systems are expected to become a significant portion of the load on the utility system in the coming years. In residential applications, EVs can potentially double a household's electrical demand. The significant load that EVs would represent in the future and their presence in Southern California Edison's (SCE) vehicle fleet and service territory requires that SCE investigate the impact these EV chargers would have on the utility.

There is also a need to educate customers on the load management of EVs. Concerns about charging impacts on the utility dictate that SCE and EPRI be involved in working closely with initial EV users to understand how to fully implement the potential for load management.

The testing discussed in this report seeks to provide the information needed for evaluating the energy consumption and charging impacts of various types of Original Equipment Manufacturer (OEM) EV charging systems. This report addresses these questions by studying the AC power quality and demand impact of three charging systems, all used with the Toyota RAV4 EV inductive and conductive versions. Both inductive and conductive versions of Toyota's RAV4 are powered by "Panasonic" NiMH batteries.

The charging systems that were tested were:

1. First generation Hughes 6.6 kW Inductive charger (Magne Charge Gen I)
2. Second generation Hughes 6.6 kW Inductive charger (Magne Charge Gen II)
3. Toyota on-board conductive charger (with EVI off-board Electric Vehicle Service Equipment (EVSE))

In order to understand the impact of these chargers, the power quality parameters of the various charging systems were measured and recorded at various power levels. Also, the demand profiles of the Toyota RAV4 EV conductive and inductive were recorded when charging from various states of charge.

Overall on-road vehicle performance was also compiled for each of the RAV 4 vehicles tested as summarized in Appendix A and B on pages A-1 and B-1.

2
TEST OVERVIEW

Performance characterization testing was the first and foremost test that was conducted on the test vehicles in order to get a general expectation of the vehicle's overall system performance (See Appendix A and B for summary sheets).

In order to evaluate the impact of EV charging, the selected OEM EVs were evaluated at several states of charge (SOC). To discharge the vehicles, they were driven on the Urban Pomona Loop (see Appendix C, page C-2) at minimum payload and with no accessories to the specified SOCs as indicated by the vehicle's SOC gage (see Appendix E, page E-1). The indicated reading on the vehicle SOC gage does not refer to actual SOC of the battery, but rather to a SOC level within the range set by the vehicle/battery manufacturer as the vehicle's operating range. After discharge, the vehicles were placed on charge and monitored for power quality and demand. The power quality parameters that were monitored were:

- True Power Factor (TPF)
- Displacement Power Factor (dPF)
- Voltage Total Harmonic Distortion (V THD)
- Current Total Harmonic Distortion (I THD)
- Fundamental Current ($I_{fundamental}$)

The values for Total Demand Distortion (TDD) were calculated using I THD, $I_{fundamental}$, and the manufacturer's advertised maximum current draw; 30 Amps for the inductive Gen I and Gen II chargers, and 22 Amps for the conductive on-board charger.

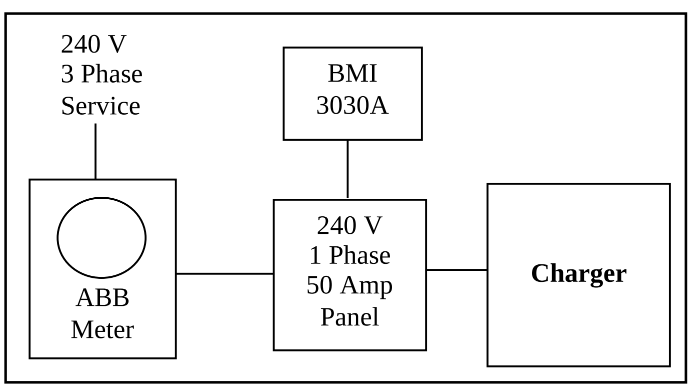


Figure 2-1
Test Set-Up Block Diagram

The power quality of the charging systems were monitored at the service panel supplying the chargers as shown in Figure 2-1, page 2-1, and recorded during charge with snapshots at various AC demand levels using the BMI 3030A PowerProfiler shown in Figure 2-2, below.

Figure 2-2
BMI 3030A PowerProfiler

In all power quality studies where harmonic distortions are analyzed, the power distribution circuit used plays a major role. For the measurements made in this study, the distribution circuit diagram in Figure 2-3, page 2-3, illustrates the circuit used in this study. The short circuit current to maximum fundamental load current (I_{SC}/I_L) ratio used in determining the IEEE 519 current distortion limits was approximately 300. To obtain this value the short circuit current was calculated to be 8000 Amps and the maximum fundamental load current was considered to be the charger's maximum draw of about 30 Amps for the Hughes chargers and about 22 Amps for the Toyota charger. With the maximum fundamental load current ratio known, the maximum Total Demand Distortion (TDD) allowable, according to IEEE 519 recommended harmonic limits table, was determined to be 15%.

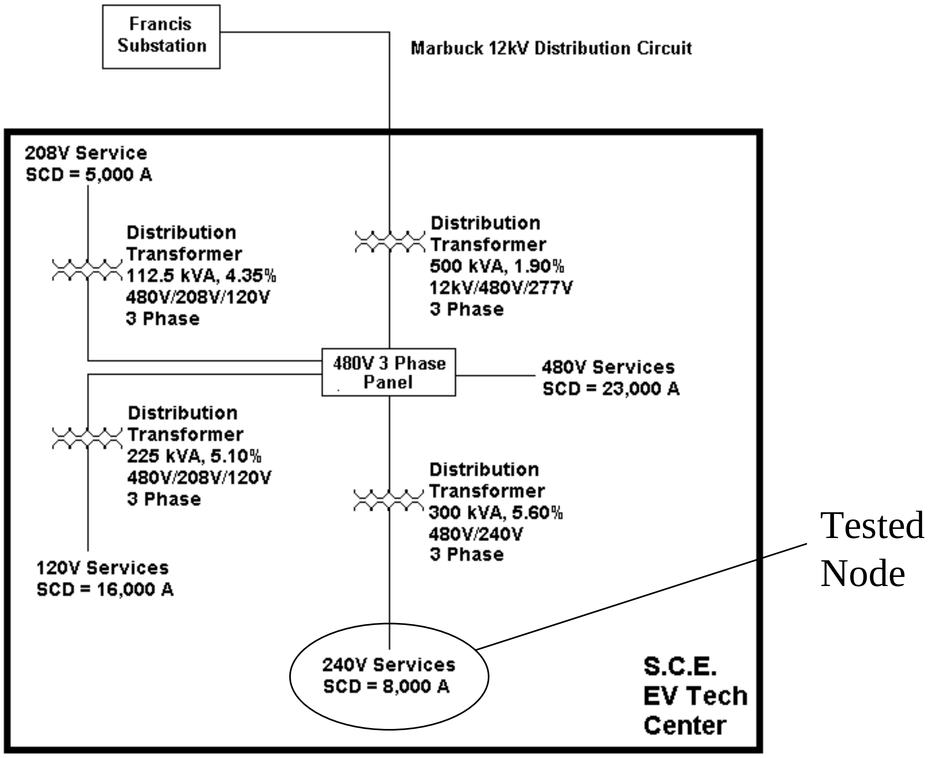


Figure 2-3
SCE EV Tech Center Line Diagram

Figure 2-4
Portable ABB FM2S Watt-hour Meter

The demand and energy consumption observed during the charging of all the vehicles in this study was measured and recorded at a sample frequency of 1 minute with a portable ABB FM2S Watt-hour meter similar the one shown in Figure 2-4.

3
CHARGING SYSTEMS OVERVIEW

Figure 3-1
Hughes 6.6 kW Gen I Inductive Charger

Figure 3-2
Hughes 6.6 kW Gen II Inductive Charger

Figure 3-3
Toyota RAV4 Off-board Conductive EVSE, with Yazaki Connector (charger on-board)

The two Hughes 6.6 kW Inductive Chargers, shown in Figure 3-1 and 3-2, are off-board Level 2 (< 240 VAC, < 60 A, and < 14.4 kW) EV battery chargers that transfer energy to the on-board system through inductance. The system, as shown in the block diagram in Figure 3-4, page 3-3, consists of an off-board floor mount charger (Figures 3-1 or 3-2), an on-board converter and a controller. The charger is coupled to the vehicle through a take-apart transformer, made up by the charge coupler and the charge port.

The system operates by transferring energy through a magnetic field created by a high frequency AC Current in the charge coupler (80 kHz to 370 kHz). The coupler / port combination acts as a one-to-one transformer which isolates the off-board charger from the on board system and sends a high frequency AC current to the converter. The converter converts this high frequency AC current to a DC current for charging the battery pack. The entire system is controlled by the on-board controller which communicates with the off-board charger via radio communications. According to the manufacturer’s specifications for the Gen I and Gen II chargers, the system AC inputs can be 208 to 240 Volts AC with a 50 to 60 Hertz frequency (60 Hertz for the Gen II) and a maximum draw of 30 Amps AC.

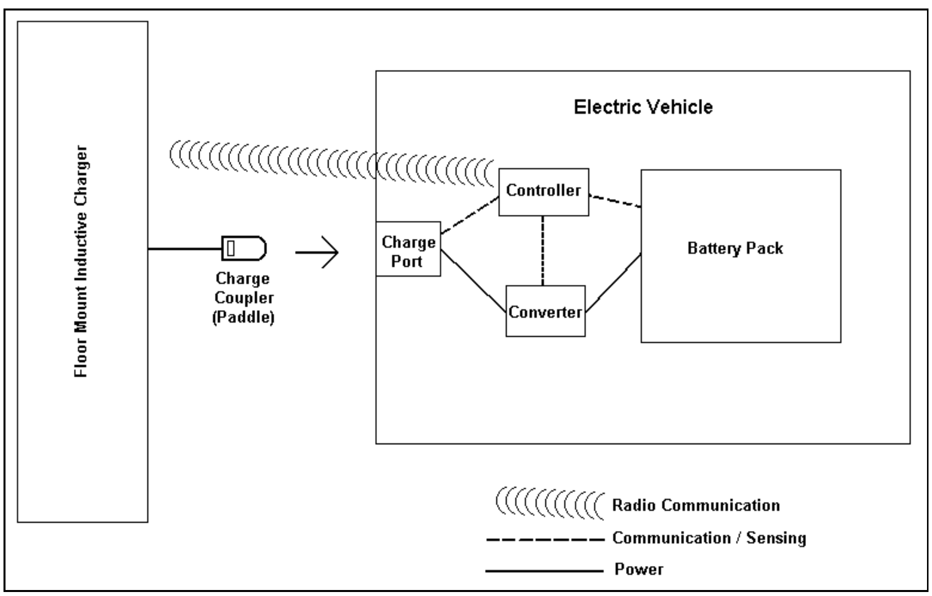


Figure 3-4
Hughes 6.6 kW Inductive Gen I and Gen II Charger Block Diagram

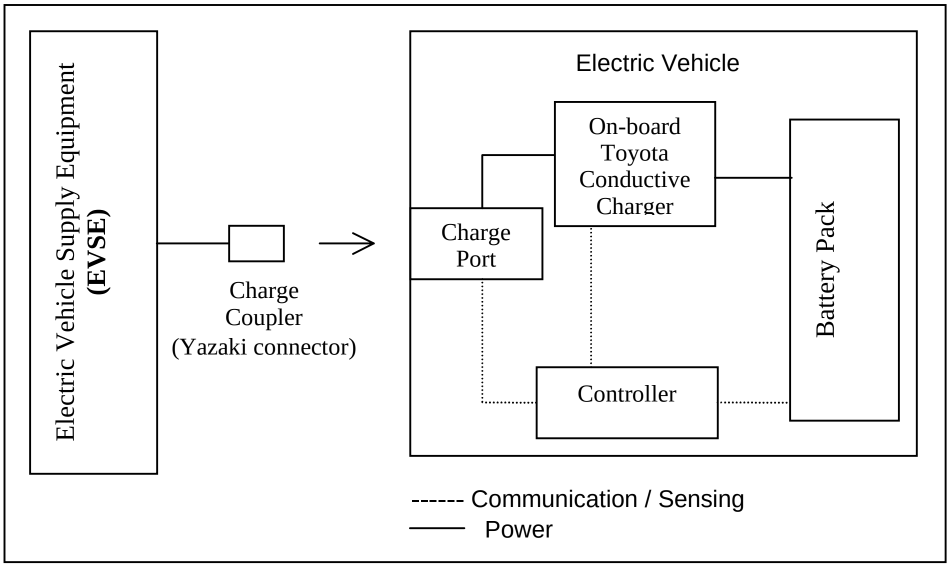


Figure 3-5
Toyota Conductive Charger Block Diagram

The Toyota conductive system seen in the block diagram in Figure 3-5 above, consists of an on-board charger that is connected to the utility grid through an Electric Vehicle Service Equipment (EVSE). The EVSE provides the on-board charger the energy that is requested by the on-board controller through hardwire communication. The connection used to charge the conductive version of the Toyota RAV4 EV is made up of a removable conductive connection, which consists of a Yazaki connector located on the EVSE and a charge port located on the right front fender of the RAV4 EV. The EVSE, Intelligent Charging Station (model # ICS-200-B), has an input rating of 208 to 240 Volts AC with a 50 to 60 Hertz frequency and 40 Amp maximum current draw. The on-board Toyota conductive charger has a 22 Amp maximum current draw rating. The on-board system, like the inductive system, is isolated from the off-board EVSE supply side with the use of an on-board transformer. The AC current from the transformer is then sent to the converter, which converts the AC current to DC current for charging the battery pack.

4
POWER QUALITY ANALYSIS

The impact of poor power quality manifests itself in a variety of ways, affecting both the customer and the utility. For example, poor power quality can damage a customers' sensitive electronic equipment or overheat electrical conductors, which would require the need for larger equipment to serve the same electrical load. In this report, there are two characteristics of EV battery charging that are examined which directly impact power quality. They are power factor and harmonic distortion.

Power Factor

Power factor is defined as the ratio of Watts to Volt-Amps and can be characterized as True or displacement depending on the assumption of linear voltage-current characteristics. For displacement power factor, only the fundamental quantities are used in the calculation while with True power factor, harmonic distortions in the voltage and current are accounted for. With True power factor, the true system efficiency is characterized while the difference in value between True and displacement power factor gives an indication to the level of harmonic distortion generated in the system.

The National EV Infrastructure Working Council (IWC) recommends that the true power factor be limited to a minimum value of 0.95 for Level 2 charging. In Figure 4-1, page 4-2, the power factor values measured for the Hughes Gen I and Gen II 6.6 kW Inductive Chargers are plotted as a function of the measured AC demand. In this plot we see that throughout the normal working demand range of the chargers, 1 kW to 7 kW, the True power factor stays well above 0.95 TPF. Also, the difference between True and displacement power factor is low, indicating that harmonic distortions are kept low.

Power factor results for the Toyota on-board conductive charger can be seen in Figure 4-2, page 4-2, which also shows to have power factors well above 0.95 throughout the working demand range. The majority of the power quality tests done with the conductive charging system were completed with the 1998 model Toyota RAV 4 EV, subsequent data was later obtained with the 1999 model Toyota RAV 4 EV to determine any differences between the two. Both model years of the Toyota RAV4 were found to have similar test results.

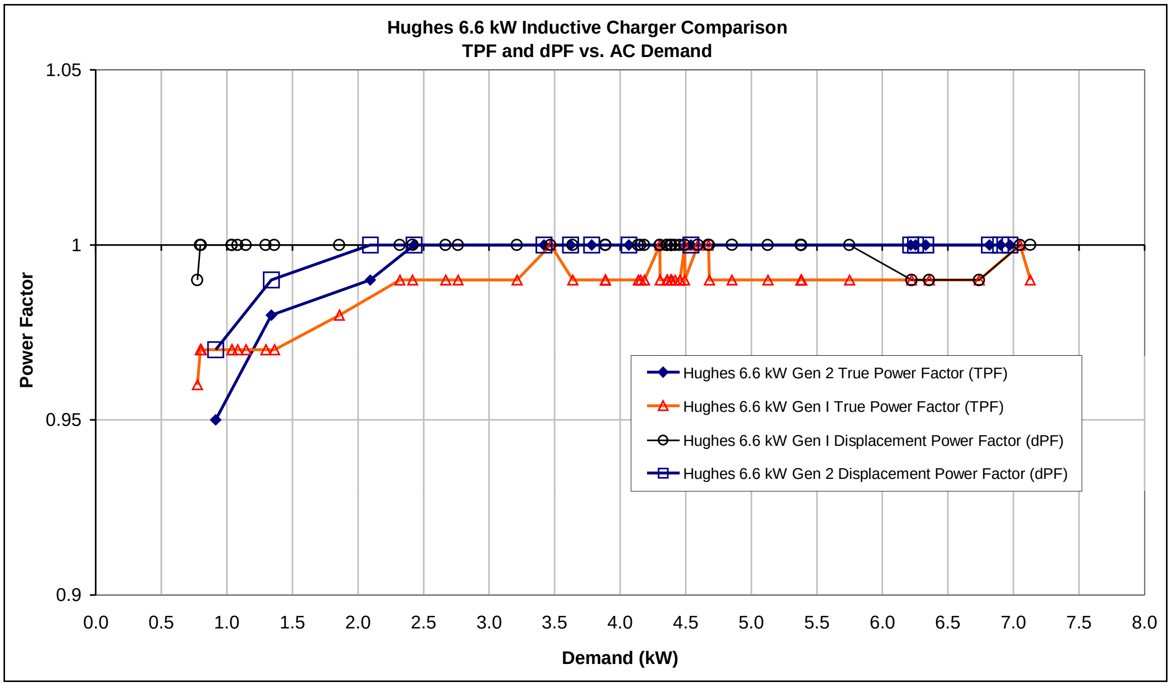


Figure 4-1
True and displacement Power Factor as a Function of the AC Demand for the Hughes 6.6 kW Inductive Gen I and Gen II Chargers

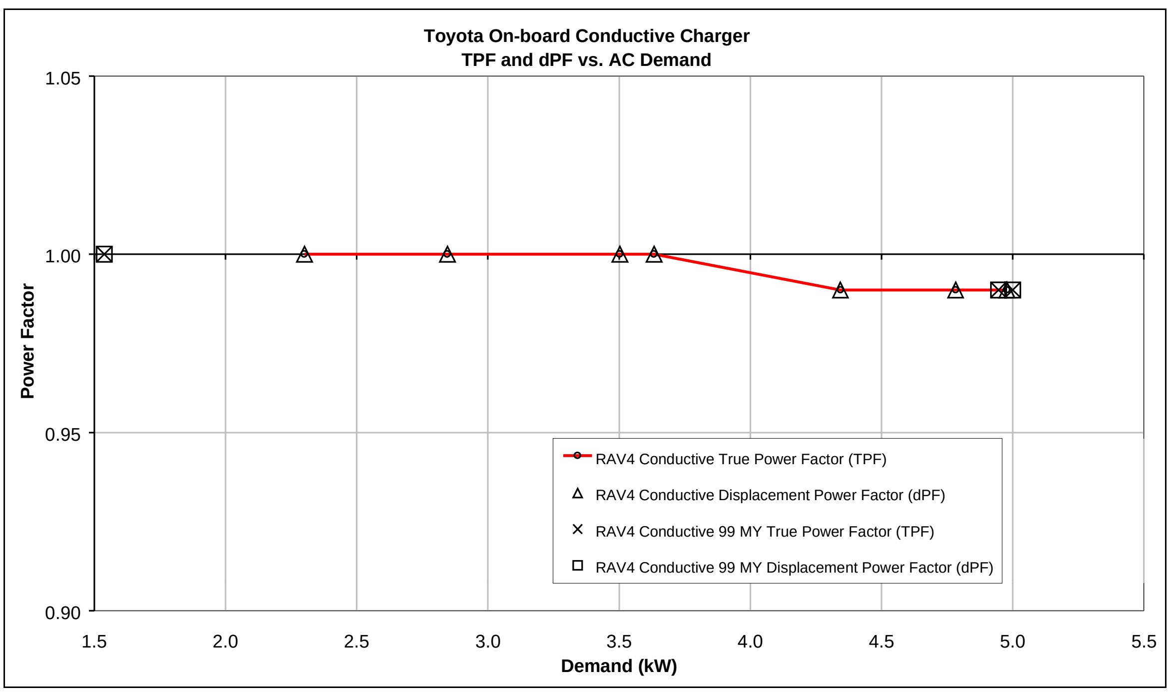


Figure 4-2
True and displacement Power Factor as a Function of the AC Demand for the Toyota on-board Conductive Charger

Harmonic Distortion

Harmonics are components of a periodic waveform that can be described as a sine wave with an amplitude, phase and integer frequency with respect to the fundamental waveform. A waveform that is a perfect sinusoidal wave has only one component, the fundamental. When other wave components exist other than this fundamental, the wave is said to be harmonically distorted.

Total Harmonic Distortion (THD) is a percentage measure, which compares the amplitude of all the harmonic components to the fundamental and can be applied to describe the magnitude of harmonic distortion in the line voltage or current. It is calculated by ratio of the root mean square of all the harmonics to the fundamental.

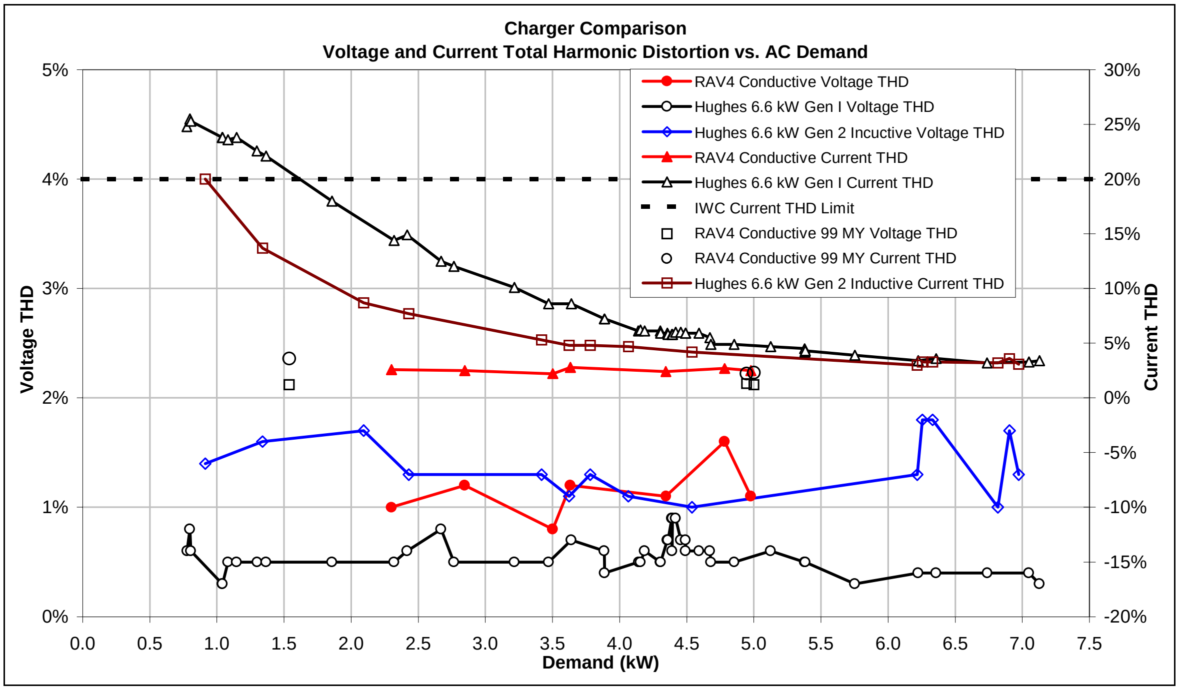


Figure 4-3
Total Harmonic Current and Voltage Distortion for All Charging Systems Tested

In Figure 4-3 above, the voltage and current THD values measured for the Hughes 6.6 kW Gen I and Gen II inductive, and the Toyota on-board conductive chargers are plotted as a function of the measured AC demand. In this plot we see that throughout the working demand range of the chargers, the voltage THD stays below 1.8%. This would usually be expected while testing on a circuit such as the one used in our tests, refer to Figure 2-3, page 2-3, for our test circuit line diagram. The test circuit used has the characteristic of low impedance, which would limit the amount of voltage distortion induced by the current harmonics. Voltage harmonic distortions are generally limited by the utilities whereas the customer should limit current harmonic distortions. The National EV Infrastructure Working Council (IWC) recommends a maximum limit of 20% for current THD. The current THD shown in Figure 4-3 illustrates that all the charging systems tested were well below the IWC recommendation for current THD at the rated maximum demand of the chargers. For demands less than this rating, only the Hughes Gen I exceeds the recommendation until demand falls to less than 2 kW. However, at this point the amount of current harmonic distortion in relation the maximum load and service size is not a problem as is shown with the total demand distortion.

Total Demand Distortion (TDD) is similar to THD in that it is a percentage measure which compares the amplitude of all the harmonic components to the base value. The difference lies in that for TDD the base value is the maximum fundamental load current. Additionally, TDD can be used only to describe the current harmonics in relation to the maximum load.

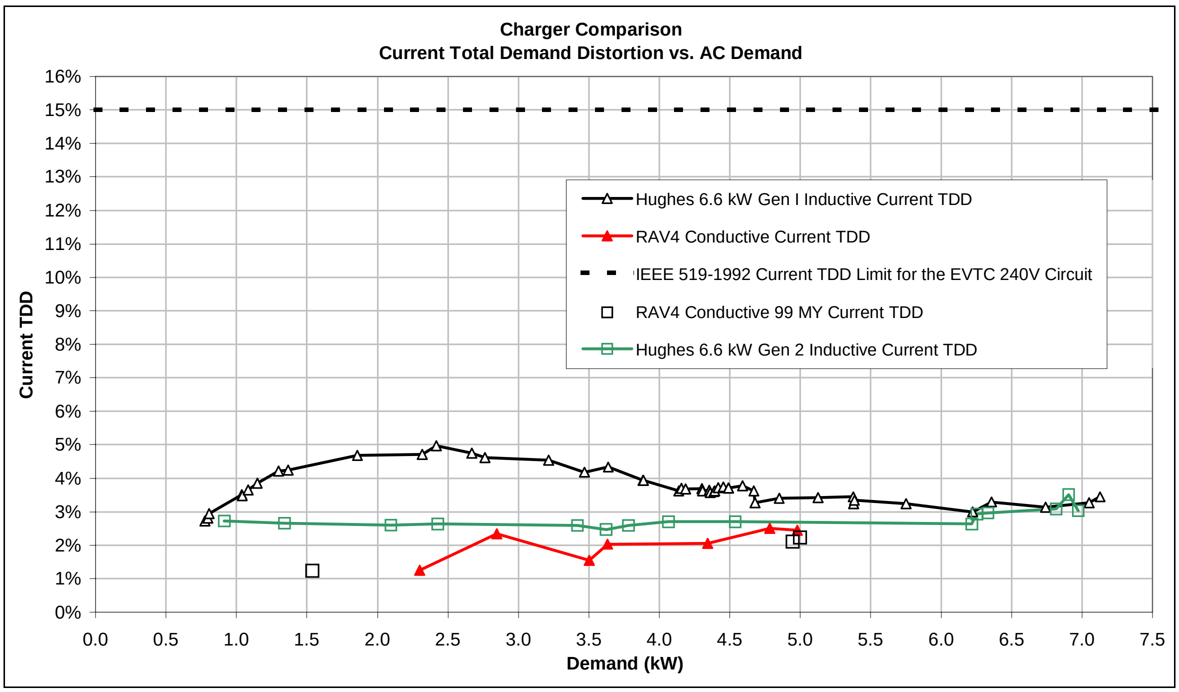


Figure 4-4
Current Total Demand Distortion was Tested for all Charging Systems

In Figure 4-4 above, it can be seen that throughout the working range of the chargers tested, the TDD stays well below the IEEE 519 recommendation for the circuit used. The TDD IEEE 519 standard is based on the short circuit current, which varies from location to location, so it should not be used as an equipment guideline. However, it does provide useful information on the interaction of the load with the circuit. To that extent, it can be used to describe the current harmonic qualities of the system under test. For the circuit tested, a total demand distortion (TDD) limit of 15% was used based on IEEE 519 recommendations.

5
AC DEMAND ANALYSIS

In conjunction with power quality issues, an analysis of the demand profiles of EV systems was examined. By studying the demand of EV systems in conjunction with EV penetration and customer usage data, electric utilities can better prepare for the impact of this new technology. The data will also help the utilities with load management, planning service upgrades, and rate planning.

In an effort to produce EVs with sufficient range to satisfy mission requirements, several different types of battery technologies have been developed. Due to this diverse population of battery technologies, the demand profiles of EVs will differ significantly from one battery technology to the next. These profiles may also differ between charger manufacturers/models as each one approaches the task of charging differently. Figure 5-1 below illustrates these differences for the Toyota inductive and conductive versions of the RAV4 EV, both of which use Panasonic NiMH batteries.

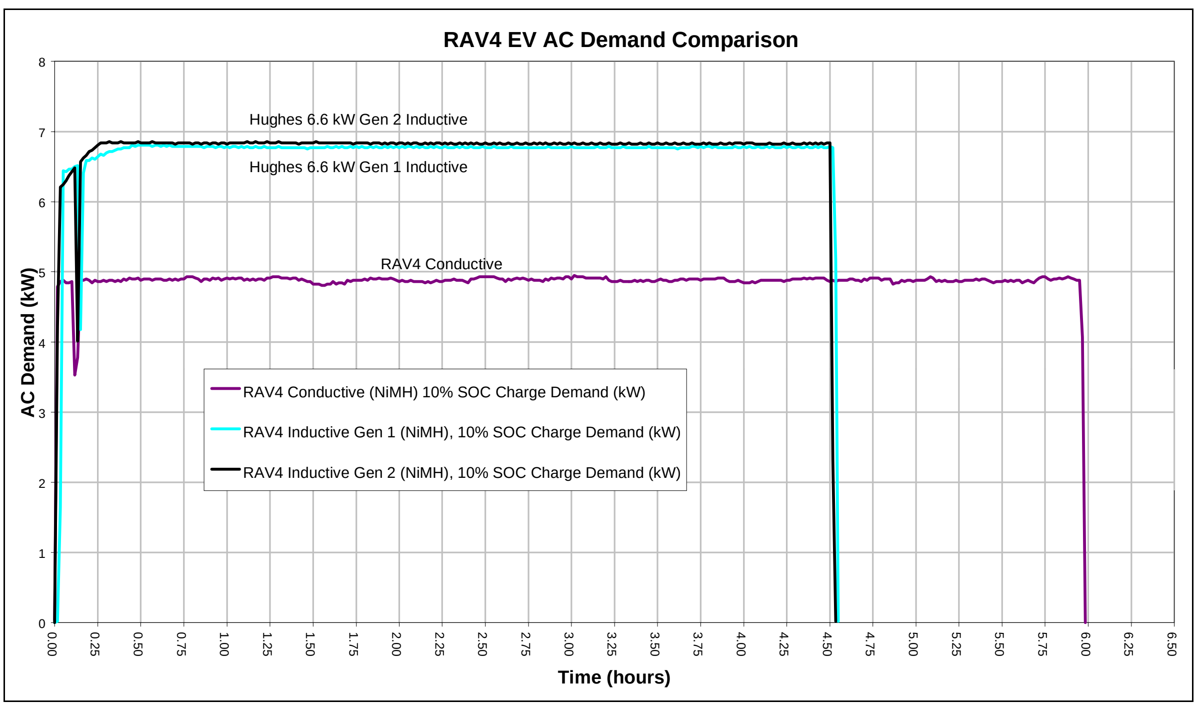


Figure 5-1
AC demand on charge from 15% to 100% SOC for the Toyota RAV4 Inductive and Conductive

Along with normal recharges, there is in some instances, an additional demand for periodic pack equalization charging. For the testing conducted in this study, Figure 5-2 illustrates the departures from the normal charging profiles that these additional demands caused.

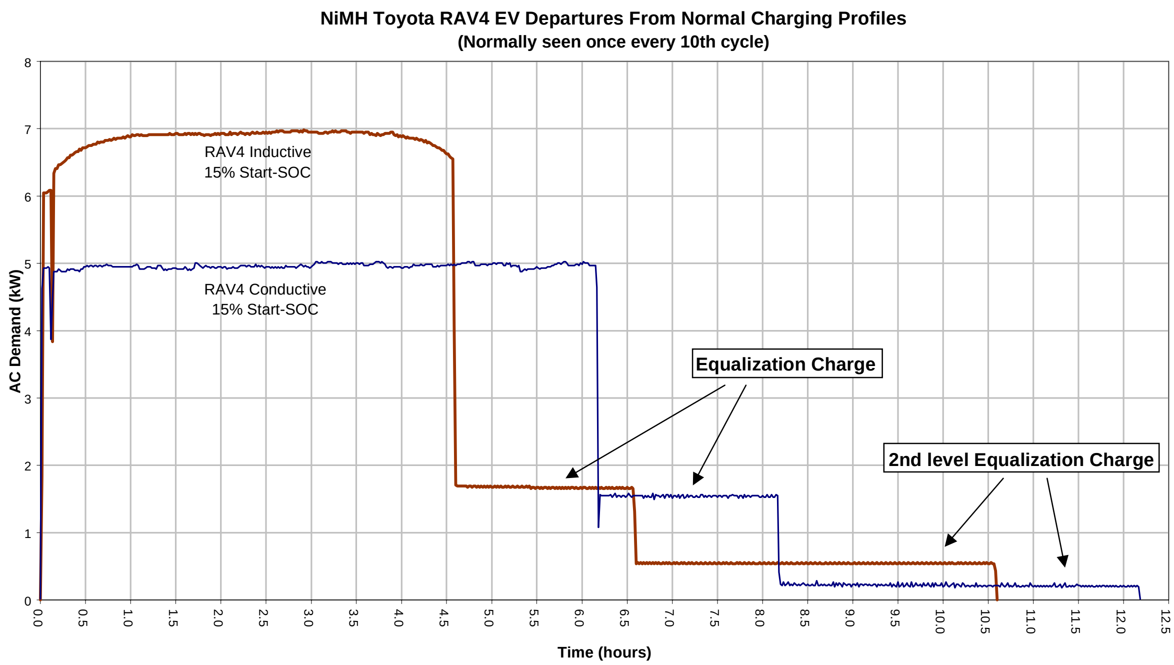


Figure 5-2
Equalization demands for the Inductive and Conductive Toyota RAV4 EV

For the purpose of simplifying the analysis of the profiles in this study, the equalization charges observed during the testing of the Toyota RAV4s were excluded from all of the following plots. The assumption made to qualify this exclusion was that these equalization portions of the recharge were at a demand level that was considered to be insignificant, less than 1.7 kW. It was also observed that in normal usage, these equalization charges occurred infrequently, only about once every 10th charge cycle, according to Toyota qualified technicians. Low power demands were also found to occur when the vehicle was charged immediately after a drive on a hot day. In this situation the battery pack temperature may dictate the demand-input level to keep the battery pack temperature low. Using the charge timer at cooler off-peak charging time could help avoid the temperature related demands by giving the battery pack some time to cool before charging.

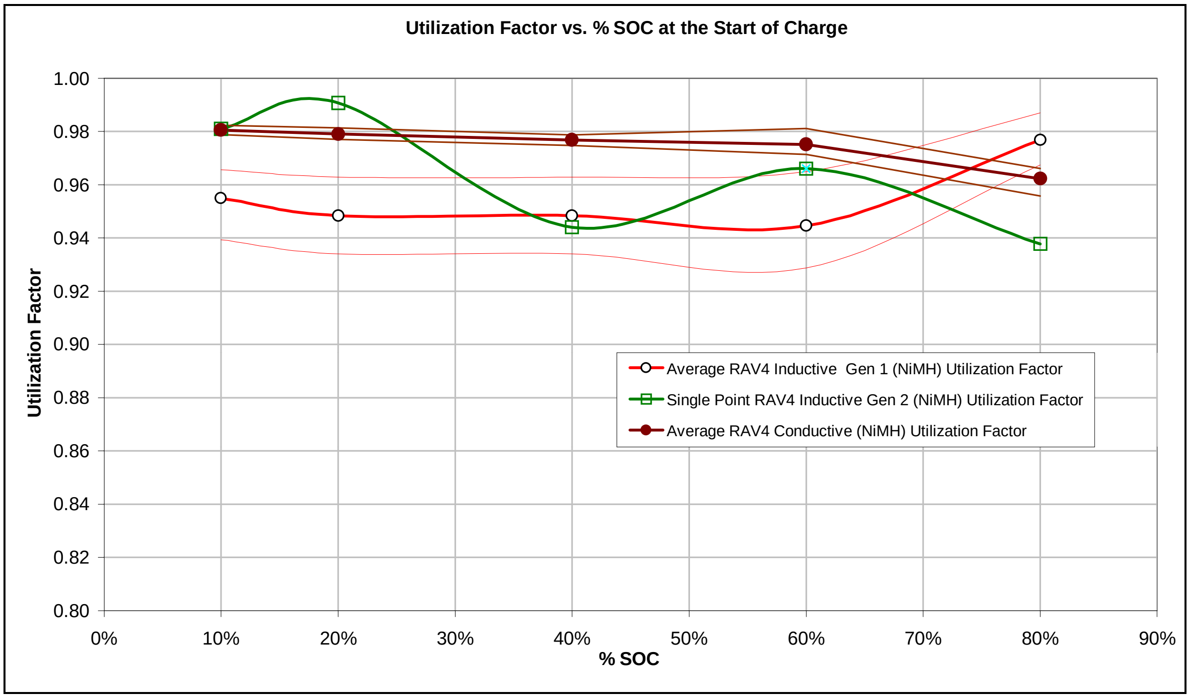


Figure 5-3
Utilization Factor for all charging systems as a function of starting SOC

In examining Figure 5-1, page 5-1, it is seen that the conductive version charges the vehicle at a lower power level when compared to the inductive version, but the conductive version can provide a more efficient charge at the peak power level. This quality is further illustrated in Figure 5-3 above. Utilization Factor, in this application, is calculated as the ratio of energy delivered to the maximum possible amount of energy that can be delivered by the charger while maintaining the same peak demand and charge duration. This describes how efficiently the system uses available charger capability. The values in this plot are the Utilization Factors of each charging system tested as a function of the Percent State of Charge (SOC) at the start of charge along with their respective minimum and maximum variance envelopes (Gen 2 uses only one data point per SOC). Good utilization factors usually represent the charger will stay at its peak charging power, where current harmonics are the lowest and power factors are closest to 1.00, for the longest amount of time. By maximizing the Utilization Factor value at all SOCs, the capital assets for charging are used most efficiently for the customer and utility. In Figure 5-3 we see that the charging technologies of the all the charging systems tested in this project showed impressive results. Utilization Factors were not found to go below 95%, which is a substantial improvement over other tested OEM technologies. It should be noted that the utilization factors do not take into account the maximum available power from the utility side at the point where the charger plugs in, but only examines the chargers available output power.

Another aspect of EV charging demand that was examined was the charge duration and its time variation. To expand on this aspect, the duration and variation of the charge times at peak demand were analyzed. Figures 5-4 and 5-5 represent these aspects of peak and total charge duration.

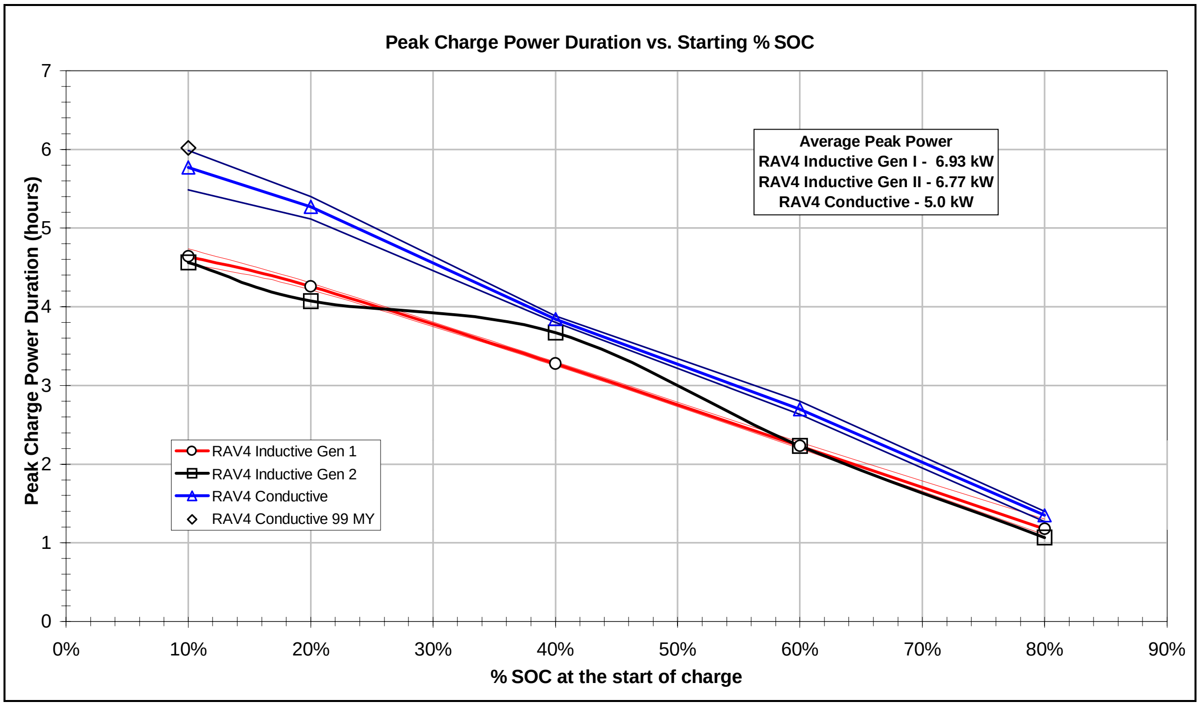


Figure 5-4
Peak Charge Power Duration as a function of SOC

In Figure 5-4, the duration of charge at peak power was found to be relatively linear for the average values found for the conductive and inductive charging systems. A favorable quality that is displayed by all the technologies tested is that the charge times at peak demand were very consistent between tests. The total charge times shown in Figure 5-5, page 5-5, were found to be very similar to the peak power duration, which would account for the excellent utilization factors found on all charging systems tested. This trend was observed because all the charging systems tested would charge at or near peak power for the duration of the charge. Only when infrequent equalization demand charges occurred, would the total charge time deviate from the peak power charge time.

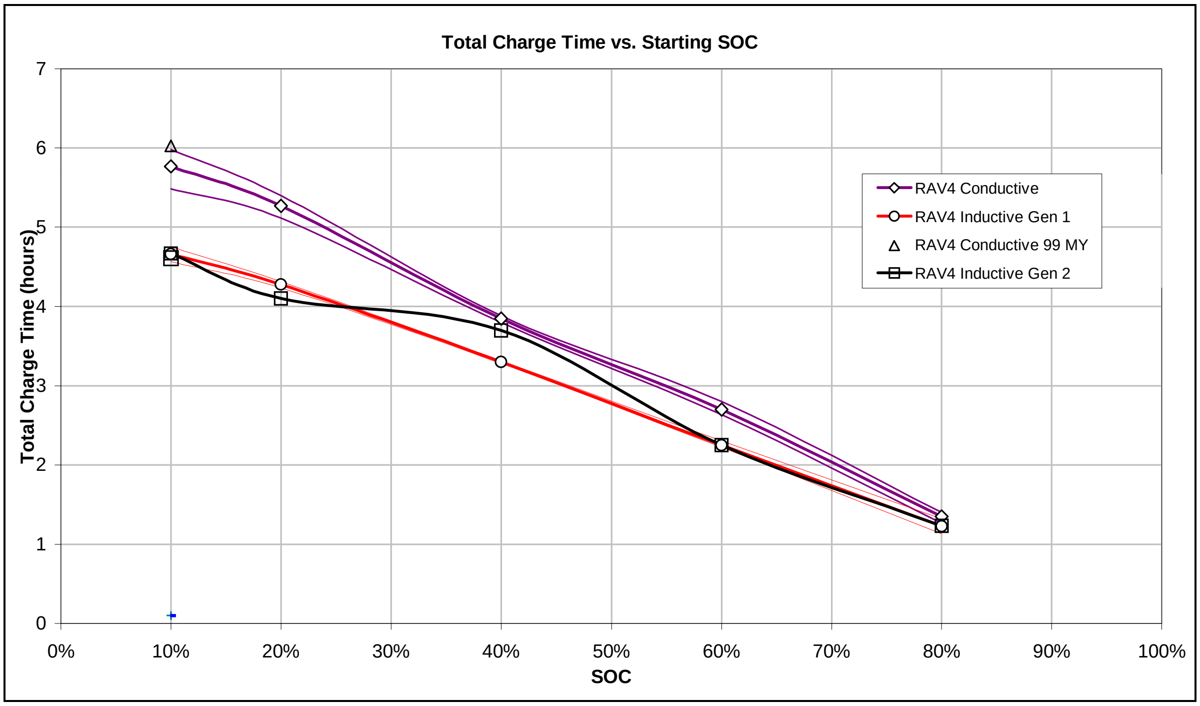


Figure 5-5
Total Charge time as a function of SOC

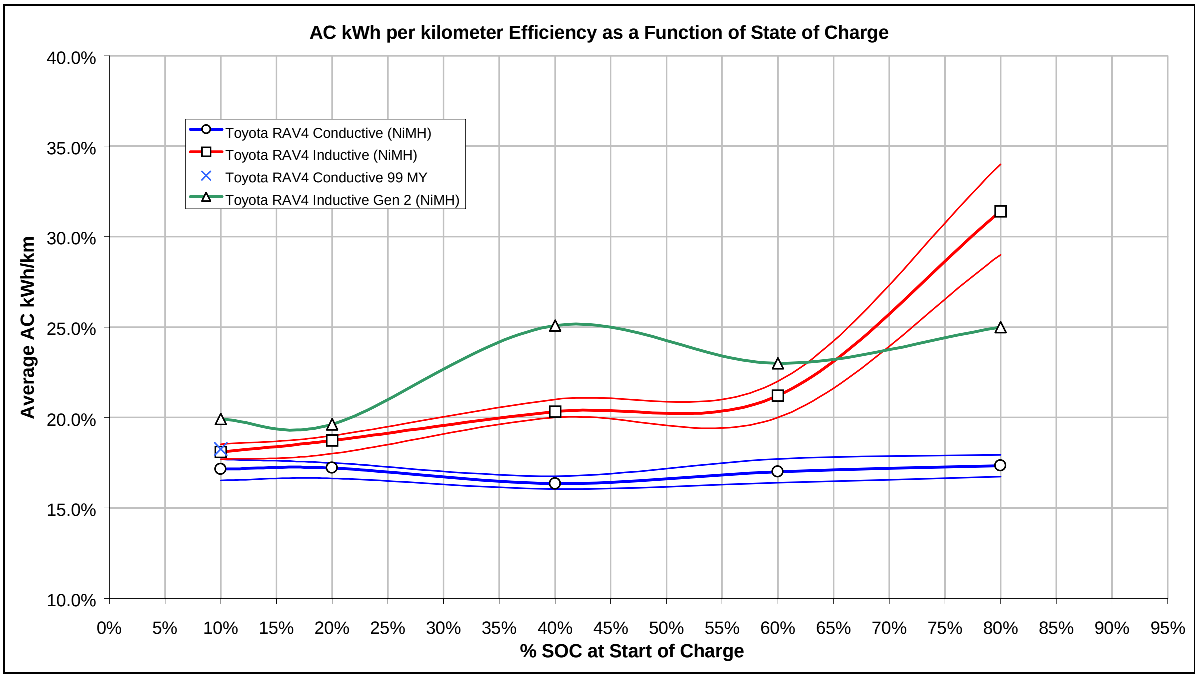


Figure 5-6
AC kWh per kilometer efficiency as a function of SOC

The AC kWh per kilometer energy efficiencies of the vehicles can be found in Figure 5-6 above. This value is used to compare the energy efficiency of electric vehicles just as Miles per Gallon or kilometers per liter are used for internal combustion engine (ICE) vehicles. The results show that the conductive charging system had a superb AC kWh per kilometer efficiency that remained constant for all the starting SOCs tested. The inductive Gen I and Gen II versions of the Hughes 6.6 kW charger showed a decreasing trend in which the best efficiency was observed at 10% starting SOC and the worst efficiency was observed at 80% starting SOC. What this translates to is that a deeper discharge will generate a better vehicle efficiency.

6
SUMMARY

Testing of both the inductive and conductive versions of Toyota's RAV4 EV during recharge from various SOCs has been completed during this project stage.

Three charging systems were looked at for power quality and demand characteristics.

In terms of the power quality of the Hughes 6.6 kW Gen I and Gen II Inductive Chargers, the data shows that on the circuit tested the chargers had excellent power quality characteristics. The power factors for the inductive chargers remained well above 0.95 throughout the normal operating range and the chargers were well within the acceptable range for harmonic distortion generated as established by the IWC and IEEE 519 standards. In terms of demand, the data shows that both inductive Gen I and Gen II chargers had a peak charging power that ranged between 6.8 kW to 7.0 kW and had a charge duration of about 1.25 hours to 4.75 hours when charging from 80% and 10% SOC respectively. The Hughes inductive Gen I and Gen II chargers showed a decreasing trend in system efficiency (AC kWh/km), which had the best efficiency at the lowest starting SOC and the worst efficiency at the highest starting SOC when recharging.

The Toyota on-board conductive charger also demonstrated excellent power quality characteristics. The power factor for the conductive charger remained well above 0.95 throughout the normal operating range and the charger was also well within the acceptable range for harmonic distortion generated as established by the IWC and IEEE 519 standards. The peak charging power of 5.00 kW for the Toyota on-board conductive charger ranged between 1.5 hours to 5.75 hours when charging from 80% and 10% SOC respectively. The AC kWh per kilometer efficiency of the Toyota conductive charger did not ever go above 0.18 and remained consistent when charging from the various starting SOCs. The conductive technology surpasses the inductive technology in terms of AC kWh per kilometer efficiency.

All charging systems were found to have high Utilization Factors (ratio of the total energy delivered to the maximum possible amount of energy that can be delivered by the charger), which characterizes the efficiency by which the system uses the charger's available capacity. These values were found to be consistent throughout the various starting SOCs and have shown improvement over other OEM technologies tested to date. Testing is still underway on the life cycle and performance testing of the two RAV4s and will be completed and reported on very shortly in an addendum report. The inductive and conductive versions of the RAV4 need to be tested one final time for performance at the Pomona Raceway. Range tests will also be performed after performance testing. These results will show what kind of performance drop-off these vehicles experienced with respect to the vehicle's final mileage and type of usage.

A
PERFORMANCE CHARACTERIZATION SUMMARY (RAV4 INDUCTIVE)

1999 TOYOTA RAV4-EV (NIMH INDUCTIVE) PERFORMANCE CHARACTERIZATION SUMMARY

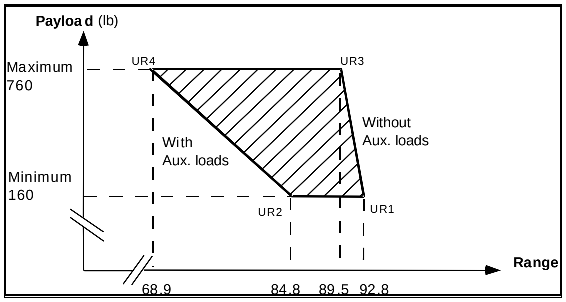
ELECTRIC TRANSPORTATION DIVISION

SOUTHERN CALIFORNIA EDISON

An EDISON INTERNATIONAL Company

Urban Range

(On Urban Pomona Loop – see other side for map)



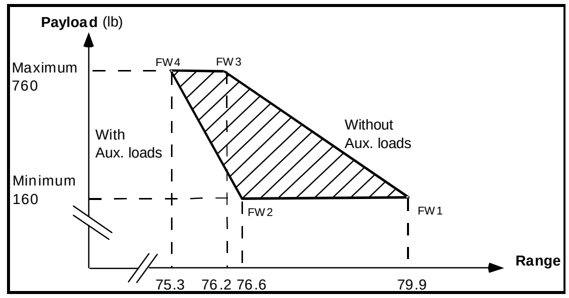
Test	UR1	UR2	UR3	UR4
Payload (lb.)	160	160	766	766
AC kWh Recharge	31.80	33.96	32.72	32.22
AC kWh/mi.	0.329	0.394	0.360	0.434
Range (mi.)	92.8	84.8	89.5	68.9
Avg. Ambient Temp.	68.5°F	75.3°F	80.0°F	87.0°F

Note: A/C fluctuated and may have impacted A/C tests

UR1	Urban Range Test, Min Payload, No Auxiliary Loads
UR2	Urban Range Test, Min Payload, A/C on High, Headlights on Low, Radio On
UR3	Urban Range Test, Max Payload, No Auxiliary Loads
UR4	Urban Range Test, Max Payload, A/C on High, Headlights on Low, Radio On

Freeway Range

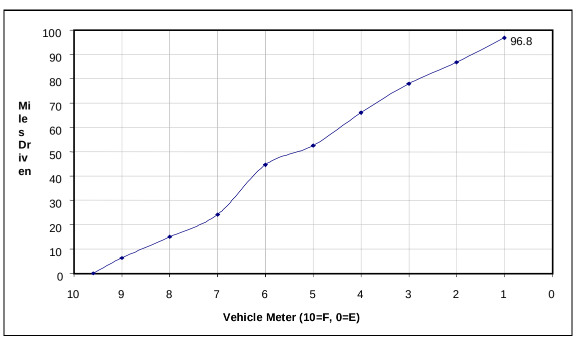
(On Freeway Pomona Loop – see other side for map)



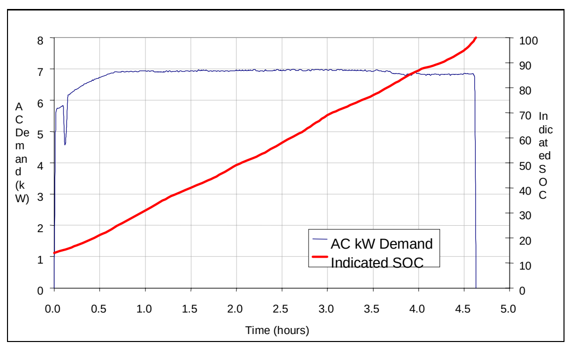
Test	FW1	FW2	FW3	FW4
Payload (lb.)	160	160	766	766
AC kWh Recharge	32.54	31.33	31.79	31.88
AC kWh/mi.	0.404	0.406	0.428	0.418
Range (mi.)	79.9	76.6	76.2	75.3
Avg. Ambient Temp.	89.5°F	88.0°F	79.0°F	81.0°F

FW1	Freeway Range Test, Min Payload, No Auxiliary Loads
FW2	Freeway Range Test, Min Payload, A/C on High, Headlights on Low, Radio On
FW3	Freeway Range Test, Max Payload, No Auxiliary Loads
FW4	Freeway Range Test, Max Payload, A/C on High, Headlight s on Low, Radio On

State of Charge Meter (UR1)



Charger



MEASURED VALUE AT PEAK AC POWER	
Voltage	238.1 V rms
Current	29.39 A rms
Real Power	6.972 kW
Reactive Power	540.5 VAR
Apparent Power	6.997 kVA
Total Power Factor	1.00 PF
Displacement Power Factor	1.00 dPF
Voltage THD	1.3%
Current THD	3.1%
Current TDD	3.0 %

B
PERFORMANCE CHARACTERIZATION SUMMARY (RAV4 CONDUCTIVE)

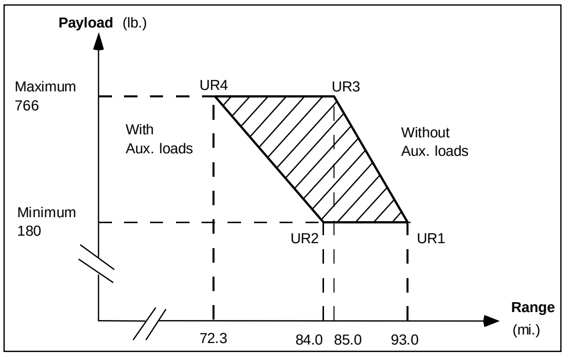
1999 Toyota RAV4-EV (NiMH Conductive) Performance Characterization Summary

Electric Transportation Division

Southern California EDISON
An EDISON INTERNATIONAL Company

Urban Range

(On Urban Pomona Loop – see other side for map)

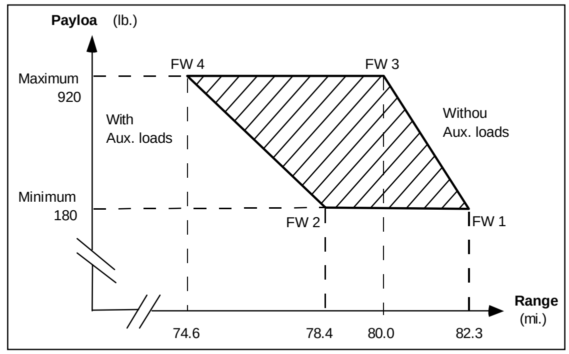


Test	UR1	UR2	UR3	UR4
Payload (lb.)	180	180	766	766
AC kWh Recharge	33.21	31.35	30.28	33.10
AC kWh/mi.	0.355	0.369	0.354	0.436
Range (mi.)	93.0	84.0	85.0	72.3
Avg. Ambient Temp.	82°F	80.5°F	72°F	83.3°F

UR1	Urban Range Test, Min Payload, No Auxiliary Loads
UR2	Urban Range Test, Min Payload, A/C on High, Headlights on Low, Radio On
UR3	Urban Range Test, Max Payload, No Auxiliary Loads
UR4	Urban Range Test, Min Payload, A/C on High, Headlights on Low, Radio On

Freeway Range

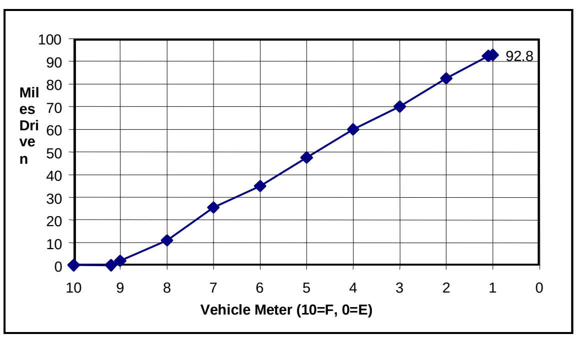
(On Freeway Pomona Loop – see other side for map)



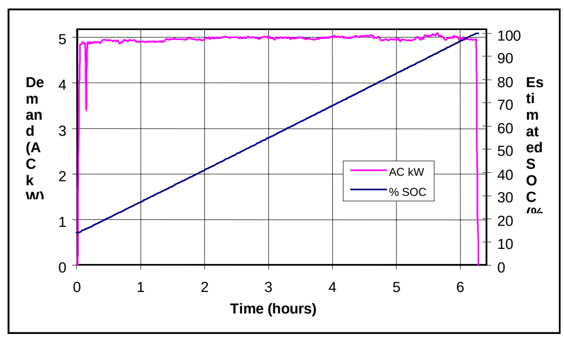
Test	FW1	FW2	FW3	FW4
Payload (lb.)	180	180	766	766
AC kWh Recharge	30.98	32.36	32.86	30.96
AC kWh/mi.	0.374	0.409	0.409	0.410
Range (mi.)	82.3	78.4	80.0	74.6
Avg. Ambient Temp.	84°F	79°F	81°F	83.5°F

FW1	Freeway Range Test, Min Payload, No Auxiliary Loads
FW2	Freeway Range Test, Min Payload, A/C on High, Headlights on Low, Radio On
FW3	Freeway Range Test, Max Payload, No Auxiliary Loads
FW4	Freeway Range Test, Min Payload, A/C on High, Headlights on Low, Radio On

State of Charge Meter (UR1)



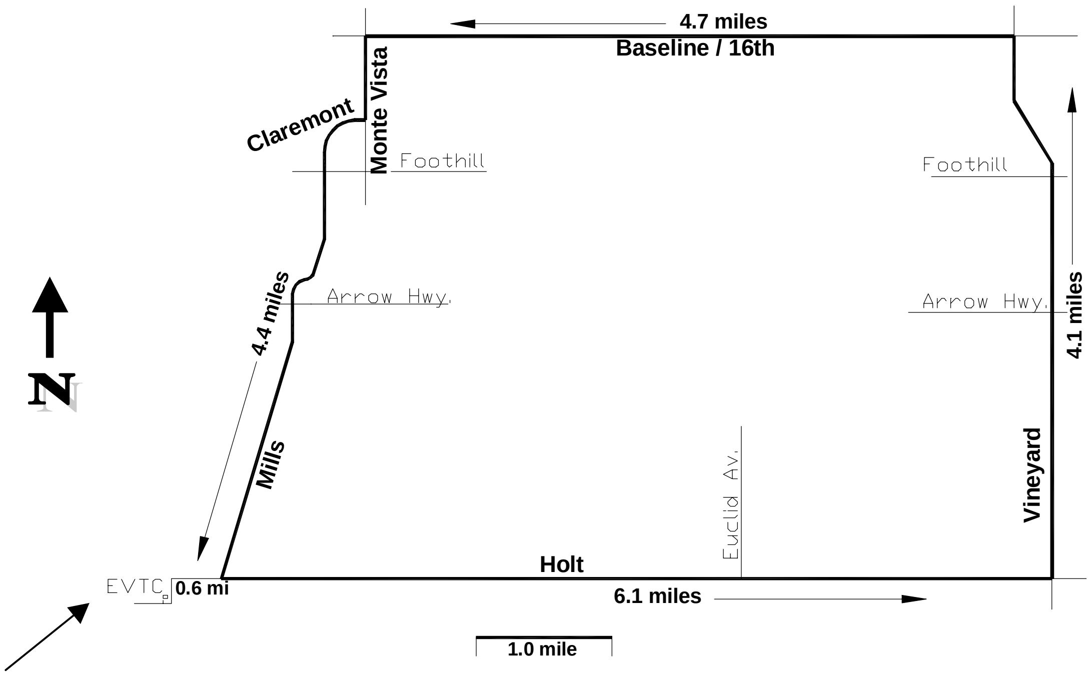
Charger



MEASURED VALUE AT PEAK AC POWER	
Voltage	232.8 V
Current	21.20 A
Real Power	4.899 kW
Reactive Power	573.8 VAR
Apparent Power	4.935 kVA
Total Power Factor	0.99 PF
Displacement Power Factor	0.99 dPF
Voltage THD	2.1%
Current THD	2.6%

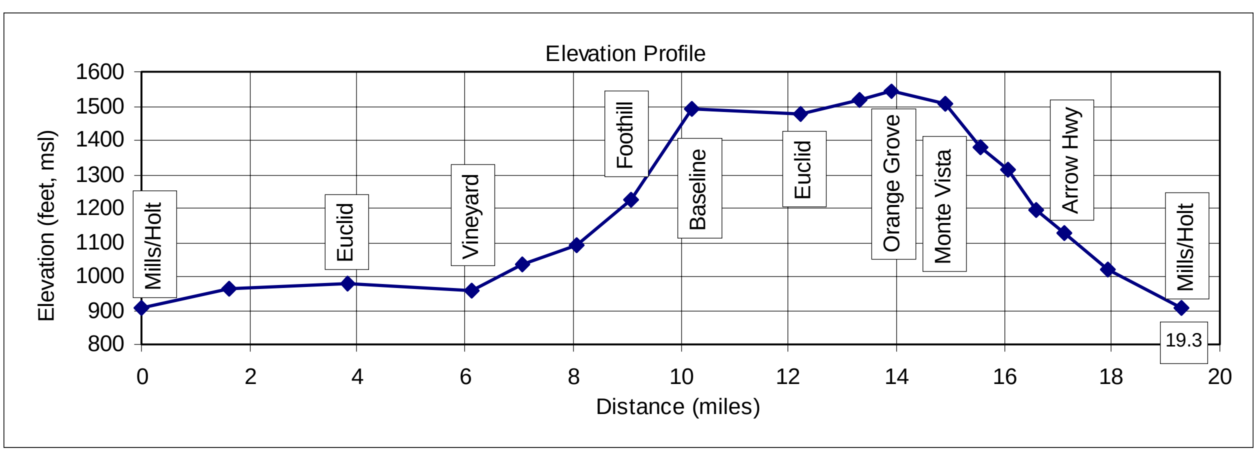
C

POMONA LOOP

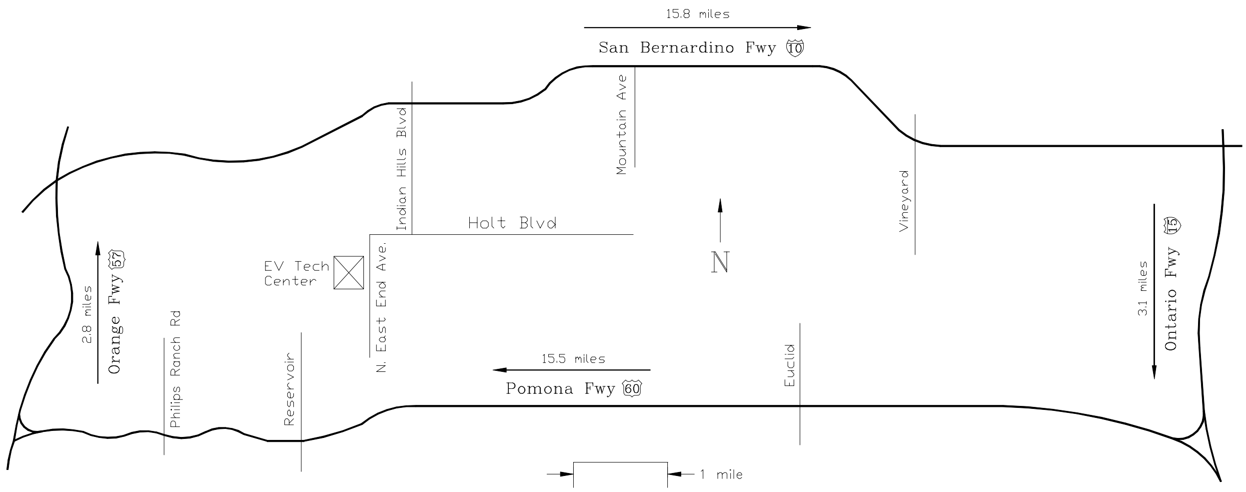


EV Technical Center
265 N. East End Ave
Pomona, California
91767

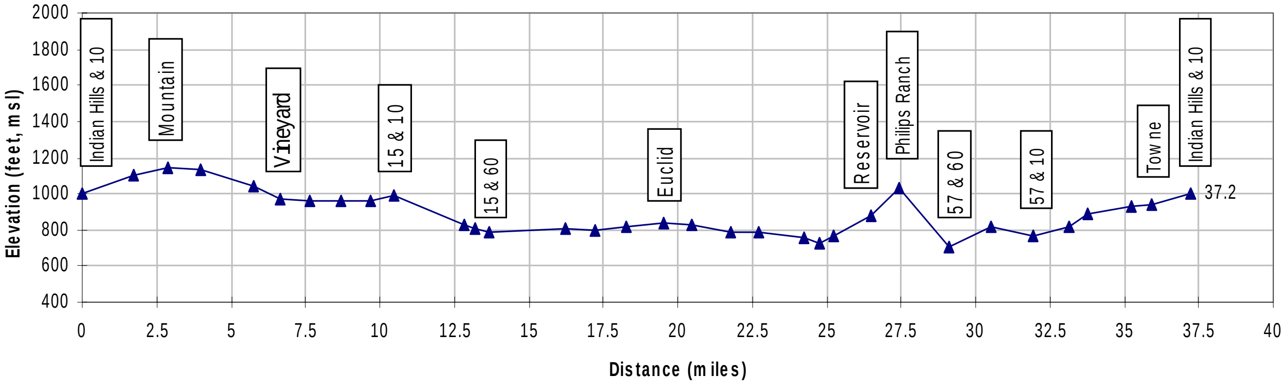
1 mile = 1.6093 km



D
FREEWAY POMONA LOOP



1 mile = 1.6093 km



E
TOYOTA RAV4 EV SOC GAGE

Note: Number labels added to SOC gage to define each of the segments

F
DISCHARGING AND TEMPERATURE DATA

Toyota RAV 4 Conductive

Date	% SOC	kilometers Driven (from 100% SOC to specified SOC)	Ambient Temp (C)
10/05/98	10%	155.3	31.7
10/06/98	10%	168.2	32.2
10/08/98	10%	161.7	30.6
10/09/98	10%	168.7	27.8
10/13/98	20%	150.5	21.7
10/15/98	20%	146.4	21.1
10/16/98	20%	149.7	22.2
10/20/98	20%	150.5	26.7
10/21/98	40%	115.1	19.4
10/22/98	40%	112.7	27.2
10/23/98	40%	115.1	31.7
10/26/98	40%	110.2	17.2
10/27/98	60%	77.2	18.9
10/28/98	60%	76.4	25
10/29/98	60%	76.4	23.3
10/30/98	60%	78.1	23.3
11/02/98	80%	37.8	18.9
11/03/98	80%	38.6	24.4
11/05/98	80%	36.2	25
11/06/98	80%	37.0	18.9

Toyota RAV 4 Inductive

Date	% SOC	kilometers Driven (from 100% SOC to specified SOC)	Ambient Temp (C)
04/21/99	10%	172.7	18.3
04/23/99	10%	169.0	16.1
04/26/99	10%	184.1	21.1
04/28/99	10%	167.8	14.4
04/29/99	20%	150.5	16.7
05/07/99	20%	146.4	27.2
05/10/99	40%	104.6	20.6
05/12/99	40%	120.7	25.6
05/17/99	60%	66.8	25.6
05/18/99	60%	69.8	23.3
05/19/99	60%	74.2	22.2
05/27/99	80%	27.4	24.4
06/01/99	80%	21.9	21.7
06/02/99	80%	24.1	17.2

Toyota RAV 4 Inductive Gen II

Date	% SOC	kilometers Driven (from 100% SOC to specified SOC)	Ambient Temp (C)
06/03/99	10%	155.8	18.3
06/04/99	10%	161.9	16.7
06/08/99	10%	155.8	27.8
06/10/99	20%	141.6	22.2
06/15/99	40%	89.0	32.2
06/09/99	60%	65.8	20.6
08/26/99	80%	23.3	30