1999 DaimlerChrysler EPIC NiMH Charging Systems Study

TR-114267-V1

Final Report, December 1999

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REPORT SUMMARY

To support safe and efficient use of electric vehicles (EV) and to minimize their potential utility system impacts, Southern California Edison (SCE) and EPRI have been involved in evaluating EVs and their corresponding chargers. This report discusses results of the charging system evaluation.

Background
Electric Vehicle (EV) charging systems are expected to become a significant portion of the load on the utility system in coming years. In addition, their growing numbers in Southern California Edison’s own vehicle fleet and service territory requires that SCE investigate the impact these EV chargers will have on the utility. To measure the energy consumption and charging impacts of EV charging systems, this project studied the AC power quality and demand impact of the Lockheed Martin off-board 14 kW charger used by the DaimlerChrysler EPIC EV.

Objective
To analyze the energy consumption and charging impacts of the DaimlerChrysler EPIC minivan and its off-board Lockheed Martin conductive charger

Approach
The project team evaluated the energy consumption and charging impacts of various types of (OEM) EV charging systems. Specifically, they studied the AC power quality and demand impacts of three charging systems (one charger, different wiring), all used with the DaimlerChrysler EPIC electric minivan. The EPIC is powered by SAFT Nickel Metal Hydride (NiMH) batteries. The charging systems were Lockheed Martin using

- 1ϕ 240V 40A circuit (6.6kW max power)
- 1ϕ 240V 60A circuit (10kW max power)
- 3ϕ 208V 60A circuit (14kW max power)

To understand the impact of these chargers, the team measured and recorded the power quality parameters of the various charging systems. Also, the demand profiles of the charging systems were recorded when charging from various states of charge. For the testing in this project, only one charging system, the three-phase charger, was evaluated in detail.

Results
The report discusses in detail the results for the three-phase 208V 60A charging system (the other two systems s were only studied superficially). The analysis covers power quality (power factor and harmonic distortion) and AC demand (AC demand profiles from 0% to 100% of state of charge, or SOC; utilization factor as a function of starting SOC; peak charge power duration

versus. starting % SOC; total charge time versus starting % SOC; and, AC kWh per kilometer efficiency as a function of % SOC). Volume 2 (TR-114267-V2) of this set discusses in detail the results of the DaimlerChrysler EPIC electric minivan evaluation according to established test procedures.

EPRI Perspective

EV charging systems are expected to become a significant portion of the load on the utility system in the near future. In residential applications, EVs also may have a significant impact. Since they can potentially double a household's electrical demand, there is a need to educate customers on EV load management. Concerns about charging impacts on utilities require that SCE and EPRI work closely with initial EV users to help them understand how to fully implement the potential for load management.

TR-114267-V1

Keywords

Electric vehicles (EV)
Advanced batteries
Battery charging systems
EV 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 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 DaimlerChrysler EPIC minivan and its off-board Lockheed Martin conductive charger. Additionally, the performance of the EPIC electric minivan was documented in the form of a Performance Characterization report (see 1999 DaimlerChrysler EPIC (NiMH) Performance Characterization report dated November, 1999), which analyzes the vehicle's overall performance.

EXECUTIVE SUMMARY

Electric Vehicle (EV) charging systems are expected to become a significant portion of the load on the utility system in the coming years. 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. The testing that was performed on the selected OEM vehicle seeks to provide the information needed for evaluating the energy consumption and charging impacts of EV charging systems. This project will attempt to address these questions by studying the AC power quality and demand impact of the Lockheed Martin off-board 14 kW charger used by the DaimlerChrysler EPIC. The Lockheed Martin charger can be setup for three distinct circuits (1ϕ, 240V, 40A; 1ϕ, 240V, 60A; and 3ϕ, 208V, 60A) and is connected conductively to the vehicle. In addition, the vehicle can be charged with a Norvik Level 3 charger with the proper vehicle software modifications. The EPIC is powered by SAFT Nickel Metal Hydride (NiMH) batteries.

Performance characterization testing on the EPIC has been completed (Task 1) and will be published separately (Please see report titled 1999 DaimlerChrysler EPIC (NiMH) Performance Characterization, dated November, 1999). The performance characterization tests have characterized the overall performance of the electric vehicle system. A summary sheet of the EPIC's performance characterization testing can be found in Appendix A, page 18. The manufacturer's specifications can be found in Appendix E, page 22.

In order to evaluate the impact of EV charging, the EPIC was evaluated at several states of charge (SOC). To discharge the vehicle, it was driven on the Urban Pomona Loop (see Appendix B, page 19) at minimum payload and no accessories to the specified SOCs as indicated by the vehicle's SOC gage (see Appendix D, page 21). The vehicle's SOC gage does not refer to the actual SOC of the battery pack, but rather to a SOC level within the range set by the vehicle or battery manufacturer as the vehicle's operating range. After discharge, the vehicle was placed on charge and monitored for power quality and demand.

Data reveals that the single-phase 40A and 60A circuit setups proved to have the lowest current total harmonic distortion (THD) with values at approximately 6% to 8% THD when charging at the charger's maximum demand. These values were well below the maximum recommended value of 20% set by the National EV Infrastructure Working Council (IWC). It was also found that the single-phase systems had the longest charging times, approximately 6 and 7 hours respectively for the 40A and 60A chargers when charging from 0% SOC.

The three-phase charging setup proved to have the lowest charge time at approximately 4.5 hours when charging from 0% SOC. An undesirable quality that was found with the three-phase charging system was its high current total harmonic distortion (THD), which was approximately 28%, 8% above the recommended limit set by IWC when charging at the charger's maximum demand.

The true power factor for the normal operating range of the single-phase 40A charger, between 1.5kW to 8kW, ranged from 0.88 TPF when charging at low demand to near ideal 0.99 TPF when charging at maximum demand. The true power factor was found to be well above the recommended minimum of 0.95 TPF, as set by IWC, for all demands higher than 3.5kW.

The true power factor for the normal operating range of the three-phase 60A charger, between 1.5 kW to 15 kW, ranged from 0.75 TPF when charging at low demand to 0.96 TPF when charging at maximum demand. The true power factor was found to be above the recommended minimum of 0.95 TPF, as set by IWC, when the charging demand was higher than 8 kW.

The average *AC kWh per kilometer* efficiency for the three-phase charging system was found to be 0.43 when accounting for all the tests conducted at the various SOCs. The AC kWh per kilometer figure was found to be the least efficient when the vehicle was charged after shallow discharge and showed some improvement when the vehicle was charged after a deep discharge. Data on the single-phase 40A system displayed the same efficiency trend.

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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 performed for this project 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 impacts of three charging systems (one charger, different wiring), all used with the DaimlerChrysler EPIC electric minivan. Evaluation of a Norvik Level 3 charger will be the topic for future reports. The EPIC is powered by NiMH batteries, which are manufactured by Saft.

The charging systems that were tested were:

1. Lockheed Martin using 1ϕ 240V 40A circuit (6.6kW max power)

2. Lockheed Martin using 1ϕ 240V 60A circuit (10kW max power)

3. Lockheed Martin using 3ϕ 208V 60A circuit (14kW max power)

In order to understand the impact of these chargers, the power quality parameters of the various charging systems were measured and recorded. Also, the demand profiles of the charging systems were recorded when charging from various states of charge. For the testing in this project only one charging system, the three-phase charger, was evaluated in detail. Since the vehicle is available only to fleets, it is expected that users will opt for the 3ϕ service because of its quicker charge time and its common availability in commercial environments.

2
TEST OVERVIEW

In order to evaluate the impact of electric vehicle charging the EPIC minivan was evaluated at several states of charge (SOC). To discharge the vehicle, it was driven on the Urban Pomona Loop (see Appendix B, page 19) at minimum payload and with no accessories to the specified SOCs as indicated by the vehicle's SOC gage (see Appendix D, page 21). 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 vehicle was 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 charger manufacturer's maximum current draw.

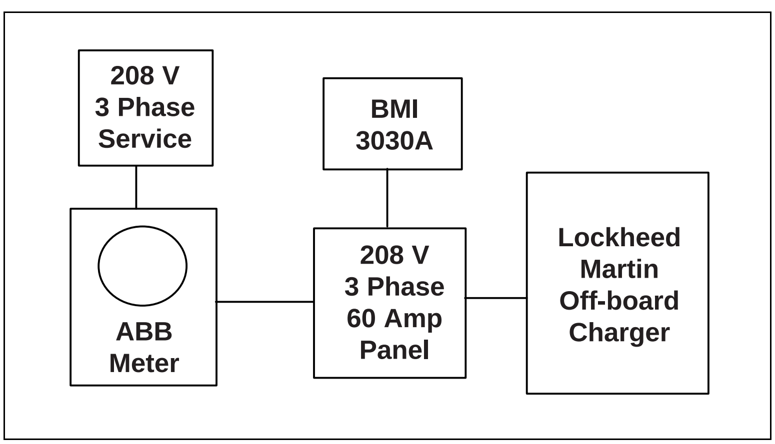


Figure 2-1
Test set-up block diagram

Figure 2-2
BMI 3030A Power Profiler

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

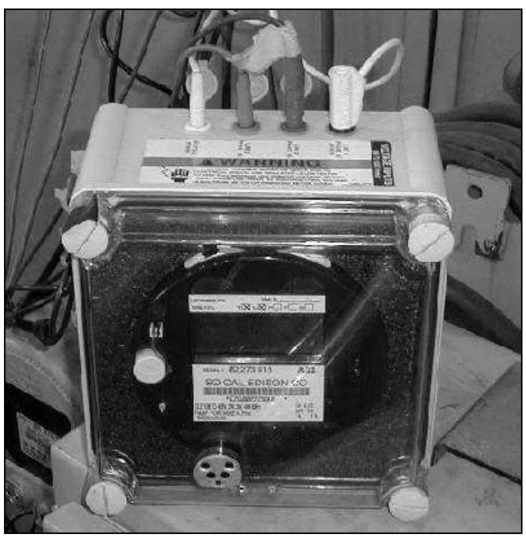


Figure 2-3
Portable ABB FM2S Watt-hour Meter.

The demand and energy consumption observed during the charging of the vehicle 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 2-3 above.

3
CHARGING SYSTEMS OVERVIEW

Figure 3-1– Lockheed Martin Charger

Figure 3-2 – ODU coupler and vehicle charge port

The Lockheed Martin charger, shown in Figure 3-1, is an off-board Level 2 (< 240 VAC, < 60 A, and < 14.4 kW) EV battery charger that transfers energy to the on-board system through conductance. The system, as shown in the block diagram in Figure 3-3, consists of an off-board floor mount charger and electric vehicle service equipment, and an on-board converter and controller. The charger is coupled to the vehicle through a metal-to-metal connection point (conductively coupled), made up by the charge coupler and the charge port (see Figure 3-2). The entire system is controlled by the on-board controller,

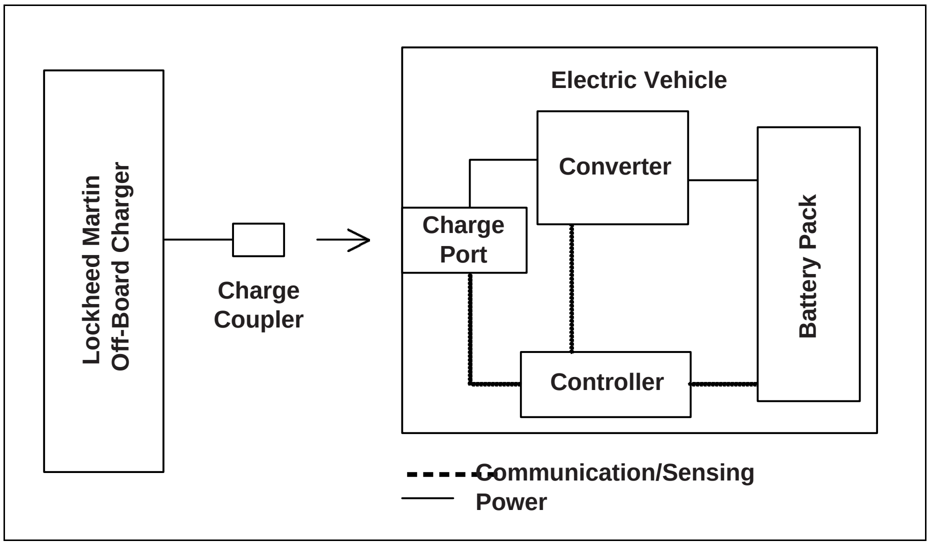


Figure 3-3
Lockheed Martin Charger block diagram.

which communicates with the off-board charger. Preliminary charger tests were completed to determine which of the three charging systems would be the most suitable for system impact testing. The three charging systems included a single-phase 240V 40A, a single-phase 240V 60A, and a three-phase 208V 60A charging system. The Lockheed Martin charger can easily be converted to any of the three charging systems by any qualified technician.

The following preliminary results were obtained when testing the EPIC with the various charging systems (Vehicle driven from 100% SOC to 0% SOC for all tests):

Table 3-1
Charging Systems Overview

	1 ϕ 240V 40A	**1 ϕ 240V 60A**	**3 ϕ 208V 60A**
Date	6-22-99	6-29-99	7-28-99
Range km (mil)	132.0 (82)	142.0 (88.2)	130.8 (81.3)
AC kWh recharge	53.5	56.0	53.9
AC kWh / km	0.405	0.394	0.412
AC kWh / mile	0.652	0.635	0.663
Charge Time	7 hrs 31 min	6 hrs 16 min	5 hrs 4 min
Avg. Amb. Temp.	69 °F	75.5 °F	80 °F
(Values taken near charger's maximum power.)			
Voltage	238.1 V rms	233.6 V rms	201.1 V rms
Current	33.8 A rms	44.12 A rms	78.9 A rms total 45 A rms / phase
Real Power	8.001 kW	10.21 kW	15.2 kW
Reactive Power	620.7 VAR	1120 VAR	832 VAR
Apparent Power	8.106 kVA	10.31 kVA	15.86 kVA
Total Power Factor	0.99 PF	0.99 PF	0.96 PF
Disp. Power Factor	1.00 dPF	0.99 dPF	1.00 dPF
Voltage THD	1.5% THD	1.6% THD	2.4% THD
Current THD	8.1% THD	6.2% THD	28.2% THD

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 project, 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 in the calculation. With true power factor, the true efficiency ofsystem 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.

In Figure 4-1, page 7, the power factor values measured for the three-phase 60A and the single-phase 40A charging systems are plotted as a function of the measured AC demand.

In this plot it can be seen that true power factor for the normal operating range of the single-phase 40A charger, between 1.5 kW to 8 kW, ranged from 0.88 TPF when charging at low demand to near ideal 0.99 TPF when charging at maximum demand. The true power factor was found to be well above the recommended minimum of 0.95 TPF, as set by IWC, for all demands higher than 3.5kW.

The displacement Power Factor for the single-phase 40A charger range from 0.94 dPF when charging at low demand to an ideal value of 1.00 dPF when charging at maximum demand. The difference between true and displacement power factor is quite high, indicating that high harmonic distortions are present.

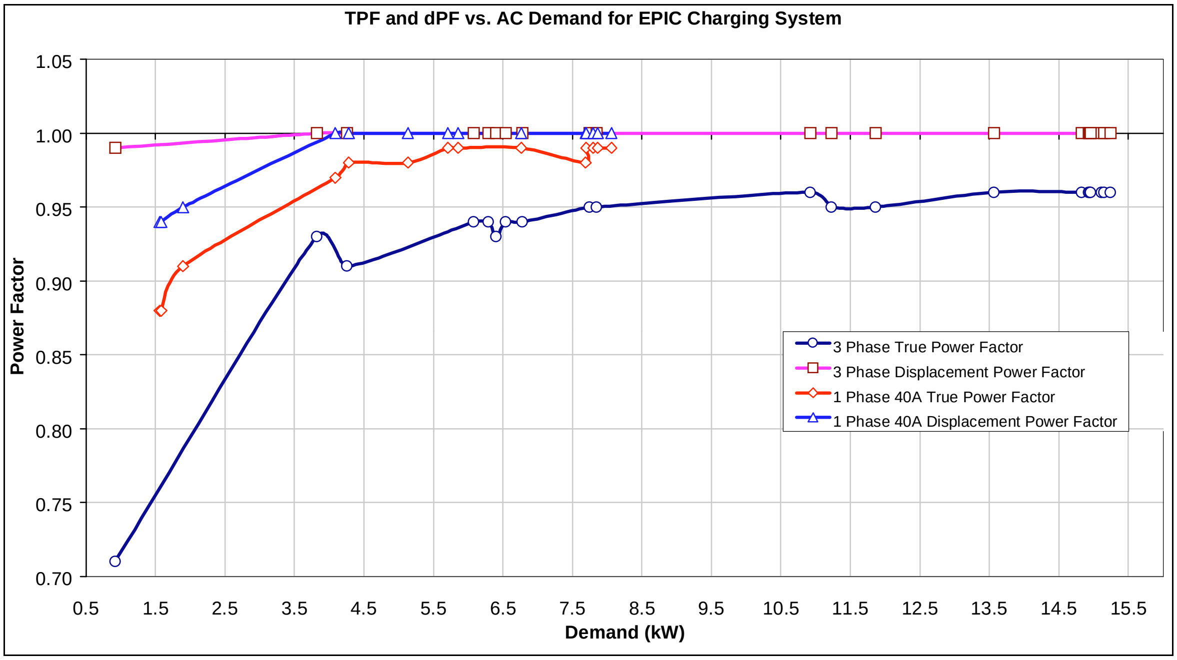


Figure 4-1
True Power Factor and Displacement Power Factor

Results for the three-phase charging system shows that for the normal operating range of 1.5 kW to 15 kW, the true power factor ranged between 0.75 TPF when charging at low demand to 0.96 TPF when charging at maximum demand. The true power factor was found to be well above the recommended minimum of 0.95 TPF, as set by IWC, when the charging demand was greater than 8 kW.

The displacement Power Factor for the three-phase 60A charger ranged from 0.99 dPF when charging at low demand to an ideal value of 1.00 dPF when charging at maximum demand. The difference between true and displacement power factor is quite high, indicating that high harmonic distortions are present

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.

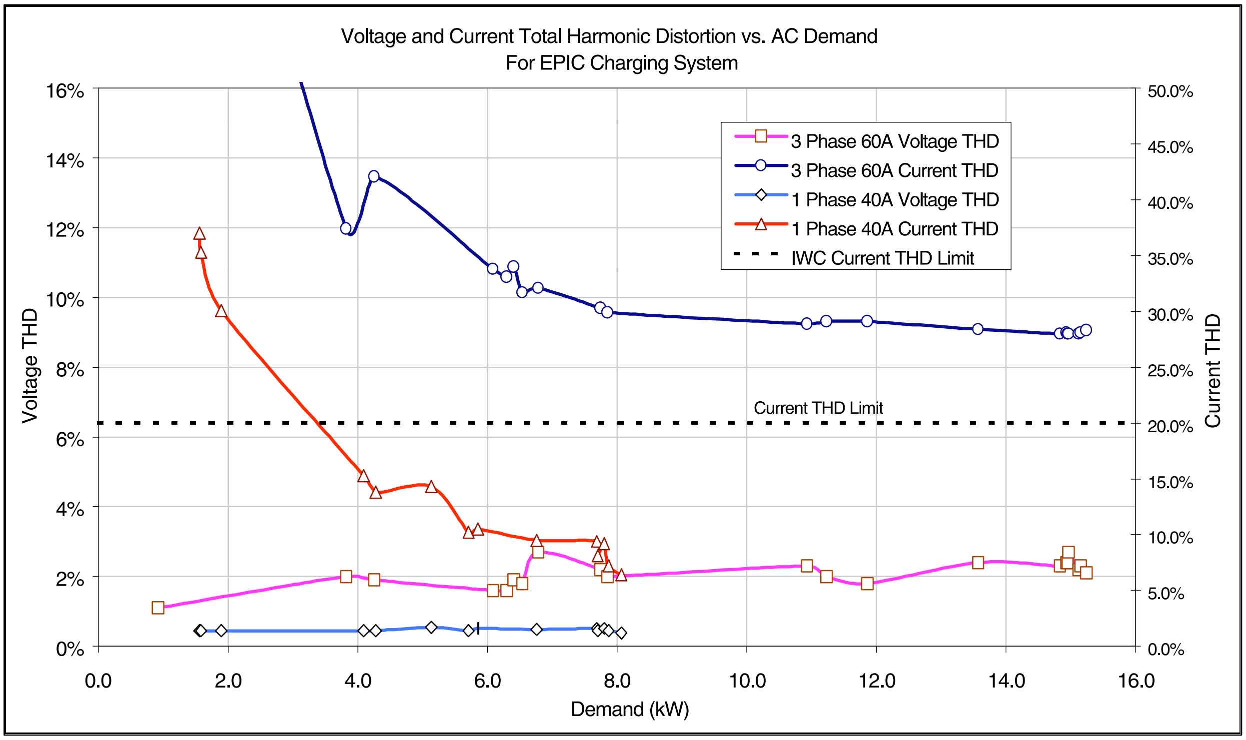


Figure 4-2
Voltage and Current Total Harmonic Distortion vs. AC Demand

In Figure 4-2 above, the voltage and current THD values measured for the Lockheed Martin charging system are plotted as a function of the measured AC demand. In this plot it can be seen that throughout the working demand range of the charging systems, the voltage THD stayed well below 2.7% when testing the three-phase 60A system and well below 1.7% when testing the single-phase 40A system. The test circuits used in these tests have the characteristics 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.

Figure 4-2 also shows that the single-phase 40A charger is well below the IWC recommendation for maximum current THD allowable at the rated maximum demand (IWC recommends a limit of 20% current THD for Level 2 chargers). For demands less than this rating, the single-phase 40A system exceeds the recommendation only until the demand falls to less than 3.5 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.

On the three-phase service, the charger exhibits a current THD of approximately 28% for demands between 8 kW to 15 kW. This is an unfavorable characteristic that is prevalent at the charger's maximum demand, where power quality characteristics should be optimized. A redesign of the three-phase charger, where the characteristics of power quality can be improved, may be implemented with the use of filters optimized for three-phase charging.

Total Demand Distortion (TDD) is similar to THD in that it is a percentage measure that 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. 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.

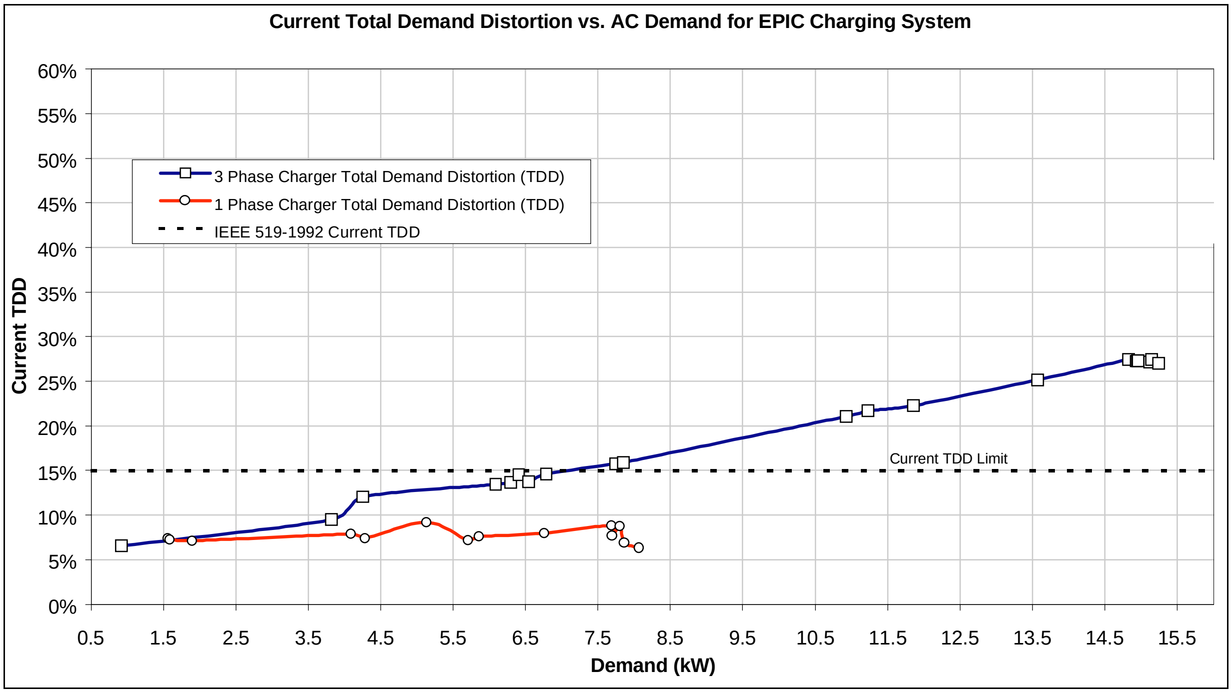


Figure 4-3
Current Total Demand Distortion (TDD) vs. AC Demand

For this project, TDD was computed for the various demand outputs of the chargers.

In Figure 4-3 above, we see that throughout the working range of the single-phase charger, the TDD stayed well below the IEEE 519 recommendation for the circuit used (recommended maximum value of 15% TDD set by IEEE 519 standard). The TDD values for the single-phase charger remained at a reasonable level, between 6.3% and 9.2% TDD, for the working demand range of 1.5 kW to 8 kW.

The three-phase charging system exceeded the IEEE 519 limit after only reaching an AC charging demand of 7 kW. All TDD values obtained for demands greater than 7 kW were well beyond the limits recommended by IEEE 519 and are very undesirable in chargers operating at such high power levels.

The short circuit current to maximum fundamental load current (I_{SC}/I_L) ratio was used when determining the IEEE 519 current distortion limits. To obtain this value for the single-phase 40A charger, the short circuit current was calculated to be 8000 Amps and the maximum fundamental load current was considered to be the charger's maximum current draw of about 35 Amps. 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%. The same technique was used for calculating the allowable TDD for the three-phase 60A system, which was also calculated to be 15%.

5
AC DEMAND ANALYSIS

In conjunction with power quality issues, an analysis of the demand profiles of the EV charging 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 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 also differ between battery manufacturers as each one approach the task of charging differently. There is also the question of matching a suitable charger with the available AC wiring at the Point of Common Coupling (PCC). Figure 5-1 below illustrates these differences for the three charging systems used with the NiMH powered EPIC minivan.

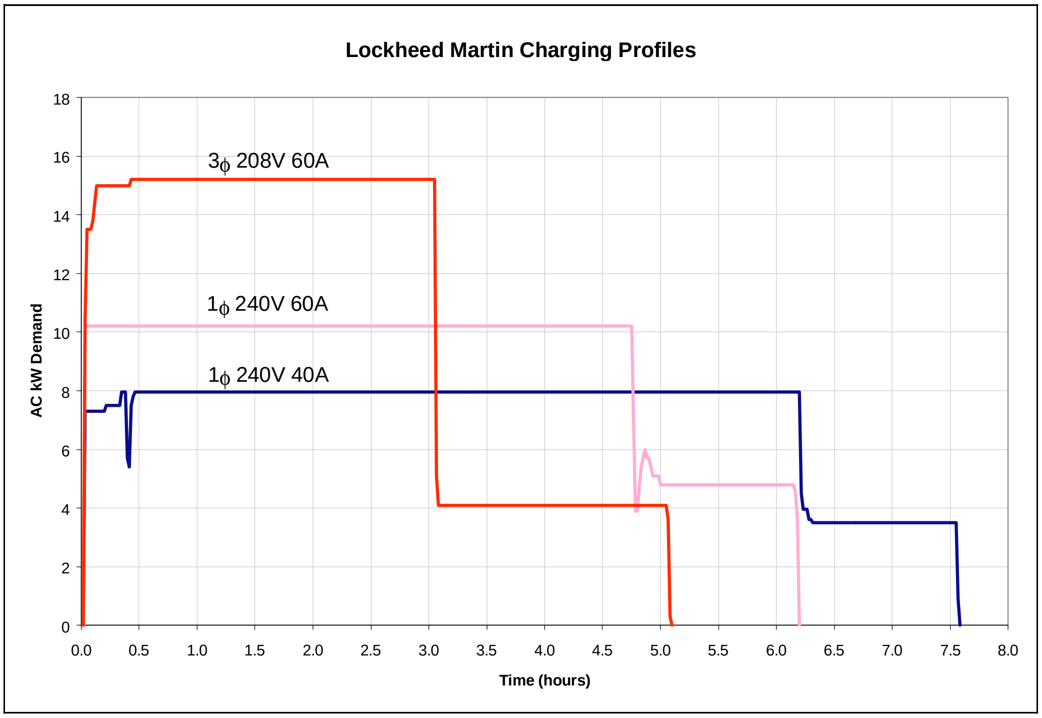


Figure 5-1
AC Demand Profiles for Three Charger Setups from 0% to 100% SOC.

Figure 5-1, page 11, shows how differently one particular vehicle can be charged depending on the charging setup used (single-phase or three-phase). Selection of the most suitable charger is dependent on the AC wiring at the PCC. When charging at a residential location, the single-phase 40A charger may be the only option. On the other hand when charging in a commercial location the single-phase 60A or the three-phase 60A systems may be incorporated.

The charging profiles for the three charging systems (as seen in Figure 5-1, page 11) revealed that a finishing charge is required at a lower power level. The finishing charge, which averaged between 4 to 5 kW, was noticed on all the charging profiles collected for the three charging systems.

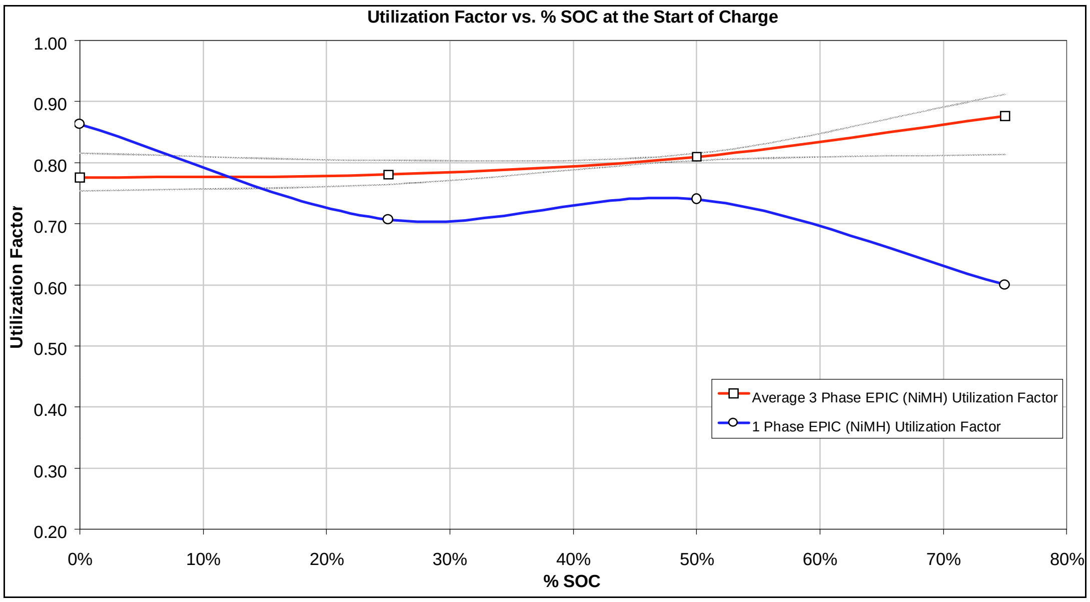


Figure 5-2
Utilization Factor as a function of starting SOC

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 the available charger capability. The values in the plot above (Figure 5-2) 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 (single-phase testing only uses one data point at each SOC). A good utilization factor usually signifies that 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. The typical charging profiles found in Figure 5-1, page 11, illustrate that a near ideal utilization factor can not be accomplished due to the consistent finishing charges that the Lockheed Martin charger exhibits.

When testing the three-phase system, the utilization factor was found to be the lowest when the vehicle was charged after deep discharges and was found to be the highest when the vehicle was charged after shallow discharges. One good quality that was found with the three-phase system was that the utilization factors were found to be relatively linear for all tested SOCs. Utilization Factors were not found to go below 78% for the three-phase charging system and the difference between the highest and lowest utilization factor value was small.

Utilization factors for the single-phase 40A system were computed using one test per SOC, rather than getting the average of three tests. From the data obtained, it was noticed that the utilization factor was lowest when the vehicle was charged after shallow discharges and was highest when charging the vehicle after deep discharges.

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 5-3 and 5-4, on page 14, represent these aspects of peak and total charge duration.

In Figure 5-3, page 14, the duration of charge at peak power for both single-phase 40A and three-phase 60A chargers were found to be relatively linear for all tested SOCs. A favorable quality that was displayed by the three-phase charger was that the charge times at peak demand were very consistent between tests.

The total charge times shown in Figure 5-4, page 14, were found to be noticeably higher than the peak power duration times, which was the result of the low power finishing charges. This trend made it impossible for the Lockheed Martin charger to achieve a near ideal utilization factor.

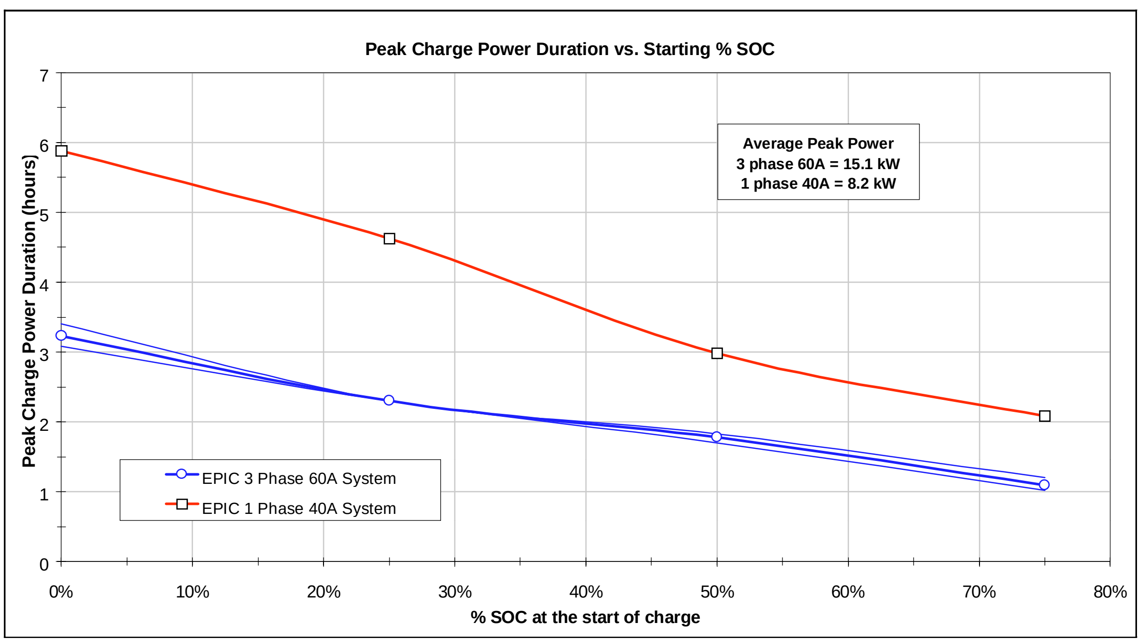


Figure 5-3
Peak Charge Power Duration vs. Starting % SOC

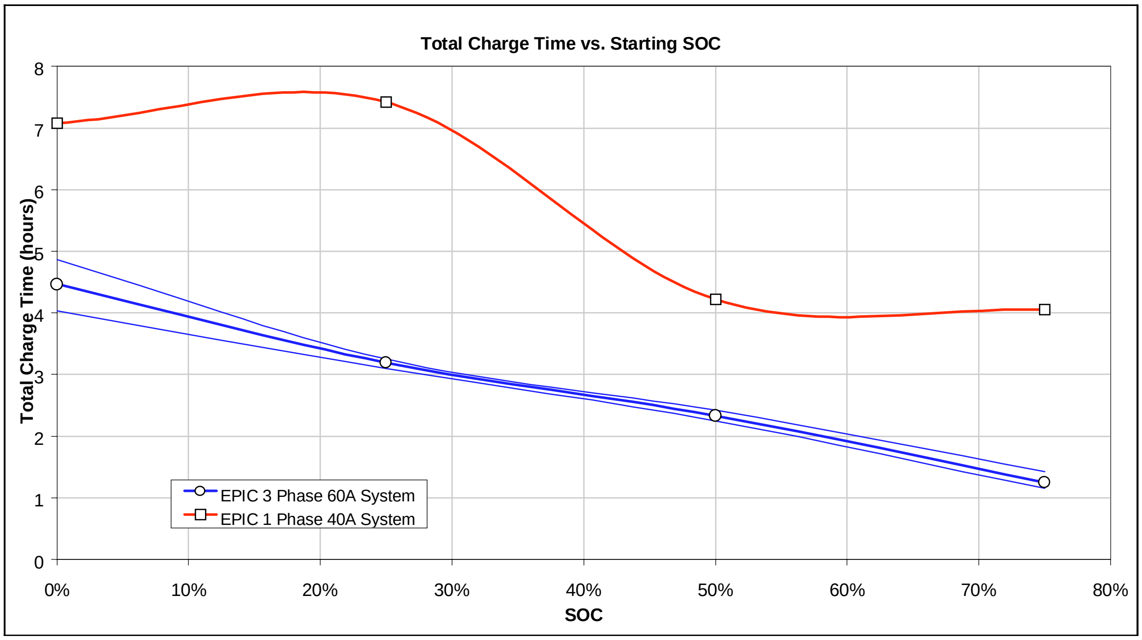


Figure 5-4
Total Charge Time vs. Starting % SOC

* Note: Single-Phase data points at each SOC are not the average of several tests, which accounts for the non-linear lines.

The AC kWh per kilometer energy efficiency of the EPIC minivan and the Lockheed Martin charging systems can be found in Figure 5-5 below.

The average *AC kWh per kilometer* efficiency for the three-phase charging system was found to be 0.43 when accounting for all the tests conducted at the various SOCs. The AC kWh per kilometer figure was found to be the least efficient when the vehicle was charged after shallow discharge and showed some improvement when the vehicle was charged after a deep discharge.

Preliminary data on the single-phase 40A system, with one data point obtained at each SOC, shows that a similar trend for the system efficiency exists. An average AC kWh per kilometer efficiency of 0.50 was found for the single-phase 40A charging system.

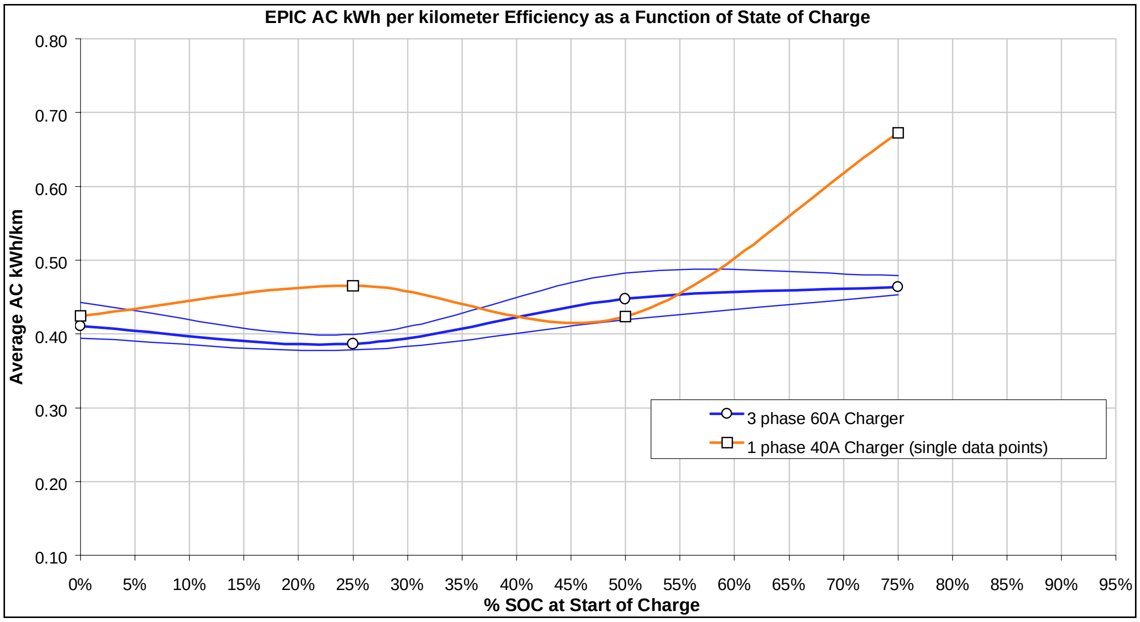


Figure 5-5
AC kWh per kilometer Efficiency as a Function of % SOC

An AC kWh per kilometer efficiency that does not change with respect to the starting SOC would be the ideal situation.

6 SUMMARY

Thorough testing of the off-board Lockheed Martin charger during recharge from various SOCs has been completed for the three-phase 60A and single-phase 40A charging setups. Testing is still underway on the single-phase 60A charging system and will be completed and reported in an addendum report. The Life cycle testing portion and the Level 3 charging portion (through collaboration with Norvik) of the report will also be included within the addendum provided that Norvik can provide the right interface for SCE's charger.

The three Lockheed Martin charging system was evaluated for power quality and demand characteristics. The three-phase 208V 60A charging system was researched in detail and all others were studied superficially (1ϕ 240V 40A and 1ϕ 240V 60A).

Results show that in terms of the power quality, the single-phase 40A charging system had exceptional power quality characteristics. The true power factor remained well above 0.95 TPF and the charger was well within the acceptable range for harmonic distortion generated as established by both the IEEE 519-1992 and the IWC standards.

The three-phase charging system, had a current total harmonic distortion (THD) of 28% when charging at full power, which exceeds the maximum recommended value set by IWC. The National EV Infrastructure Working Council (IWC) recommends that the current total harmonic distortion not exceed a maximum of 20% and also recommends a limit on the Total Power Factor (TPF) to a minimum of 0.95 for level 2 charging. The power factor did remain above 0.95 for the three-phase system when charging at maximum demand. Although charging time is reduced significantly with the three-phase charging system, undesirable current harmonics are present for the entire AC demand range.

In terms of demand, the data shows that the peak charging power of 15.2 kW for the three-phase 208V 60A system lasted approximately 3 hours, followed by a finishing charge of 4 kW that lasted approximately 2 hours.

Data for the single-phase 240V 60A charging system shows that the charger had a peak charging power of 10.2 kW that lasted approximately 4 hours and 45 minutes, followed by a finishing charge of 4.8kW, which lasted approximately 1 hour and 25 minutes.

The single-phase 240V 40A charging system had a peak charging power of 8 kW that lasted approximately 6 hours and 15 minutes, followed by a finishing charge of 3.5 kW, which lasted approximately 1 hour and 20 minutes.

The average *AC kWh per kilometer* efficiency for the three-phase charging system was found to be 0.43 when accounting for all the tests conducted at the various SOCs. The AC kWh per kilometer figure was found to be the least efficient when the vehicle was charged after shallow discharge and showed some improvement when the vehicle was charged after a deep discharge.

The single-phase charging system has shown some similarities with the three-phase system in terms of AC kWh per kilometer efficiency. Both showed a higher AC kWh per kilometer efficiency when the vehicle was charged from a deeper discharge.

The single-phase 40A and 60A chargers are an optimum choice for vehicle charging when considering the exceptional characteristics they have with power quality. The single-phase systems have current harmonics and power factors that are well within the recommended limits set by IEEE 519 and IWC. Charge time with the 40A system and 60A system can take up to 7 hours and 6 hours respectively for charging the EPIC completely.

The three-phase charging system has the characteristic of being a rapid charging unit, taking only about 5 hours or less to completely charge the EPIC minivan. The drawback of the three-phase system was found to be with the poor power quality characteristics that exceed some of the recommended values set IEEE 519and IWC standards.

A
EPIC PERFORMANCE CHARACTERIZATION SUMMARY

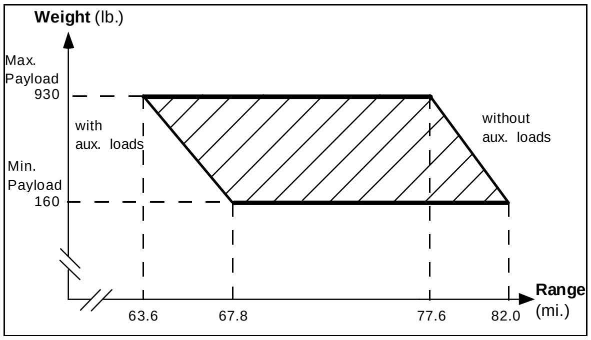
1999 Chrysler Epic (NiMH Batteries) Performance Characterization Summary

Electric Transportation Division

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL Company

Urban Range

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

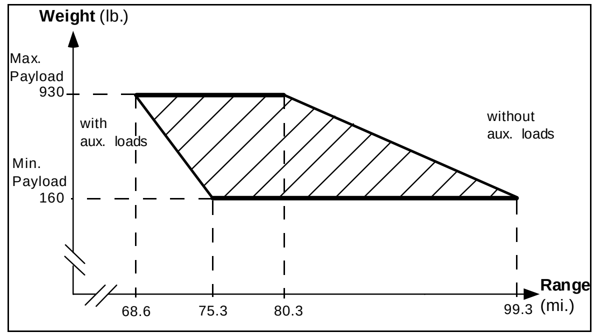


Test	UR1	UR2	UR3	UR4
Payload (lb.)	160	160	930	930
AC kWh Recharge	53.91	50.03	53.02	52.61
AC kWh/mi.	0.663	0.734	06.75	0.823
Range (mi.)	82.0	67.8	77.6	63.6
Avg. Ambient Temp.	75º F	80º F	79º F	85º F

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, Max Payload, A/C on High, Headlights on Low, Radio On

Freeway Range

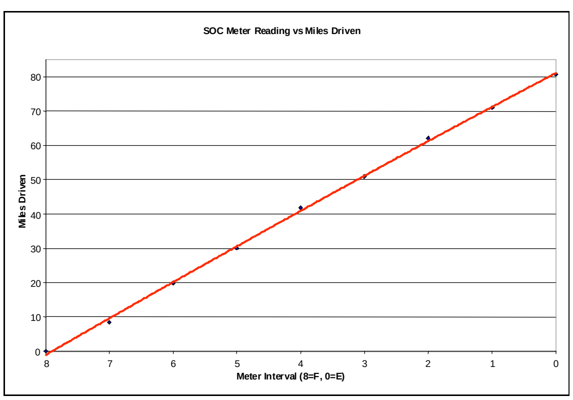
(On Freeway Pomona Loop – see other side for map)



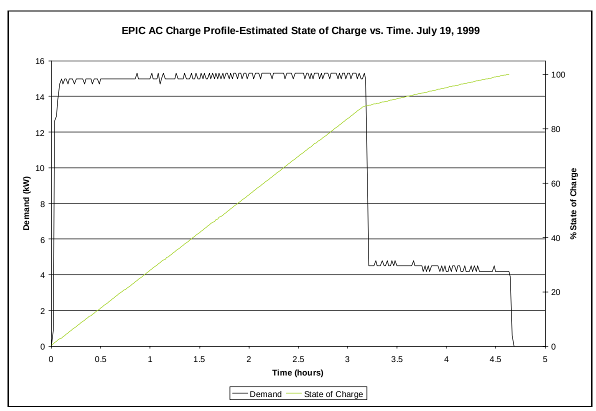
Test	FW1	FW2	FW3	FW4
Payload (lb.)	160	160	930	930
AC kWh Recharge	54.08	51.54	50.42	55.52
AC kWh/mi.	0.542	0.674	0.598	0.799
Range (mi.)	99.3	75.3	80.3	68.6
Avg. Ambient Temp.	86º F	88º F	83º F	101º F

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, Headlights on Low, Radio On

State of Charge Meter (UR1)



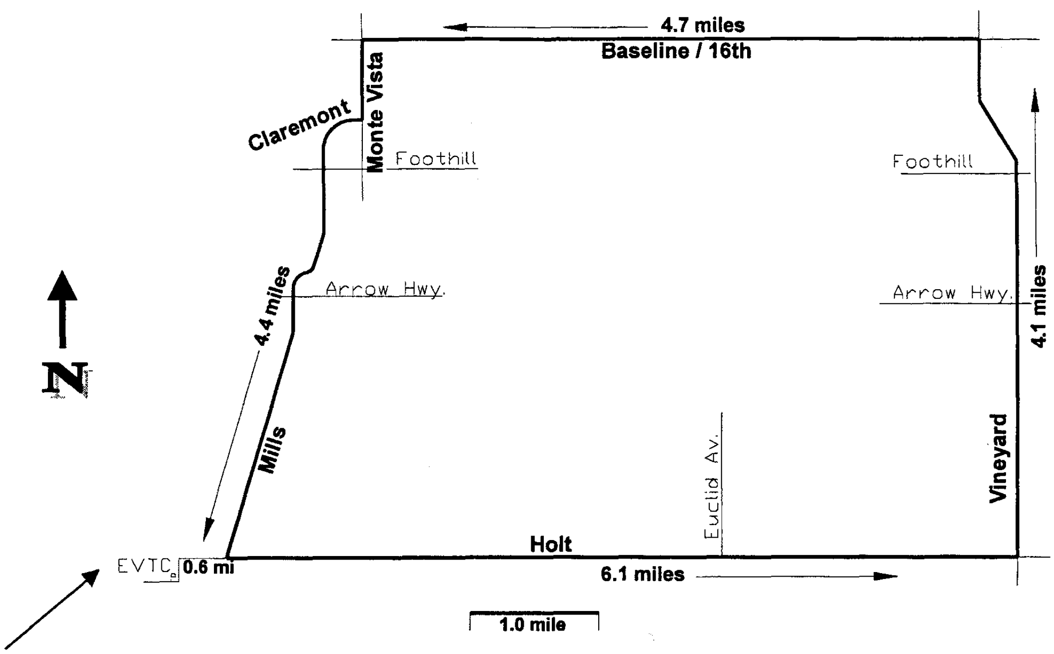
Charger



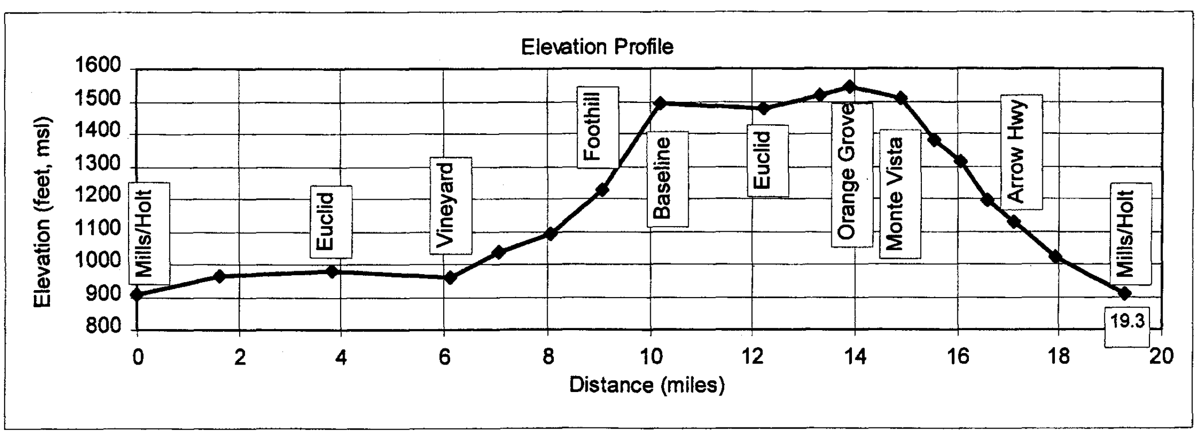
MEASURED VALUE AT PEAK AC POWER*	
Voltage	204.9V
Current	77.5 A
Real Power	15.22 kW
Reactive Power	771 VAR
Apparent Power	15.87 kVA
Total Power Factor	0.96 PF
Displacement Power Factor	1.00 dPF
Voltage THD	2.2%
Current THD	28.2%
Current TDD	27.1%

*Total/average on a three phase grid connection.

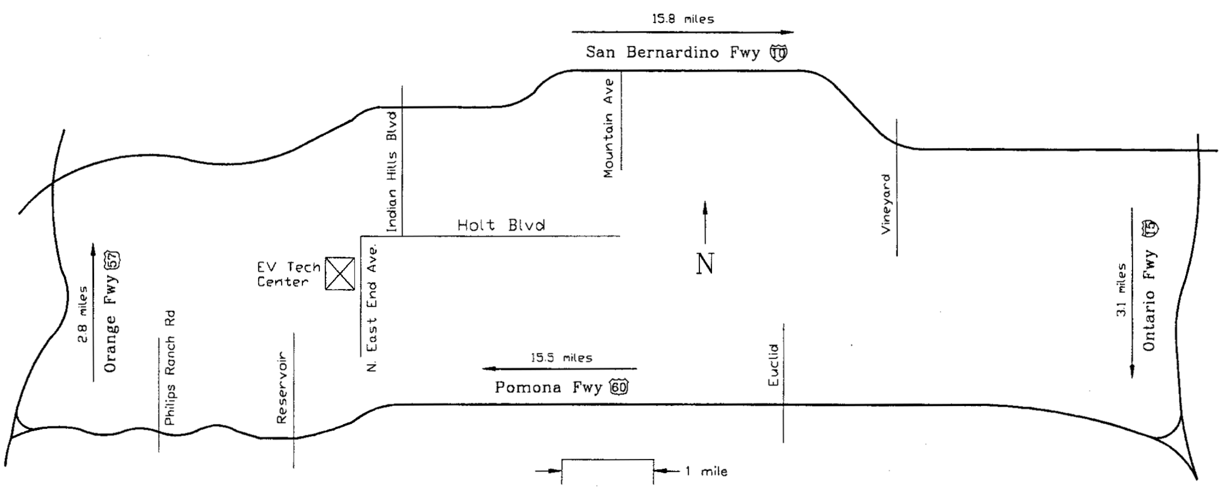
B
URBAN POMANA LOOP

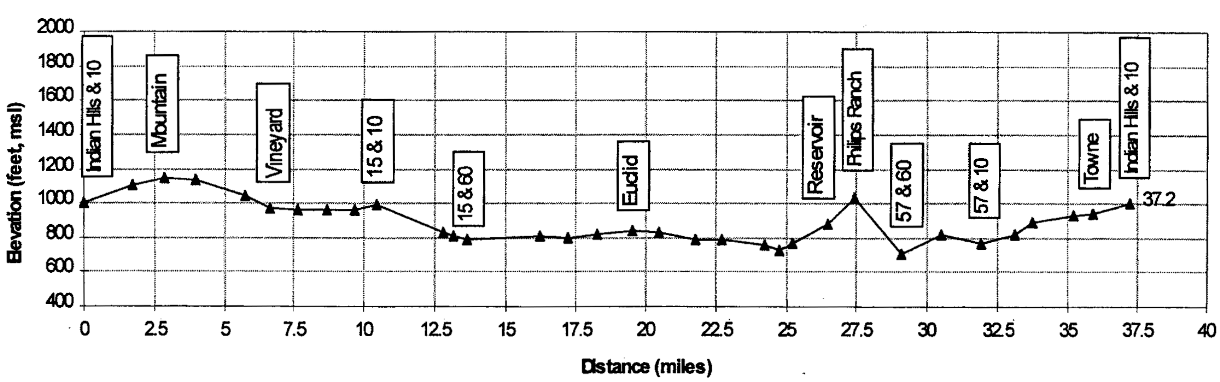


EV Technical Center
265 N. East End Ave
Pomona, California 91767

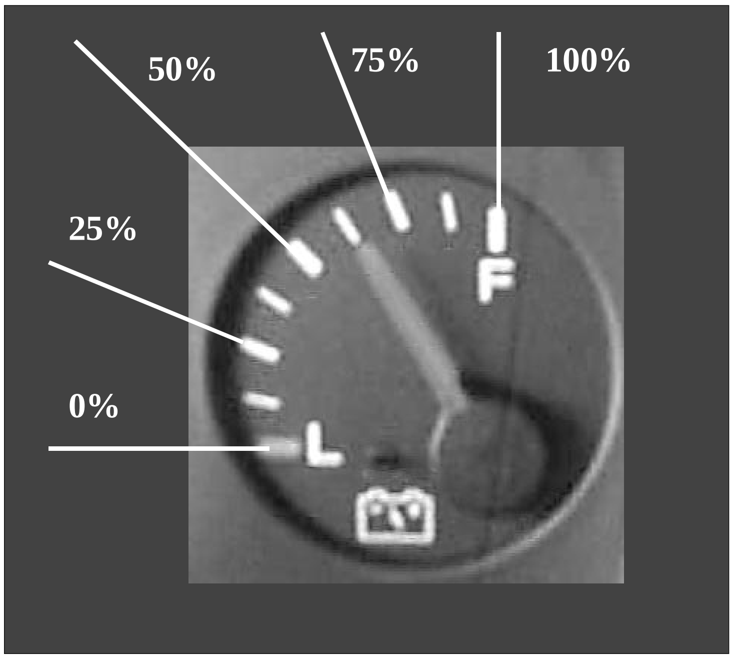


C
FREEWAY POMONA LOOP





D
EPIC EV SOC GAGE



E
MANUFACTURER'S SPECIFICATIONS

Wheelbase:	113.3"
Powertrain:	AC induction motor 100 hp peak / 75 hp continuous. Single speed front-wheel-drive transaxle.
Batteries:	Nickel-metal-hydride 336 volts (28 12-volt modules). Anticipated battery life 4-6 years.
Charging:	Compatible with off-vehicle charger – 208/240-volt, up to 60-amp circuit (approximately 6 to 8 hour charge time) Quick charge capability (440-volt public charging facility where available)
Chassis:	5800 Gross Vehicle Weight Rating 925-pound payload. Heavy duty shocks springs and struts. Cast aluminum wheels. P205/75R/15 low rolling resistance tires.
Performance:	0 to 60 mph in 17 seconds and top speed of 80 mph. Range of 80 to 90 miles (SAEJ1634 combined city/highway in warm weather with no accessories. Range is reduced in cold weather and varies with driving conditions and driving style.
Standard Equipment:	Dual air bags Anti-lock brakes Regenerative braking Power steering Power Brakes Power door locks Four doors Air conditioning and heater Rear defrost Sunscreening glass AM/FM radio Rear wiper Off Vehicle Charger
Warranty: Vehicle and battery:	3-year/36,000 mile limited warranty.