Pacific Gas and Electric Company

Emerging Technologies Program

Application Assessment Report #0808

Industrial Battery Charger
Energy Savings Opportunities

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1. Executive Summary

Large battery chargers are used with such products as forklifts, airport transport equipment, neighborhood electric vehicles and golf carts. Large battery chargers can be found in residential, commercial and industrial applications using both single phase and three phase power. Industrial battery-powered motive equipment has been utilized in warehouses, ports, airport baggage systems and manufacturing facilities for decades. In addition, smaller single phase golf cart chargers are common on courses and in retirement neighborhoods. California's population of approximately 275,000 large chargers uses over 4,200 GWh per year. A test procedure for consumer battery chargers was finalized in April 2008 to support Title 20 standards for small chargers, but that procedure did not include the ability to test the efficiency of large chargers.

This project facilitated the development of a technically rigorous large battery charger efficiency test procedure, which was adopted as the official California Energy Commission procedure in December of 2008. Using data gathered by PG&E Applied Technology Services Group, Southern California Edison and one charger manufacturer, PG&E's consultant Ecos compared the efficiency of charger technologies, and estimated opportunities for energy and peak demand savings in PG&E's service territory.

Results indicate that the most common technologies installed today, ferroresonant and silicon controlled rectifier (SCR), tend to use more energy than newer technologies. Encouraging early retirement of ferroresonant and SCR chargers and replacing them with the average high frequency chargers, could save nearly 4 MWh per unit annually. If 5% of PG&E's total three phase lift-truck battery charger stock were replaced, 14,300 MWh could be saved per year. Coincident peak demand savings are likely negligible because of the duty cycle requirements associated with shift work. However, smart technologies may be explored for demand response load management opportunities.

Because there are significant variations in energy use even within technologies, a technology neutral program specification based on the test procedure could help ensure energy savings. Review of the data demonstrated that charge return factor and power conversion efficiency were the two metrics that had the greatest impact on annual energy performance. A program standard based on annual energy consumption as determined by the accepted test procedure would help to capture available energy savings from the best performing chargers.

Further research would allow for an adequate population of data points to set program standards. Additional testing of golf cart battery chargers would inform an analysis of saving opportunities for this product. The savings opportunities that have been identified merit further investigation by PG&E's Emerging Technology and ATS group.

2. Project Background

Industrial battery-powered motive equipment has been utilized in warehouses, airport baggage systems and manufacturing facilities for decades. Although the typical product is usually known as a forklift, the category of lift-truck has been created to encompass all machines used for this purpose. Smaller single phase golf cart chargers are utilized on courses and in retirement neighborhoods all over California. PG&E's consultant Ecos estimates that the population of these large battery chargers in California is approximately 275,000 units. Table 1 shows the break out of existing stock and annual energy use by battery charger type. As shown in Table 1, the energy use in California associated with these chargers is estimated to be over 4,200 GWh per year (Hebert, Porter et al. 2009). Little data are publicly available on the efficiency of large battery charger systems, although Southern California Edison (Smith 2008) and EPRI (2002) have independently conducted testing and research on these chargers. PG&E and its consultant Ecos finalized a consumer battery charger test procedure version 1.2 in April 2008 (Porter, Bendt PhD et al. 2008), but this test procedure did not include provisions for testing larger single phase and three phase systems such as lift-trucks. This project filled this gap by supporting the development of a comprehensive large battery charger test procedure, which was officially adopted by the California Energy Commission in December 2008.

Battery Charger Type	Estimate of Existing CA Stock	Annual Energy Use (GWh)
Three Phase Lift-trucks	27%	3,400
Golf Carts/Electric Carts	56%	635
Single Phase Lift-trucks	19%	246

Table 1: Industrial Battery Charger Technologies (Hebert, Porter et al. 2009)

Ferroresonant and silicon controlled rectifier (SCR) have been the dominant large battery charger technologies for decades. Two emerging technologies, hybrid (controlled ferroresonant) and high frequency (switch mode) chargers, typically have more sophisticated charge control and improved power conversion efficiency than then dominant technologies. A more detailed discussion of industrial battery charger technologies can be found in Appendix C. Table 2 summarizes market trends for the four major technologies.

Technology	Estimate of Existing CA Stock [a]	Market Share Projection	Relative Efficiency	Cost Range [b]	Average Cost [b]	Status of Technology
Ferroresonant	50%	Decreasing	Average	$1,500 - $2,300	$1,840	Proven
SCR	30%	Decreasing	Average	$1,300 - $2,700	$2,100	Proven
Hybrid	5%	Marginally Increasing	Good	$2,000 - $3,500	$2,540	Developing
High Frequency	10%	Increasing	Best	$2,000 - $3,500	$2,810	Developing

Source: [a] Stock share was estimated based on conversations with manufacturers and industry experts (Wilson, 2008), (Smith 2009), and (Munton 2008). [b] Cost range and average cost was estimated based on cost data for 22 chargers provided by a manufacturer and industry expert (Smith 2008) (Munton 2008). One industry expert suggests that the cost difference between ferroresonant and high frequency may be closer to zero than these in the table above. Recent increases in raw materials in ferroresonant chargers are driving up cost. First cost may possibly exceed high frequency chargers (Smith 2009).

Table 2: Industrial Battery Charger Technologies

3. Project Objectives

The objectives of this project included:

- With input from PG&E Applied Technology Services (ATS) Group, Southern California Edison (SCE) and other stakeholders, adapt the consumer battery charger test procedure to enable testing of high-power single phase and three phase battery charger systems
- Provide technical and logistical support to PG&E's ATS Group during charger testing
- Develop metrics that account for all modes of battery charger operation for comparing the energy use of these large battery chargers
- Calculate the energy consumption and peak demand contributions for each battery charger tested using different assumed facility operating profiles (single shift, two shift, 24-hour operation)
- Calculate energy and peak demand savings opportunities associated with moving the market to more efficient technology

In addition, the data collected in this project supported PG&E's 2009 codes and standards work to develop a minimum efficiency performance standard for large battery charger systems (Hebert, Porter et al. 2009).

4. Project Methodology

The project occurred in three key phases:

1. Test procedure revision and finalization (June 2008 to December 2008)
2. PG&E test set up and collection of test data (December 2008 to April 2009)
3. Data analysis and reporting (March 2009 to May 2009)

In 2003, The California Energy Commission's Public Interest Energy Research Program (PIER) funded PG&E's consultant Ecos to begin developing a battery charger test procedure that measured the efficiency of small consumer battery chargers sold with cell phones, power tools, toothbrushes, and other rechargeable appliances. This test procedure, known as version 1.2 (Porter, Bendt et al. 2008), was finalized by PG&E's consultant Ecos in April 2008, but did not include technical details needed to test high-power battery charger systems, such as golf carts and lift-trucks. Southern California Edison (SCE) had developed an informal method for testing these products, but there was no public written record of the test protocol. Under this project, PG&E's consultant Ecos coordinated with SCE to incorporate its draft large charger test procedure as "Part 2" of the already developed consumer test procedure. This became version 2.1.4 (Porter, Bendt, et al. 2008).

With input from PG&E's ATS Group and charger manufacturers, PG&E's consultant Ecos worked with SCE to clarify the required data to be reported and included technical details needed for a wide variety of chargers. The test procedure was publicly reviewed in a California Energy Commission rulemaking process and a revised procedure was adopted as version 2.2 by the California Energy Commission in December of 2008. A full copy of the California Energy Commission adopted test procedure version 2.2 may be reviewed in Appendix E and is available on www.efficientproducts.org.

Once the test procedure was finalized, the testing phase began. PG&E's consultant Ecos facilitated conversations with SCE and PG&E's ATS Group to clarify the intent of certain sections of the test procedure, and provided PG&E's ATS Group a data collection template based on the publically available template created to collect data for the Title 20 standards process at the California Energy Commission (California Energy Commission 2008). PG&E's consultant Ecos advised PG&E's ATS Group on which chargers should be tested first to best inform the 2009 PG&E CASE report for battery charger systems (Hebert, Porter et al. 2009). PG&E's ATS Group successfully used the test procedure to collect data for five chargers. PG&E's consultant Ecos garnered an additional 22 charger tests from SCE and one test from manufacturer Ametek for a total of 28 raw data points. For more details on the test procedure approach and required equipment, please refer to the California Energy Commission adopted test procedure version 2.2.

In order to compare the efficiency of the chargers, PG&E's consultant Ecos conferred with SCE to develop efficiency metrics for large three phase chargers. The metrics were designed to enable policymakers and program implementers to distinguish not only the highest but also the lowest efficiency products in the market. They therefore work equally well for minimum performance standards and market transformation programs. PG&E's consultant Ecos then gathered market information to estimate the number and technology types of installed units, and identified the relative efficiency of all chargers in the data set. Using these data, PG&E's consultant Ecos calculated energy and peak demand savings associated with replacing installed lift-truck chargers with high efficiency chargers under three duty cycle scenarios: single shift, double shift, and 24-hour shift scenarios.

5. Project Results

Part 2 of the California Energy Commission test procedure version 2.2 calls for the charger to be engaged in three discharge/charge cycles at three different depths of discharge. The measurements taken distinguish between energy lost in the charger and energy lost in the battery. Five energy efficiency metrics are used to compare the efficiency and energy use of the chargers in the data set:

- *Charge return factor*: the number of ampere hours (Ah) returned to the battery during the charge cycle divided by the number of ampere hours delivered by the battery during discharge. This metric measures how well the charger tailors its charge profile to the battery's depth of discharge. For example, all lead acid batteries require some amount of over charge to prevent the build-up of sulfides on the electrodes and ensure proper battery health, but excessive overcharge taxes the battery and shortens its useful life. Charge return factor should never fall below 1.05 and should not exceed 1.15 in order to maintain proper battery health. Charge return factor in this data varies between 1.05-1.30.
- *Power conversion efficiency*: the instantaneous dc output power of the charger (to the battery) divided by the instantaneous ac input power. Power conversion efficiency at the

maximum, median and minimum power levels of the charge are used to evaluate the power conversion efficiency performance of the charger.[1]

- *Maintenance power*: the average ac power when the battery charger is connected to the battery and delivering current in order to counteract or compensate for the self discharge of the battery. Energy consumption is measured for 72 hours to determine average power of the charger during maintenance mode.
- *No battery power*: the average ac power when the battery charger is not connected to the battery. The no battery mode test is conducted for one hour. The average power over that one hour is reported as the no battery power.
- *Power factor:* the ratio of the active power consumed by the battery charger in watts to the apparent power drawn in volt-amperes.

PG&E's consultant Ecos evaluated 28 raw data points from PG&E's ATS Group, SCE, and Ametek. Only nine unique chargers were tested by SCE (11 were duplicative tests). In some cases, the test results among these duplicative tests varied up to 14%, so PG&E's consultant Ecos averaged data points from duplicate chargers and used these averages for the analysis.

Variation in charge return test results among identical SCR and ferroresonant charger models can generally be attributed to imprecise technology used to detect charge completion. Variation in charge return factor for hybrid and high frequency chargers was within test procedure margins of error. Variation in power conversion efficiency for duplicative tests was typically less than 1% for all technology types.

The data set included only two golf cart battery charger data points and no single phase lift-truck battery charger data points, making it impossible to provide meaningful quantitative analysis of golf cart charger or single phase lift-truck trends by technology. The results below focus on the results of 15 three phase lift-truck battery chargers, nine from SCE, five from PG&E's ATS Group, and one from Ametek. Complete results used for this lift-truck analysis and the two golf cart charger points are summarized in Appendix B.

The most common depth of discharge (DOD) is 80%; however, the test procedure requires the charger to be tested at 100% and 40% DOD as well. The charge return factor for the 100% depth of discharge was generally lower than the 80% value, and the charge return factor for the 40% depth of discharge was generally higher than the 80% value. Ideally a charger should provide the same amount of overcharge for every depth of discharge. The data include eight complete charger tests with 100%, 40%, and 80% depth of discharge results. The worst case showed a difference between the charge return factor of 80% DOD and 40% DOD of 0.10. The best case varied less than 0.01.

[1] For some of the data provided by SCE, power conversion efficiency was not available at all three of these charge cycle points. For the purposes of this analysis, PG&E's consultant Ecos averaged the data points that were available.

Technology		Charge Return Factor	Average [a] Power Conversion Efficiency	Maintenance Power (W)	No Battery Power (W)	Average [a] Power Factor
Ferroresonant	Range	1.12 - 1.21	84% - 87%	7.0 - 293.5	7.0 - 39.5	0.91 - 0.97
	Average	1.15	85%	81.7	18.2	0.92
SCR	Range	1.09 - 1.35	81% - 88%	10.0 - 262.8	10.0 - 285.0	0.60 - 0.85
	Average	1.18	85%	137.1	125.3	0.76
Hybrid	Range	1.10 - 1.14	80% - 89%	53.0 - 73.9	6.0 - 19.0	0.87 - 0.97
	Average	1.12	86%	62.3	14.1	0.91
High Frequency	Range	1.06 – 1.29	91% - 92%	23.8 - 108.0	23.8 - 108.0	0.93 - 0.99
	Average	1.15	92%	48.4	48.4	0.96

Note: Charge return factor varies based on depth of discharge of the battery; the charge return data in this table represents 80% depth of discharge, which is the most common state of discharge. Battery capacity was normalized to 760 Ah to account for the different size batteries that were used in individual tests. [a] Average values represent the average of the data at the high, low, and middle power levels.

Table 3: Three Phase Lift-truck Battery Charger Range of Performance

Table 3 shows the four major charger types and associated efficiency metrics. Note that there are significant differences in all the metrics, even within one technology. Because of the wide variation, the average does not necessarily represent a typical product, but it does provide some insight into strengths and weakness of each technology type. Power conversion efficiency and power factor are characteristics associated with technology type. The charge return factor, maintenance, and no battery power averages are less meaningful because these characteristics are associated with charge control circuitry design and sophistication of standby power circuitry. Charge return factor, maintenance, and no battery power can be improved in any of the four technologies. [2]

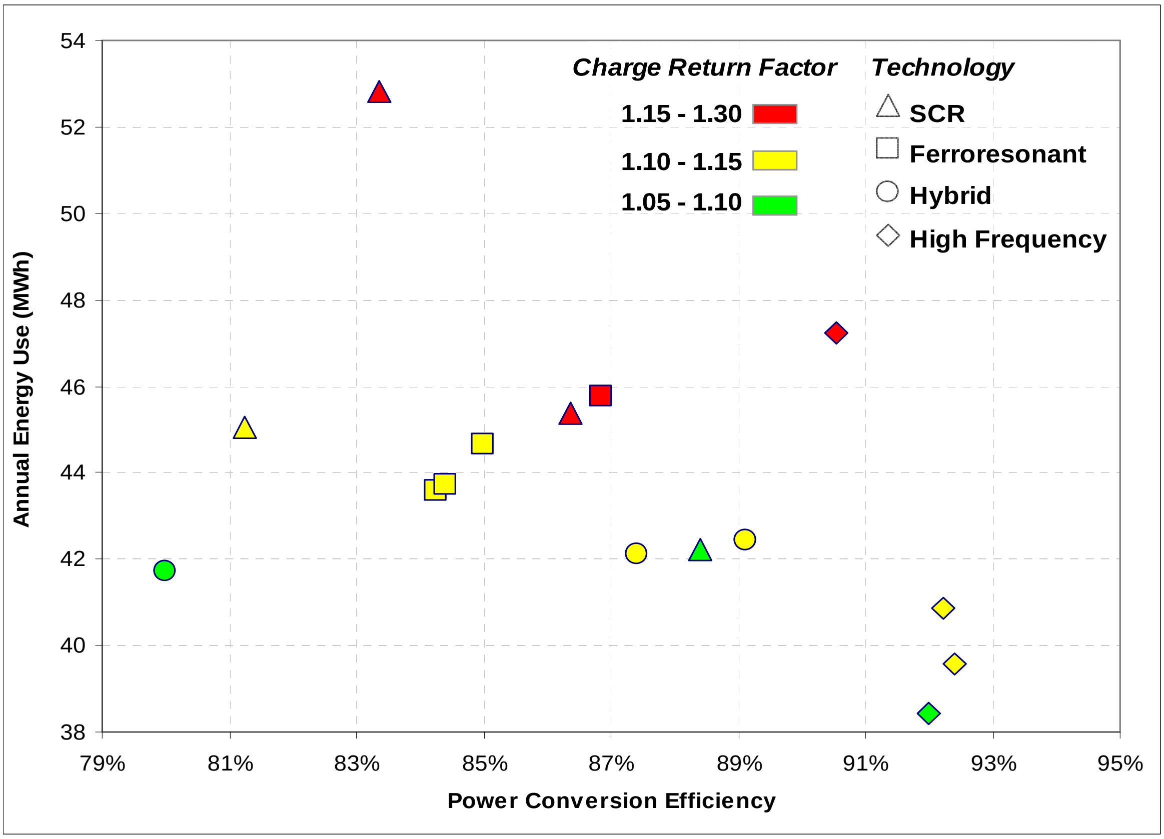
Figure 1 compares annual energy use of 15 three phase lift-truck battery chargers[3] to the two most important energy use performance factors: charge return factor and power conversion efficiency. Chargers closest to the bottom of the chart are the most efficient (lowest energy use). Although it is possible to group battery chargers by technology, it is also notable that there are

[2] The data set supports this conclusion for SCR, hybrid, and high frequency (Figure 1 green marks), but no ferroresonant chargers in the data set have excellent charge return factor. PG&E’s consultant Ecos technical research suggests that better charge control circuitry could be implemented in a ferroresonant design.

[3] For many of these lift-truck chargers, there are duplicative tests in the data set.

significant variations within each technology suggesting that charger type alone is not the sole indicator of energy use.

The most efficient chargers have the best charge return factor (green) and efficient power conversion above 91%. Charge return factor, or how well the charge control is implemented, is the most important indicator of overall charger energy use. Poor charge control (red marker in Figure 1) can not only shorten the life of the battery, but can also be the greatest source of energy waste in the charging system. Implementing good charge control strategies is cost effective, is applicable to all technologies, and can garner significant energy savings. Power conversion, the second most important metric of energy use, is limited by charger technology. The different battery charger technologies primarily fall within bands of power conversion efficiency; high frequency chargers are 90% and above, ferroresonant chargers 83% to 87%, and SCR/hybrid chargers 80% to 90%.



Note: Annual energy use is calculated using the assumptions of a 24-hour shift, which is equivalent to 20 charges a week at 7.5 hours per charge. 24-hour shift assumptions show the largest energy use, but even for single or double shift scenarios, the power conversion efficiency and charge return factor are the two most important predictors of annual energy use. The charge return data in this figure represents 80% depth of discharge.

Figure 1: Three Phase Lift-truck Energy Usage Sensitivity Plot

Even though there were variations within technology, it was useful to compare technology averages to identify savings opportunities. PG&E's consultant Ecos created energy savings estimates associated with replacing an average ferroresonant, SCR, or hybrid charger with an average high frequency charger. The data set indicated that high frequency chargers have the lowest energy use.

Table 4 gives a range of possible energy savings, peak demand savings, and payback periods in the absence of incentives. Note that the largest opportunities for savings are associated with replacing SCR and ferroresonant chargers with high frequency chargers. Replacing SCR or ferroresonant chargers with high frequency charges could save industrial customers $371 to $1,008 per year. This replacement would give the customer a simple payback period of two to five years. Payback period for replacing SCR or ferroresonant chargers with more efficient units would occur long before the expected 20-year useful life of a three phase lift-truck battery chargers (Smith 2008).

Technology Replaced	**Savings Achieved from Average High Frequency**	**8-hour Shift [e]**	**16-hour Shift [f]**	**24-hour Shift [g]**
Average Ferroresonant	Annual Savings per Unit (kWh) [a]	1,035	2,125	2,911
	Peak Demand Reduction per Unit (kW) [b]	1.3	1.3	1.3
	Payback Period: Incremental Cost (years) [c]	8.5	4.2	3.0
	Payback Period: Full Replacement Cost (years) [d]	16.2	7.9	5.7
Average SCR	Annual Savings per Unit (kWh) [a]	2,169	3,627	4,849
	Peak Demand Reduction per Unit (kW) [b]	0.4	0.4	0.4
	Payback Period: Incremental Cost (years) [c]	2.5	1.5	1.1
	Payback Period: Full Replacement Cost (years) [d]	8.8	5.3	3.9
Average Hybrid	Annual Savings per Unit (kWh) [a]	149	439	575
	Peak Demand Reduction per Unit (kW) [b]	1.1	1.1	1.1
	Payback Period: Incremental Cost (years) [c]	16.3	5.5	4.2
	Payback Period: Full Replacement Cost (years) [d]	155.3	52.6	40.2

Note: [a] Details of calculation can be found in Appendix C. [b] Peak demand savings is this case represents the total peak power reduction during the charge mode of the battery chargers operation. This number does not represent coincident peak demand reduction. [c] $110 per megawatt hour is used to calculate payback period. PG&E's consultant Ecos estimated the average incremental cost difference between ferroresonant and high frequency chargers is about $970, between SCR and high frequency: $593, between hybrid and high frequency: $267. These estimates are based on a price list of 18 products from SCE (Smith 2008) as well as sales and cost data on four chargers from EnerSys (Munton 2008).[d] The average costs shown in Table 2 are used to calculate payback period associated with replacement costs. [e] An 8-hour shift is defined as seven charges per week with a charge time of 7.5 hours, 63 hours per week of maintenance time and 52.5 hours of no battery time. [f] A 12-hour shift is defined as 14 chargers per week with a charge time of 7.5 hours, 63 hours of maintenance time and 0 hours of no battery time. [g] 24-hour shift as 20 chargers per week, 18 hours of maintenance time, and 0 hours of no battery time.

Table 4: Three Phase Lift-truck Battery Charger Savings of Average of Technology Performance

Performance	Technology	Charge Return Factor	Power Conversion Efficiency	Maintenance Power (W)	No Battery Power (W)	Power Factor
Best	High Frequency	1.06	92%	23.8	23.8	0.93
Average	Ferroresonant	1.12	84%	239.5	39.5	0.91
Poor	SCR	1.35	83%	10.0	10.0	0.85

Note: Charge return data in this table represents 80% depth of discharge.

Table 5: Key Three Phase Lift-truck Battery Chargers by Performance

Another way to consider energy savings is to select three actual products in the data set (Table 5) that represent poor, average and best efficiency. PG&E's consultant Ecos determined energy use savings associated with replacing the average and poor performers with the best performer in a hypothetical retrofit scenario (Table 6). Creating an efficiency program standard that required the best of the high efficiency chargers, similar to the high frequency shown in Table 4, and identifying and replacing the worst of the SCR and ferroresonant chargers would enable payback periods of less than one year to five years. Customer energy savings would range from 2,500 to 14,000 kWh per year.

Performance	Technology	Savings compared to *Best High Frequency*	8-hour Shift	16-hour Shift	24-hour Shift
Average	Ferroresonant	Annual Savings Per Unit (kWh)	2,694	4,419	5,303
		Peak Demand Reduction per Unit (kW)	n/a [a]	n/a [a]	n/a [a]
		Payback Period: Incremental Cost (years)	3.3	2.0	1.7
		Payback Period: Full Replacement Cost (years)	6.2	3.8	3.2
Poor	SCR	Annual Savings Per Unit (kWh)	4,963	10,046	14,403
		Peak Demand Reduction per Unit (kW)	n/a [a]	n/a [a]	n/a [a]
		Payback Period (years): Incremental Cost	1.1	0.5	0.4
		Payback Period: Full Replacement Cost (years)	3.8	1.9	1.3

Note: Methodology and assumptions identical to Table 4. [a] The peak power demand of the best high frequency charger is higher than the alternatives, thus no reduction is realized.

Table 6: Three Phase Lift-truck Battery Charger Savings Table: Moving to Best High Frequency

The data suggest that reducing large battery charger energy use by replacing the least efficient units with high efficiency units is unlikely to produce product peak power reductions (Table 6) and unlikely to produce coincident peak power demand reductions (Table 7). Coincident peak demand reductions could potential be realized through demand response devices although these devices are not yet integrated into chargers.

Technology [a]	**Coincident Peak Demand Reduction Per Unit Compared to *Average* [b] *High Frequency* (kW)**		
	8-hour Shift	**16-hour Shift**	**24-hour Shift**
Ferroresonant	0.39	0.39	1.3
SCR	0.12	0.12	0.4

Note: [a] Hybrid chargers were not considered here because they were not the likely targets for programmatic replacement. [b] There were minimal peak power demand reductions garnered by switching to the best high frequency charger in this study. The average of the data set was used to illustrate the opportunities. Coincident peak demand reduction was calculated using the following load factors[4] per shift operation: *8-hour shift*: The load factor is 30%, because on average the charge cycle will begin at 5:00 pm and last for 7.5 hours; this equates to 2 hours of charge during peak period, *16-hour shift*: The load factor is 30%, because on average one charge cycle will begin at 5:00 pm and last for 7.5 hours and the other charge cycle will be at night; this equates to two hours of charge during peak period.*24-hour shift*: The load factor is 100%, because on average the charger will be charging the battery during the peak demand period. Maintenance and no battery mode power levels were not included in the coincident peak demand calculation because the power levels on average are negligible.

Table 7: Coincident Peak Demand Reduction [5]

5. Discussion

Based on technical work in this project, widespread implementation of high efficiency charger technology is likely to be feasible, cost effective, and to garner significant energy savings. Research findings suggest:

- Because efficiency varies even within each technology type, a program specification based on the California Energy Commission test procedure version 2.2 metrics could help ensure program savings and enable fair comparison of products. Making requirements more stringent over time would continue to encourage market transformation.
- An initial program standard could be set based on annual energy use consumed in MWh based on the test results created by using the California Energy Commission approved test procedure version 2.2. More data points would be necessary to select a standard. In examining figure 1, a standard could be selected for chargers that demonstrated reduced

[4] Coincident peak demand reduction is calculated by multiplying the connected load reduction during the system peak demand period by a load or duty cycle factor during the system peak demand period.

[5] Peak demand period, as defined in the CPUC Energy Efficiency Policy Manual Version 2 (prepared by the Energy Division and dated August 2003) is noon to 7 p.m. Monday through Friday, June 1 through September 30.

consumption by having improved charge return factor, power conversion efficiency or both.

- A retrofit program may be preferable, as it could encourage early retirement of the worst performing chargers. The proposed Title 20 standard, which is scheduled for rulemaking this year, will address efficiency opportunities in new installations. A retrofit program could continue to deliver savings long after the most stringent proposed standards are projected to take effect.
- Three Phase Lift-truck battery chargers could be added to PG&E industrial site auditing programs. Targeting large industrial ports with significant lift truck use could enable extremely cost-effective retrofits. A similar approach could target golf courses with large banks of golf cart chargers that may add significant load during peak periods.
- Demand response systems are not integrated into existing large chargers although the most efficient and sophisticated chargers give consumers detailed information about the state of health of the battery and other parameters. The more sophisticated controls may provide PG&E an opportunity to work with manufacturers to develop smart controls with demand response features.
- In addition to PG&E customer energy savings, increased use of high efficiency chargers may lead to longer battery lifetime, and therefore reduced waste and lower long term customer costs for replacement batteries. (High efficiency chargers have more sophisticated charge control that avoids battery overcharge, which shortens the life of the battery.)

Table 8 shows the potential PG&E territory savings associated with early retirement of the average SCR and ferroresonant three phase lift-truck chargers. Replacing a modest 5%, or 3,600, of these low efficiency units with products that have high efficiency could garner 14,300 MWh of energy savings annually. If only the highest efficiency high frequency chargers were installed, the total savings would more than double (Table 9). Given that lower efficiency ferroresonant and SCR chargers make up approximately 80% of the installed stock, replacing 5% of the total stock could be a reasonable programmatic goal.

Percentage of Three Phase Lift-truck Units Retrofitted in PG&E Service Territory to *Average High Frequency*	**Number of Three Phase Lift-truck Units Retrofitted in PG&E Service Territory**	**Annual Energy Savings in PG&E Service Territory Associated with Retrofit (MWh)**
5%	3,600	14,300
10%	7,400	28,600
20%	14,700	57,200

Note: The energy savings was calculated using the difference between the "field unit" and average high frequency charger. The field unit was calculated using a blend of 50% ferroresonant and 50% SCR chargers. Calculation assumes 24-hour shift.

Table 8: Three Phase Lift-truck Retrofitting Scenarios: Moving to Average High Frequency

Scenario: Percentage of Units Retrofitted to *Most Efficient High Frequency*	Lift-truck Units Retrofitted in PG&E Service Territory	Annual Energy Savings in PG&E Service Territory (MWh)
5%	3,600	36,300
10%	7,400	72,500
20%	14,700	145,100

Note: The energy savings was calculated using the difference between the "field unit" and most efficient high frequency charger. The field unit was calculated using a blend of 50% ferroresonant and 50% SCR chargers. Calculation assumes 24-hour shift

Table 9: Lift-truck Retrofitting Scenarios: Moving to Most Efficient High Frequency

5. Conclusions

Large battery chargers are more efficient than the wide variety of small consumer battery chargers, such as cell phone, laptops, and power tool chargers. However, large battery chargers consume more than 4,200 GWh in California each year. A careful investigation reveals that modest improvements in large battery charger efficiency metrics translate into substantial energy savings. This can be attributed to the high power required by large battery chargers and their extended duty cycles.

Although research by PG&E's consultant Ecos suggests that there is significant efficiency variation even within one technology type, high frequency chargers tend to be the best performers. The older and more common SCR and ferroresonant chargers tended to be the least efficient.

Part 2 of the California Energy Commission test procedure version 2.2 provides a technology neutral methodology to accurately measure large battery charger performance. Although all five metrics are important to measure, power conversion efficiency and charge return factor are the two most significant contributors to annual energy use. The wide disparity in the estimated annual energy consumption of battery chargers in the data set suggests a retrofit program could yield substantial cost-effective savings. A technology neutral specification, which could be increased in stringency over time would encourage early retirement of the least efficient chargers. Preliminary finding suggest that replacing only 5% of low efficiency units in PG&E's service territory could yield 36,300 MWh per year in energy savings.

6. Recommendations for Future Work

The purpose of this project was to conduct an initial analysis of testing results and identify energy savings opportunities for large battery chargers. The scope of the study required PG&E's consultant Ecos to use some preliminary assumptions to generate comparisons. This preliminary research also generated some research questions that could merit further study. Below is a brief list of topics PG&E and its consultant Ecos identified that could benefit from more detailed research. Opportunities may exist to partner with PIER or other IOUs to fund this research.

- Increasing the overall population of the dataset would enable researchers to more clearly define the best performing chargers. Testing more hybrid chargers to investigate whether there are units with both high conversion efficiency and good charge control available in the market would be valuable. In addition, SCR chargers had a wide disparity of results and could be better understood with further testing. No ferroresonant chargers were identified that had exceptional charge return factor in the sample set although this could be technically feasible.
- Further testing of at least ten more golf cart chargers could help identify whether or not opportunities exist to garner savings from this product class. Efforts could be made to continue to acquire golf cart test information from SCE and combine this with tests from PG&E's ATS Group.
- The variation charge return efficiency for SCR and ferroresonant chargers could use additional study to ensure estimates of accurate potential energy savings associated with moving from these lower efficiency units to higher efficiency chargers.
- A concise site audit study in the PG&E service territory could be conducted with utility customers that use lift-truck chargers heavily. Further information could be gathered about baseline chargers to verify duty cycle assumptions, battery life, frequency of battery failure, and the potential for demand response or load shifting.
- A qualitative study with manufacturers of the best battery chargers may better inform the potential for improvement. Understanding what barriers exist to technical improvement, market dynamics, product differentiation by efficiency and demand response capabilities could inform program design.
- If utility customers indicate that charging lift-truck batteries could be shifted off-peak, conversations with manufacturers about the feasibility of incorporating smart demand response controls into large chargers could identify if there are coincident peak demand opportunities. Time of use rates could create financial incentives for end users to shift load.
- Although outside of the scope of this project, more information needs to be gathered to understand if there are operational limitations associated with hybrid and high frequency chargers (temperature, sturdiness, etc.).
- Aspects of this preliminary research and research topics mentioned above may also inform policy on automobile battery chargers for electric and hybrid vehicles that are outside the scope of this project. Advancements in battery charger technologies for vehicles could be monitored as the extended battery life and efficient charging technologies would be a highly desirable as well.

Appendix A: References

California Energy Commission. (2008). "2008 rulemaking on appliance efficiency standards, Docket # 07-AAER-3." Retrieved 5/27/2009, from http://www.energy.ca.gov/appliances/2008rulemaking.

California Energy Commission (2008). California Energy Commission Test Data Template.

EPRI (2002). Electric Lift Trucks and Market Potential: 2002 Addendum to EPRI TR-109189 “Lift Trucks – Market Description and Business Opportunities,” EPRI, Palo Alto, CA: 2002. 1007518.

Hebert, J., S. F. Porter, et al. (2009). "Analysis of Standards Options for Battery Charger Systems” Pacific Gas and Electric report for Codes and Standards Enhancement (CASE) Initiative For PY2009: Title 20 Standards Development."

Munton, S. (2008). Personal Communication with Steve Munton, EnerSys, by Jonathan Hebert, December 2008.

Porter, S. F., P. Bendt PhD, et al. (2008). Energy Efficiency Battery Charger System Test Procedure Version 1.2

Porter, S. F., P. Bendt PhD, et al. (2009). "Energy Efficiency Battery Charger System Test Procedure Version 2.2."

Porter, S. F., P. Bendt PhD, et al. (2008). "Energy Efficiency Battery Charger System Test Procedure Version 2.1.4."

Smith, J. (2009). Personal Communication with Jordan Smith by Jonathan Hebert, April to December 2008.

Smith, J. (2009). Personal Communication with Jordan Smith, Southern California Edison, by Jonathan Hebert, 5/27/2009.

Wilson, G. (2008). Personal Communication with Grover Wilson, Ametek, by Jonathan Hebert, December 2008.

Appendix B: Test Data

Tables 10 & 11 show test data compiled for this project. Test data is for 80% depth of discharge.

Technology	Index Number	Charge Return	Average [a] Power Conversion Efficiency	Maintenance Power (W)	No Battery Power (W)	Average [a] Power Factor
Ferroresonant	1	1.12	84%	293.5	39.5	0.91
	2	1.13	84%	7.0	7.0	0.92
	3	1.21	87%	18.2	18.2	0.91
	4	1.15	85%	8.0	8.0	0.97
SCR	5	1.18	86%	262.8	188.0	0.80
	6	1.11	81%	257.2	285.0	0.78
	7	1.09	88%	18.3	18.3	0.60
	8	1.35	83%	10.0	10.0	0.85
Hybrid	9	1.14	89%	73.9	19.0	0.90
	10	1.10	80%	53.0	17.4	0.87
	11	1.12	87%	59.9	6.0	0.97
High Frequency	12	1.14	92%	108.0	108.0	0.99
	13	1.06	92%	23.8	23.8	0.93
	14	1.29	91%	28.8	28.8	0.99
	15	1.11	92%	32.9	32.9	0.93

[a] Average values represent the average of the data at the high, low, and middle power levels.

Table 10: Lift-truck Battery Charger Test Data

Technology	Index Number	Charge Return	Average [a] Power Conversion Efficiency	Maintenance Power (W)	No Battery Power (W)	Average [a] Power Factor
Ferroresonant	16	1.13	74%	50.0	50.0	0.95
High Frequency	17	1.13	91%	50.0	50.0	0.97

Note: Battery capacity normalized to 112 Ah for golf cart battery charger efficiency metric analysis.
[a] Average values represent the average of the data at the high, low, and middle power levels.

Table 11: Golf Cart Battery Charger Test Data

Appendix C: Energy Savings Calculations

$$E_{\text{annual}} = (E_{\text{per charge}} * \frac{\text{Charges}}{\text{week}} + P_{\text{maintenance}} * t_{\text{maintenance per week}} + P_{\text{no battery}} * t_{\text{no battery per week}}) * \frac{weeks}{year}$$

$$E_{\text{savings}} = E_{\text{high frequency annual}} - E_{\text{charger annual}}$$

where E is energy in watt hours, P is power in watts, t is time in hours, E_{annual} is annual energy use, and $E_{savings}$ is annual energy savings.

Appendix D: Large Charger Technology Description

Ferroresonant

Ferroresonant battery chargers are the most durable and widely used battery charger for industrial applications. They are composed of a transformer and a tank circuit that resonates at the designed ac input frequency to provide a flux regulated circuit. The capacitor in parallel with the inductive winding of the transformer creates a resonance at the specific ac input frequency. Then the current through the winding and the voltage on across the capacitor dictates the amount of flux through the transformer. Thus, the voltage and current delivered to the battery are limited as a function of flux. See Figure A for the circuit diagram.

Even the most modern ferroresonant charger are limited in power conversion efficiency to approximately 86% because of eddy current and magnetic saturation heating losses in the transformer core.

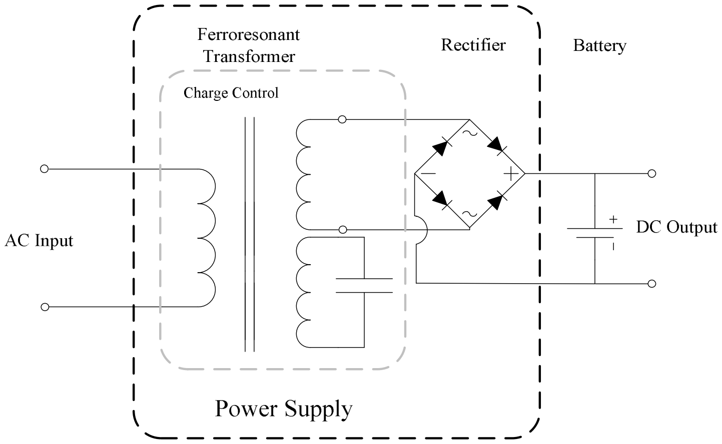


Figure A: Basic Ferroresonant Battery Charger

Silicon Controlled Rectifier

SCR battery chargers are also very popular in industrial applications because of their low cost and durability. SCR battery chargers are high powered cousins to typical switch mode battery chargers. A silicone controlled rectifier (SCR) is used to regulate voltage and current to the battery. SCRs are a mature technology that is able to withstand high power applications. They are limited in power conversion efficiency by switching losses. This is primarily due to the fact that they have a significantly limited frequency at which they can switch.

SCR's are being steadily supplanted by high frequency, insulated gate bipolar transistor (IGBTs), because IGBTs have significantly lower switching losses and can obtain much power conversion efficiencies.

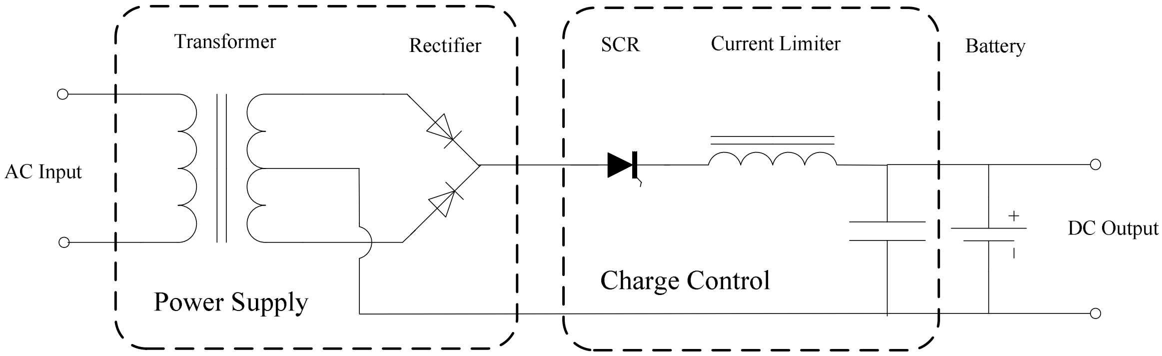


Figure B: Basic SCR Battery Charger

Hybrid
Hybrid, also known as controlled ferroresonant, battery chargers uses a switching circuit in place of the capacitor in the tank circuit to optimize the resonances and reduce losses in the transformer core. Power conversion efficiency can be increased to approximately 89% with this change and charge return can also be improved.

High Frequency
High frequency battery chargers are composed of a switching circuit that utilizes insulated-gate bipolar transistors (IGBTs), which can switch at much at much higher frequencies than SCRs. High switching frequencies reduce loss and improve power conversion efficiency. IGBTs also enable better voltage and current control, because of their ability to be switched on and off precisely, and can improve charge return, reduce maintenance, and no battery power. Power conversion efficiencies as high as 92% are common in high frequency chargers.

Appendix E: Energy Efficiency Battery Charging System Test Procedure Version 2.2, January 26, 2009

Energy Efficiency Battery Charger System Test Procedure

Version 2.2, January 26, 2009

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Development funded by: Pacific Gas and Electric,

California Energy Commission-Public Interest Energy Research (PIER) Program,
and Southern California Edison

Scope

General Scope

The purpose of the test procedure is to measure the energy efficiency of battery chargers coupled with their batteries, which together are referred to as ***battery charger systems***. This term covers all rechargeable batteries or devices incorporating a rechargeable battery and the chargers used with them. Battery charger systems include, but are not limited to:

1) electronic devices with a battery that are normally charged from ac line voltage or dc input voltage through an internal or external power supply and a dedicated battery charger;
2) the battery and battery charger components of devices that are designed to run on battery power during part or all of their duty cycle (such as many portable appliances and commercial material handling equipment);
3) dedicated battery systems primarily designed for electrical or emergency backup (such as emergency egress lighting and uninterruptible power supply (UPS) systems);
4) devices whose primary function is to charge batteries, along with the batteries they are designed to charge. These units include chargers for power tool batteries and chargers for automotive, AA, AAA, C, D, or 9 V rechargeable batteries, as well as chargers for batteries used in motive equipment, such as golf carts, electric material handling equipment and vehicles, including lift trucks (forklifts), airport electric ground support equipment (EGSE), port cargo handling equipment; tow tractors, personnel carriers, sweepers and scrubbers are examples of these types of motive equipment.
5) The scope of this procedure is limited to battery charger systems that are rated for ac input of 600 volts or less and that connect to the utility grid with a plug or are permanently connected.

Part 1 and Part 2

This test procedure contains two parts: Part 1 and Part 2. Battery charger systems are to be tested using either Part 1 or Part 2, based upon the specific scopes in C and D. Note that the test procedures in Parts 1 and 2 share common reference and definition sections.

If a battery charger system appears to be described by the scope of both parts, it is to be tested using Part 2.

Part 1 Scope

The scope of Part 1 is limited to those battery charger systems that operate on single-phase ac input power or dc input power and that have a nameplate input power rating of 2 kW or less.

This scope for Part 1 specifically excludes any battery charger system which meets the criteria of Part 2 in Section D of this Scope.

Excluded from the scope of Part 1 are battery charger systems for on-road full-function electric or plug-in hybrid-electric vehicles.

Laboratory testing equipment used to test and analyze batteries is specifically excluded from the scope of this test procedure. However, battery charger systems that provide power for portable laboratory testing equipment are included.

The scope of Part 1 includes any battery charger that meets the other criteria and that is packaged or sold without batteries. Part 1, Section II.C herein specifies the selection of suitable batteries for test using the procedures contained in Part 1.

Some examples of battery charger systems included in the scope of Part 1 are: cellular and cordless telephones, cordless power tools, laptop computers, cordless shavers, uninterruptible power supplies emergency egress lighting, portable lawn tools, rechargeable toys, and marine and recreational vehicle chargers,.

Note: The charging circuitry of battery charger systems may or may not be located within the housing of the end-use device itself. In many cases, the battery may be charged with a dedicated external charger and power supply combination that is separate from the device that runs on power from the battery.

Note: This test procedure is not intended to test batteries in the absence of a corresponding charger.

Part 2 Scope

Part 2 includes test and analysis methods to evaluate the energy usage and impact of battery charger systems for powering motive equipment.

Some examples of battery charger systems included in the scope of Part 2 are chargers for batteries used in motive equipment, such as golf carts, neighborhood electric vehicles, electric material handling equipment and vehicles, including lift trucks (forklifts), airport electric ground support equipment (EGSE), port cargo handling equipment; tow tractors, personnel carriers, sweepers and scrubbers.

Part 2 of this procedure does not cover the following:

a) Consumer electronics products and/or household-type devices, with either internal or external charger.
b) On-road full-function electric or plug-in hybrid-electric vehicles.

c) Battery chargers for automotive, marine and/or recreational vehicle starter batteries, or batteries used in conjunction with starting or running internal combustion engines and their accessories.
d) Battery chargers for signaling devices.
e) Electric wheelchairs or personal mobility devices.
f) Systems rated for input greater than 600V.
If they meet the criteria in Section C, above, these excluded devices may be covered by the scope of Part 1.

References

This list is included for informational purposes only, and a manufacturer/tester is not required to follow the provisions of all of the following reference material to conform to this test method:

ANSI/NCSL Z540-1-1994, *American National Standard for Calibration – Requirements for Calibration of measuring and Test Equipment,* ANSI and NCSL, 1994.
BCIS-05: Battery Council International, *BCI Specifications for Electric Vehicle Batteries*, BCIS-05 Rev. DEC02.
BCIS-14: Battery Council International, *Determination of Capacity of Lead-Acid Industrial Storage Batteries for Motive Power Service,* BCIS-14 Rev. DEC02.
BCIS-16: Battery Council International, *Standard for Deep Cycle Battery Chargers*, BCIS-16 Rev. DEC02.
BCIS-18: Battery Council International, Standard for Deep Cycle Fast/Battery Chargers, and BCIS-18 Rev. MAR06
Buchmann, Isidor, *Batteries in a Portable World: A Handbook on Rechargeable Batteries for Non-Engineers*, Cadex Electronics Inc., 2001.
IEC 60050-300: International Electrotechnical Commission, *International Electrotechnical Vocabulary- Electrical and Electronic Measurements and Measuring Instruments*, IEC 60050-300, Edition 1.0, 2005.
IEC 60051: International Electrotechnical Commission, *Direct Acting Indicating Analogue Electrical Measuring Instruments and their Accessories*, IEC 60051, parts 1-9, Edition 5.0, 1997.
IEC 60254-1: International Electrotechnical Commission, *Lead-acid traction batteries – Part 1: General requirements and methods of tests*, IEC 60254-1, Edition 4.0, 2005.
IEC 61056-1: International Electrotechnical Commission, *General Purpose Lead-Acid Batteries (Valve Regulated Types) – Part 1: General Requirements, Functional Characteristics – Methods of Test*, IEC 61056-1, Edition 2.0, 2002.
IEC 61951-1: International Electrotechnical Commission, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Portable sealed rechargeable single cells – Part 1: Nickel-cadmium*, IEC 61951-1. Edition 2.0, 2003-2004.
IEC 61951-2: International Electrotechnical Commission, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Portable sealed rechargeable single cells – Part 2: Nickel-metal hydride*, IEC 61951-2, Edition 2.0, 2003.
IEC 61960: International Electrotechnical Commission, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for portable applications*, IEC 61960, Edition 1.0, 2003.

IEC 62133: International Electrotechnical Commission, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications*, IEC 62133, Edition 1.0, 2002.
IEC 62301: International Electrotechnical Commission, *Household Electrical Appliances - Measurement of Standby Power*, IEC 62301, Edition 1.0, 2005.
IEEE 100: Institute of Electrical and Electronics Engineers, *The Authoritative Dictionary of IEEE Standards Terms*, IEEE 100, Edition 7.0, 2006.
IEEE Std 1625™ - 2008, revision of IEEE 1625-2004, IEEE Standard for Rechargeable Batteries for Multi-cell Mobile Computing Devices. The Institute of Electrical and Electronics Engineers, Inc., New York, NY, USA.
USABC *Electric Vehicle Battery Test Procedures Manual*, DOE/ID-10479, Rev. 2, INEL, U.S. DOE, 1996.

Definitions

Active Power (P)
Active power is the average value, taken over one or more cycles, of the instantaneous power (which is the product of instantaneous voltage and current).

Ambient Temperature
Ambient temperature is the temperature of the ambient air surrounding the UUT.

Ampere-hour (Ah) Capacity
See "Rated Charge Capacity."

Apparent Power (S)
The apparent power (S) is the product of rms voltage and rms current (VA).

Batch Charger
A batch charger is a battery charger that charges two or more identical batteries simultaneously in a series, parallel, series-parallel, or parallel-series configuration. A batch charger does not have separate voltage or current regulation nor does it have any separate indicators for each battery in the batch. When testing a batch charger, the term “battery” is understood to mean, collectively, all the batteries in the batch that are charged together. A charger can be both a batch charger and a multi-port charger or multi-voltage charger.

Battery Chemistry
The chemistry of the rechargeable battery, such as nickel cadmium, nickel metal hydride, lithium ion, lithium polymer, rechargeable alkaline, or lead-acid.

Note: The chemistry of the battery is typically printed on the label of the battery itself, can be found in the manufacturer's instructions, or can be obtained from the manufacturer of the battery system.

Battery Conditioning
A special procedure performed on a battery to ensure optimal performance.

Battery Discharge Energy
The energy, in watt-hours (Wh) delivered by the battery as measured by this test procedure.

Note: This is the *measured* battery discharge energy as distinct from the *Rated Battery Energy* defined below.

Battery Maintenance Mode
The state in which the battery charger system is connected to input power, and the battery charger may be delivering current to the battery in order to counteract or compensate for self-discharge of the battery.

Note: In this state, the battery is at or near 100% capacity.

Battery Rest Period
A period of time, between discharge and charge or between charge and discharge, during which the battery is resting in an open-circuit state in ambient air.

Calculated Energy Capacity
The product (in Wh) of the Rated Battery Voltage and the Rated Charge Capacity.

Note: This is distinct from the *measured* Battery Discharge Energy defined below.

Charge Energy Management
The interactive way in which the battery is returned to proper charge and health with the optimum amount of energy.

Charge Mode
The state in which the battery charger system is connected to input power, and the battery charger is delivering current in order to bring the battery from a state of discharge to a state at or near 100% capacity.

Note: a battery charger system may have more than one charge mode.

Charge Return Factor

The number of Ah returned to the battery during the charge cycle divided by the number of Ah delivered by the battery during discharge.

C-Rate

The rate of charge or discharge, expressed in terms of the rated charge capacity (see definition) of the battery. A discharge rate of one-C draws a current (in A or mA) equal to the rated charge capacity (in Ah or mAh) and would theoretically discharge the battery in one hour. Other currents are expressed as multiples of one-C, so 0.2C is one fifth of that current.

Cradle

Electrical interface between integral battery product and the rest of the battery charging system designed to hold the product between uses.

Crest Factor

For an ac or dc voltage or current waveform, the crest factor is the ratio of the peak instantaneous value to the root-mean-square (rms) value.

Note: Crest factor is expressed as a ratio, for example a pure sine wave has a crest factor of 1.414.

Detachable Battery

A battery which is separable from the appliance and is intended to be removed from the appliance for charging purposes. The battery pack may contain additional circuitry.

End-of-Discharge Voltage

Specified closed-circuit battery voltage at which discharge of a battery is terminated.

Equalization

A process whereby a battery is overcharged, beyond what would be considered “normal” charge return, so that cells can be balanced, electrolyte mixed, and plate sulfation removed.

External Power Supply (EPS)

An external power supply is an external module which connects to ac line power and provides power to other components of the battery charger system. In this test procedure, this term is used broadly and generically. It is not limited to nor does it exclude power supplies that may be regulated by any particular jurisdiction or standard.

External power supplies are designed to covert ac line voltage into low voltage output (either ac or dc) and are contained in a separate housing from the product they are powering.

Note: For further clarification, see Test Method for Calculating the Energy Efficiency of Single Voltage External Ac-Dc and Ac-Ac power Supplies, August 11, 2007, at www.efficientpowersupplies.org.

Integral Battery

A battery which is contained within the appliance and is not intended to be removed from the appliance for charging purposes. A battery that is to be removed from the appliance for disposal or recycling purposes only is considered to be an integral battery.

Instructions

The instructions (or "manufacturer's instructions") shall mean the documentation packaged with the product in printed or electronic form and any information about the product listed on a website maintained by the manufacturer and accessible by the general public. "Instructions" includes any information on the packaging or on the product itself. "Instructions" also includes any service manuals or data sheets that the manufacturer offers for sale to independent service technicians, whether printed or in electronic form.

Maintenance Management

The way in which the charger maintains the battery when the battery is left connected and not used for long periods.

Measured Charge Capacity

Measured charge capacity of a battery is the product of the discharge rate in amperes and the time in decimal hours required to reach final voltage.

Multi-port Charger

A multi-port charger is a battery charger which charges two or more batteries (which may be identical or different) simultaneously. The batteries are not connected in series or in parallel. Rather, each port has separate voltage and/or current regulation. If the charger has status indicators, each port has is own indicator(s). A charger can be both a batch charger and a multi-port charger if it is capable of charging two or more batches of batteries simultaneously and each batch has separate regulation and/or indicator(s).

Multi-voltage Charger

A battery charger that, by design, can charge a variety of batteries (or batches of batteries if also a batch charger) that are of different rated battery voltages. A multi-voltage charger can also be a multi-port charger if it can charge two or more batteries simultaneously with independent voltage and/or current regulation.

No-Battery Mode

The state in which the battery charger system is connected to input power, is configured to charge a battery, but there is no battery connected to the charger output.

Note: Under normal operation by the user, the system would begin charging a battery if one were connected. For no-battery mode test setup of specific products, please refer to section IV. A. of the test procedure.

No-Battery Energy

The energy used by the charger when in no-battery mode.

Off Mode

The state in which the battery charger is switched "off" using a switch located on the charger, if such a switch is included, while the charger is connected to the input power source and used in accordance with the manufacturer's instructions.

Note: If the charger does not have an on/off switch, off mode is the same as no-battery mode. If the charger does have an on/off switch, the charger will not begin charging a battery if one is connected while the charger is switched off. Products operating in Off Mode may still have some residual power consumption, which is the purpose of measuring power consumption in the Off Mode.

Overcharge

See "Charge Return Factor."

Periodic Equalization Strategy

A part of charge energy management: the length, power, and frequency of cell overcharge and balancing sessions necessary for the long-term health of a battery.

Power Conversion Efficiency

The instantaneous DC output power of the charger divided by the simultaneous utility AC input power.

Power Factor

The power factor is the ratio of the active power (P) consumed in watts to the apparent power (S), drawn in volt-amperes (VA).

$$PF = \frac{P}{S}$$

Note: This definition of power factor includes the effect of both harmonic distortion and phase angle displacement between the current and voltage.

Power Quality

The nonlinear effects of a battery charger system (power factor, harmonic distortion) on the interactive utility grid – an impact on system energy efficiency.

Rated Battery Voltage

The battery voltage specified by the manufacturer and typically printed on the label of the battery itself. If a batch of batteries includes series connections, the Rated Battery Voltage of the batch is the total voltage of the series configuration, that is, the rated voltage of each battery times the number of batteries connected in series. Connecting multiple batteries in parallel does not affect the Rated Battery Voltage.

Note: if not printed on the battery, the rated battery voltage can be derived from the electrical configuration and chemistry of the battery.

Rated Charge Capacity

The capacity, usually given in ampere-hours (Ah) or milliampere-hours (mAh), specified by the manufacturer and typically printed on the label of the battery itself. If a batch of batteries includes parallel connections, the rated charge capacity of the batch is the total charge capacity of the parallel configuration, that is, the rated charge capacity of each battery time the number of batteries connected in parallel. Connecting multiple batteries in series does not affect the rated charge capacity.

Note: it is the quantity of electric charge the manufacturer declares the battery can store under particular pre-specified test conditions.

Rated Input Frequency

Range of ac input frequencies designed to operate the UUT; assigned by the manufacturer and usually printed on the housing of the charging device. If the UUT includes an EPS, this is the frequency of the input to the EPS, not the frequency of the input to the other component(s) of the UUT.

Rated Input Voltage

Range of ac or dc input voltage designed to operate the UUT; assigned by the manufacturer and usually printed on the housing of the charging device. If the UUT includes an EPS, this is the voltage of the input to the EPS, not the voltage of the input to the other component(s) of the UUT (from the EPS).

Specific Gravity

The ratio of the density of a given substance (e.g. battery electrolyte) to the density of water, when both are at the same temperature.

Swappable Battery

A battery that is intended to be charged in the appliance but which may be detached from the appliance so that another battery can be attached to the appliance.

Total Harmonic Distortion (THD)

Total harmonic distortion is a measure of the degree to which a waveform departs from a pure sinusoidal waveform. It is defined as the ratio of the vector sum of all harmonic components (greater than 1) to the magnitude of the fundamental. For instance, for a voltage waveform, THD is defined by the equation:

$$\text{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1}$$

where V_i is the rms voltage of the i^{th} harmonic.

UPS

Uninterruptible Power Supply

UUT

UUT is an acronym for "unit under test," which in this document refers to the combination of the battery charger and battery being tested.

PART 1:

I. Standard Test Conditions

General

The test sequence is summarized in the table below. Measurements shall be made under test conditions and with the equipment specified below. For some products, multiple tests are required. The required tests may be at different input voltages (see Part 1, Section I.D), different charge rates (see Part 1, Section II.A), and using different batteries (see Part 1, Section II.C). When two or more of these apply, all combinations of specified input voltages, specified charge rates, and specified batteries shall be tested.

Table A: Test Sequence

Step	Description	Data Taken?	Equipment Needed			
			Battery	Charger	Battery Analyzer	Ac Power Meter
1	Record general data on UUT	Yes	X	X		
2	Battery conditioning, Section VI.A	No	X		X	
3	Prepare battery for test, Section VI.B	No	X		X	
4	Battery rest period, Section VI.C	No	X			
5	Conduct Charge Mode and Battery Maintenance Mode Test, Section VI.D	Yes	X	X		X
6	Battery rest period, Section VI.E	No	X			
7	Conduct Battery Discharge Energy Test, Section VI.F	Yes	X		X	
8	Conduct No-Battery Mode Test and Off Mode Test, Section VII	Yes		X		X
9	Compile data into report	No				

Measuring Equipment

All input power measurements shall be made with a suitably calibrated power analyzer. Measurements of active power of 0.5 W or greater shall be made with an uncertainty of ≤ 2 %. Measurements of active power of less than 0.5 W shall be made with an uncertainty of ≤ 0.01 W. The power measurement instrument shall have a power resolution of:

- 0.01 W or better for measurements up to 10 W,
- 0.1 W or better for measurements of 10 to 100 W,
- 1 W or better for measurements over 100 W.

Measurements of energy (Wh) shall be made with an uncertainty of ≤ 2%.
Measurements of voltage and current shall be made with an uncertainty of ≤ 1 %.

Measurements of temperature shall be made with an uncertainty of ≤ 2 °C.

Note: For suggestions on measuring low power levels, see IEC 62301, especially Section 5.3.2 and Annexes B and D.

Test Room

All tests, battery conditioning, and battery rest periods shall be carried out in a room with an air speed near the UUT of ≤ 0.5 m/s. The ambient temperature shall be maintained at 20° C ± 5° C throughout the test. There shall be no intentional cooling of the UUT by use of separately powered fans, air conditioners, or heat sinks. The UUT shall be conditioned, rested, and tested on a thermally non-conductive surface.

Note: Products intended for conditions outside of this specified range may be tested at additional temperatures, provided those are in addition to the conditions specified above and are noted in a separate section on the test report. When not undergoing active testing, batteries shall be stored at 20° C ± 5 °C.

Input Reference Source: Input Voltage and Input Frequency

If the UUT is intended for operation on ac line-voltage input, it shall be tested at two voltage and frequency combinations: 115 V at 60 Hz and 230 V at 50 Hz, if its nameplate input voltage and frequency indicate that it can operate safely under both conditions. If testing at both conditions is not possible, the UUT shall be tested at the one voltage and frequency combination above that is within its nameplate voltage and frequency ranges.

If the UUT is intended for operation on ac input at other than line voltage, it shall be tested once with the following combination of voltage and frequency:

The voltage at the midpoint of its rated input voltage range
The first of the following frequencies that is within its rated input frequency range: 60 Hz, 50 Hz, or the midpoint of its rated input frequency range.

If a charger is powered by a low-voltage dc or ac input, and the manufacturer packages the charger with an EPS, sells, or recommends an optional EPS capable of providing that low voltage input, then the charger shall be tested using that EPS and the input reference source shall be a suitable input for the EPS.

If the UUT is intended for operation only on dc input voltage (and does not include an EPS), it shall be tested with one of the following input voltages: 12.0 V dc for products intended for automotive, recreational vehicle or marine use, 5.0 V dc for products drawing power from a computer USB port, or the midpoint of the rated input voltage range for all other products.

The input voltage shall be within ± 1 % of the specified voltage.

If the input voltage is ac, the input frequency shall be within ± 1 % of the specified frequency. The THD of the input voltage shall be ≤ 2%, up to and including the 13^{th} harmonic. The crest factor of the input voltage shall be between 1.34 and 1.49.

If the input voltage is dc, the ac ripple voltage (rms) shall be:

for dc voltages up to 10 V, ≤ 0.2 V;
for dc voltages over 10 V, ≤ 2 % of the dc voltage.

II. Battery Charger System Setup Requirements

General Setup

The battery charger system shall be prepared and set up in accordance with the manufacturer’s instructions, except where those instructions conflict with the requirements of this test procedure. If no instructions are given, then factory or “default” settings shall be used, or where there are no indications of such settings, the UUT shall be tested as supplied. If the battery charger unit is powered by an external power supply, it shall be tested with the external power supply packaged with the unit.

If the battery charger has user controls to select from two or more charge rates (such as regular or fast charge) or different charge currents, the test shall be conducted with each of the possible choices. If the charger has user controls for selecting special charge cycles that are recommended only for occasional use to preserve battery health, such as equalization charge, removing memory, or battery conditioning, these modes are not required to be tested. The settings of the controls shall be listed in the report for each test.

Age of Battery Charger System

The UUT, including the battery charger and its associated battery, shall be new products of the type and condition that would be sold to a customer. It shall be tested within 3 months of the date of purchase. If the battery is lead-acid chemistry and the battery is to be stored for more than 24 hours between its initial acquisition and testing, the battery shall be charged before such storage.

Selection of Batteries to Use for Testing

The battery or batteries to be used for testing are selected by a two-step process. First, the technician shall determine all the batteries that are "associated with" the charger, as described below. Then, from the set of associated batteries, the technician shall select those to be tested, as described below.

1) Batteries "associated with" the charger shall be determined using Table B. For a batch charger, technician shall follow first the procedure for either "packaged with batteries" or "not packaged with batteries," then consider all configurations of those batteries.

Table B. Batteries Associated with a Charger

Conditions		**Associated Batteries**
Charger comes packaged with batteries		(1) All batteries included with the product, and (2) Any and all optional or high-capacity batteries sold by the same manufacturer and identified in the instructions of either the product or the battery as suitable for use with the product.
Charger is not packaged with batteries	Charger manufacturer also sells batteries	Any and all batteries sold by the same manufacturer and identified in the instructions of either the product or the battery as suitable for use with the product.
	Manufacturer does not sell batteries, but does recommend batteries in the instructions	Any and all batteries recommended in the instructions as suitable for use with the charger. If more than three manufacturers are recommended, it shall be sufficient to consider only readily available batteries by three major manufacturers.
	Manufacturer neither sells nor recommends batteries	Any and all readily-available batteries made by three major manufacturers and which the charger is capable of charging
For any batch charger (whether or not multi-port and whether or not multi-voltage)		Also include as a separate “associated battery”: every combination of two or more identical batteries (meaning same manufacturer and same model) as determined above, connected in a configuration that the charger is capable of charging.

Note:

Example 1: a AA charger can charge batches of either 2 or 4 AA batteries. It comes packaged with 4 standard AA batteries. The manufacturer also sells high-capacity AA batteries. Result: there are four associated batteries:

2 standard AA

4 standard AA

2 high-capacity AA

4 high-capacity AA

Example 2: Another manufacturer makes a charger that charges batches of 2 or 4 AA batteries, or it can charge 2 C or 2 D batteries. This manufacturer neither sells nor recommends batteries to use with it. A survey of some local retail stores show that manufacturers X, Y and Z are carried at most stores. The survey also finds that: X sells both standard and high-capacity AA batteries and C and D batteries; Y sells one type each of AA, C, and D; Z sells only one capacity of AA batteries. Result: there are twelve associated batteries:

2 standard AA batteries by X	2 AA batteries by Y
4 standard AA batteries by X	4 AA batteries by Y
2 high-capacity AA Batteries by X	2 C batteries by Y
4 high-capacity AA batteries by X	2 D batteries by Y
2 C batteries by X	2 AA batteries by Z
2 D batteries by X	4 AA batteries by Z

2) From the list of associated batteries, technician shall use Table C to select the batteries to be used for testing depending on the type of charger being tested. A charger is considered as:

Single-capacity if all associated batteries have the same rated charge capacity (see definition) and, if it is a batch charger, all batch configurations have the same rated charge capacity; or

Multi-capacity if there are associated batteries or batch configurations that have different rated charge capacities.

In many cases, multiple tests are required with different batteries. Each of these batteries shall be tested at each applicable input voltage and each applicable charge rate, as specified by Part 1, Sections I.D and II.A.

In Table C, below, each row represents a mutually exclusive charger type. Technician shall find the single applicable row for the UUT, and test according to those requirements.

Table C. Battery Selection for Testing

Type of charger			Tests to perform	
Multi-voltage?	Multi-port?	Multi-capacity?	Number of tests	Battery selection (from all configurations of all associated batteries)
No	No	No	1	Any associated battery
No	No	Yes	2	Lowest charge capacity battery

				Highest charge capacity battery
No	Yes	Yes or No	2	Use only one port and use the minimum number of batteries with the lowest rated charge capacity that the charger can charge
				Use all ports and use the maximum number of identical batteries of the highest rated charge capacity that the charger can accommodate
Yes	No	No	2	Lowest voltage battery
				Highest voltage battery
Yes	Yes to either or both		3	Of the batteries with the lowest voltage, use the one with the lowest charge capacity. Use only one port
				Of the batteries with the highest voltage, use the one with the lowest charge capacity. Use only one port.
				Use all ports and use the battery or the configuration of batteries with the highest total calculated energy capacity

Other Non-Battery-Charger Functions

Any optional functions controlled by the user and not associated with the battery charging process (i.e., a radio integrated into a cordless tool charger) shall be switched off. If it is not possible to switch such functions off, they shall be set to their lowest power-consuming mode during the test. The actions taken by the technician to reduce power use by non-battery charging functions shall be recorded in the report.

If the battery charger unit has other electrical connections associated with its other functionality (such as phone lines, serial or USB connections, Ethernet, cable TV lines, etc.) these connections shall be left disconnected during the testing.

Note: some examples of other functionality are:

Example 1: If there is a radio in the same housing as a tool battery charger, the radio shall be switched off for all the tests. The user is no longer able to listen to the radio, so the only functionality available to the user (to be recorded on the report) is the “On-Off switch for the radio.” If the radio also provides a digital clock display that remains operating when the radio is switched off, that shall be noted in the report as well.

Example 2: A cordless phone battery charger also contains the circuitry for monitoring the phone line for a call. This functionality cannot be disabled and so shall be recorded on the test procedure report as "monitoring phone line for incoming call."

Duration of the Charging and Maintenance Mode Test

The charging and maintenance mode test, Part 1, Section III.D, shall be 24 hours or longer, as determined by the items below, in order of preference:

If the battery charger has an indicator to show that the battery is fully charged, that indicator shall be used as follows: If the indicator shows that the battery is charged after 19 hours of charging, the test shall be terminated at 24 hours. Conversely, if the full-charge indication is not yet present after 19 hours of charging, the test shall continue until 5 hours after the indication is present.

If there is no indicator, but the manufacturer's instructions indicate that charging this battery or this capacity of battery should be complete within 19 hours, the test shall be for 24 hours. If the instructions indicate that charging may take longer than 19 hours, the test shall be run for the longest estimated charge time plus 5 hours.

If there is no indicator and no time estimate in the instructions, but the charging current is stated on the charger or in the instructions, calculate the test duration as the longer of 24 hours or:

$$\text{Duration} = 1.4 * \frac{\text{RatedChargeCapacity(Ah)}}{\text{ChargeCurrent(A)}} + 5\ \text{Hours}$$

If none of the above applies, the duration of the test shall be 24 hours.

Access to the Battery for Discharge Test

The technician may need to disassemble the end-use product to gain access to the battery terminals for the Battery Discharge Energy Test. Manufacturer's instructions for disassembly shall be followed, except those instructions that: a) lead to any alteration of the battery charger circuitry or function or b) that contradict requirements of this test procedure. Care should be taken by the technician during disassembly to follow appropriate safety precautions. If the functionality of the device or of its safety features is damaged, the product shall be discarded after testing.

Some products may include protective circuitry between the battery cells and the remainder of the device. In some cases, it is possible that the battery cannot be discharged without activating protective control circuitry. If the manufacturer provides a description for accessing connections at the output of the protective circuitry, the energy measurements shall be made at the terminals of the batteries, so as to not include energy used by the protective control circuitry.

If the battery terminals are not clearly labeled, technician shall use a voltmeter to identify the positive and negative terminals. If there are more than two terminals, the additional ones are usually a temperature sensor and/or data lines. Technician shall search for the two terminals that give largest voltage difference and are able to deliver significant current (0.2C) into a load.

If the technician, despite diligent effort and use of the manufacturer's instructions:

a) is unable to access the battery terminals;
b) determines that access to the battery terminals destroys charger functionality; or
c) is unable to draw current from the battery

then the Battery Discharge Energy and the Charging and Maintenance Mode Efficiency shall be reported as "zero." The notes on the report shall describe the problems encountered.

Batteries with No Rated Charge Capacity.
If there is no rating for the battery charge capacity on the battery or in the instructions, then the technician shall determine a discharge current which meets the following requirements. The battery shall be fully charged and then discharged at this constant-current rate until it reaches the end-of-discharge voltage specified in Table D. The discharge time must be not less than 4 hours nor more than 5 hours. In addition, the discharge test (Part 1, Section III.F) (which may not be starting with a fully-charged battery) shall reach the end-of-discharge voltage within 5 hours. The same discharge current shall be used for both the preparations step (Part 1, Section III.B) and the discharge test (Part 1, Section III.F). The test report shall include the discharge current used and the resulting discharge times for both a fully-charged battery and for the discharge test.

For this section, the battery is considered as "fully charged" when either (a) it has been charged by the UUT until an indicator on the UUT shows that the charge is complete, or (b) it has been charged by a battery analyzer at a current not greater than the discharge current until the battery analyzer indicates that the battery is fully charged.

Note: When there is no capacity rating, a suitable discharge current must generally be determined by trial and error. Since the conditioning step does not require constant-current discharges, the trials may also be counted as battery conditioning. Further, the preparation step may be used as the proof that a discharge current is suitable, provided that the battery is "fully charged."

III. Measuring the Battery Charger System Efficiency

Condition the Battery

No conditioning is to be done on lead-acid or lithium-based batteries.

NiCd or NiMH batteries that have not been previously cycled are to be conditioned as follows: The batteries are to be fully charged and then fully discharged (100% DOD). This cycle is repeated once, then the battery is fully charged again. This amounts to three charges separated by two discharges. Either a battery analyzer or the UUT may be used to perform the battery conditioning.

NiCd or NiMH batteries that are known to have been through at least two previous full charge/discharge cycles shall be charged only once.

Note: The full discharge, which is the battery preparation step, should erase any memory effect in NiCd or NiMH batteries. Any conditioning necessary for lead-acid or lithium batteries is generally done by the manufacturer before the product is packaged.

Prepare the Battery for Testing

Prior to testing, the battery shall be discharged. This discharge shall be done using a battery analyzer that draws a constant discharge current of 0.2C. When the battery voltage reaches the end-of-discharge voltage for that battery chemistry or the UUT circuitry terminates the discharge, the discharge shall be terminated by opening the battery circuit.

If the battery has been previously used for testing (for example, testing the charger in another mode) and the battery has just completed the Battery Discharge Energy Test (section VI.F below), that battery may be considered as having just completed this preparation step.

If the discharge time required to reach the end-of-discharge condition is less than 30 minutes, these additional steps shall be taken: The battery shall be recharged to 30% or more of its rated charge capacity (see definition). Then the battery preparation shall be conducted again. If the discharge time is again less than 30 minutes, the battery shall be considered defective. Technician shall repeat the test procedure with another suitable battery.

Battery Rest Period

The battery or batteries shall be rested between preparation and charging. The rest period shall be at least one hour and not more than 24 hours. For batteries with flooded cells, the electrolyte temperature shall be < 30 °C before charging, even if the rest period must be extended longer than 24 hours.

Charge Mode and Battery Maintenance Mode Test

The Charge and Battery Maintenance Mode test measures the energy consumed during charge mode and some time spent in the maintenance mode of the UUT. Functions required for battery conditioning that happen only with some user-selected switch or other control shall **not** be included this measurement. (The technician shall manually turn off any battery conditioning cycle or setting.) Regularly occurring battery conditioning/maintenance functions that are not controlled by the user will, by default, be incorporated into this measurement.

During the measurement period, power values shall be recorded at least every minute. If possible, technician shall set the data logging to record the average power during the sample interval. This allows the total energy to be computed as the sum of power samples (in watts) times the sample interval (in hours). If this setting is not possible, then the power analyzer shall be set to integrate or accumulate the input power over the measurement period and this result shall be used as the total energy.

Technician shall follow these steps:

- Ensure that the battery(ies) used in this test have been conditioned, prepared, and rested as described above.
- Connect the metering equipment to the battery charger.
- Ensure that user-controllable device functionality not associated with battery charging and any battery conditioning cycle or setting are turned off.
- Record the start time of the measurement period, and begin logging the input power.
- Connect battery(ies) to the battery charger within 3 minutes of beginning logging.
- After the battery(ies) are in inserted, record the initial time, power (W), power factor, and crest factor of the input current. These measurements should be taken within the first 10 minutes of active charging.
- Record the input power for the duration of the “Charging and Maintenance Mode Test” period, as determined by Part 1, Section II.E. The actual time that power is connected to the battery charger system shall be within ±5 minutes of the specified “Charging and Maintenance Mode Test” period, as determined by Part 1, Section II.E.
- During the last 10 minutes of the test, record the power factor and crest factor of the input current.
- Disconnect power for the battery charger and terminate data logging. Record the final time.

After the measurement period is complete, technician shall determine the average maintenance mode power consumption as follows: Examine the power-versus time data. If the last 4 hours show the power consumption to be steady or slowly varying, use the average power value over the last 4 hours. If the maintenance mode power is cyclic or shows periodic pulses, compute the average power over a time period that spans an integer number of cycles and includes at least the last 4 hours.

Battery Rest Period

The battery or batteries shall be rested between charging and discharging. The rest period shall be at least one hour and not more than 4 hours. For batteries with flooded cells, the electrolyte temperature shall be < 30 °C before charging, even if the rest period must be extended longer than 4 hours.

Battery Discharge Energy Test

The purpose of this test is to measure the extractable energy from the battery associated with the battery charger system. The battery used in this test shall be the same battery used for previous tests in this section.

If multiple batteries were charged simultaneously, the discharge energy is the sum of the discharge energies of all the batteries:

For a multi-port charger: batteries that were charged in the separate ports shall be discharged independently.

For a batch charger: batteries that were charged as a batch may be discharged individually, as a batch, or in sub-batches connected in series and/or parallel. The position of each battery in the batch configuration need not be maintained.

During discharge, the battery voltage and discharge current shall be sampled and recorded at least once per minute. The values recorded may be average or instantaneous values.

For this test, technician shall follow these steps:

Ensure that the battery has been charged by the UUT and rested according to the procedures above.

Set the battery analyzer for a constant discharge current of 0.2C and the end-of-discharge voltage in Table D for the relevant battery chemistry.

Connect the battery to the analyzer and begin recording the voltage and current.

When the end-of-discharge voltage is reached or the UUT circuitry terminates the discharge, the battery shall be returned to an open-circuit condition. If for any reason, current continues to be drawn from the battery after the end-of-discharge condition is first reached, this additional energy is not to be counted in the battery discharge energy.

The battery discharge energy (Wh) is calculated by multiplying the voltage (V), current (A) and sample period (h) for each sample, and then summing over all sample periods until the end-of-discharge voltage is reached.

Table D: Required Battery Discharge Rates and End-of-Discharge Battery Voltage

Battery Chemistry	**Discharge Rate**	**End-of-Discharge Voltage**
Valve-Regulated Lead Acid (VRLA)	0.2 C	1.75 volts per cell
Flooded Lead Acid	0.2 C	1.70 volts per cell
Nickel Cadmium (NiCd)	0.2 C	1.0 volts per cell
Nickel Metal Hydride (NiMH)	0.2 C	1.0 volts per cell
Lithium Ion (Li-Ion)	0.2 C	2.5 volts per cell
Lithium Polymer	0.2 C	2.5 volts per cell
Rechargeable Alkaline	0.2 C	0.9 volts per cell
Other Chemistries	0.2 C	Per appropriate IEC standard

IV. No-Battery Mode and Off Mode Tests

These tests measure the power consumed by the charger when it is not charging a battery. The tests shall be conducted after the Charging and Battery Maintenance Mode Test (Part 1, Section III.D), while the battery is resting or being discharged.

If Part 1, Section II.C requires testing with more than one battery, the No-Battery Mode and Off Mode tests do not need to be repeated with each battery. If the charger has multiple charging modes, as described in Part 1, Section II.A, the No-Battery Mode Test shall be performed for each mode and at each input voltage (see Part 1, Section I.D). The Off Mode Test needs to be performed only once at each input voltage (see Part 1, Section I.D).

Setup

Technician shall determine which of these three categories best describes the product:

1) The charger, the battery, and the product being powered are never disconnected during normal use of the product. There is only a power cord between the power source and the single housing that contains all of these components.

   Examples: Most emergency egress lights, UPSs and standby power supplies, many electric shavers and electric vehicles.

   Note: In these products, it may be possible for the consumer to disconnect the battery for battery replacement, but the battery is not disconnected during normal use.

2) The charger and the product being powered are not connected. The batteries are moved between them for charge and product end use.

   Examples: Many cordless power tools and most AA and universal battery chargers.

3) The battery and the product being powered stay connected during normal use. The product can be readily connected to or removed from a charger or a charging base. This category applies even if the charge control circuitry is in the device with the battery and the external “charger” is really a constant-voltage power supply, such as most laptop computers.

Examples: most cordless phones, cell phones, laptop computers, and electric toothbrushes, many cordless vacuums and most automotive and golf cart chargers.

Category 1 Products

The no-battery test does not apply to products in Category 1. The no-battery mode power shall be reported as “not applicable” (N/A). The off mode test may or may not apply depending on the following:

- If the product does not have an “on/off” switch that turns the charger off, the off mode does not apply. The off-mode power shall be reported as “not applicable”. The off mode power and a separate test shall not be conducted.

  Note: the battery should be resting open circuit at this stage in preparation for the battery discharge energy test of Section VI.F.

Category 2 Products

Both the no-battery mode and off mode tests shall be conducted for products in category 2. After completion of the Battery Charging and Maintenance Mode Test, the batteries shall be removed from the charger and the charger shall be connected to input power. Do not change any settings or controls on the charger for the no-battery mode test.

Category 3 Products

Both the no-battery mode and off mode tests shall be conducted on products in category 3. After completion of the Battery Charging and Maintenance Mode Test, set up the product for the no-battery mode test as follows:

- If the product has a charging base: the portable device shall be removed from the charging base and the charging base shall be connected to input power. If the charging base uses an EPS, the EPS shall be connected to input power and to the charging base.
- If the product does not have a charging base but does have an external charger or an EPS: the product shall be disconnected from the charger or the EPS. The charger or EPS shall be connected to input power.

Technician shall not change any settings or controls on the charger or charging base for the no-battery mode test.

No-Battery Mode Test

After connecting and powering the UUT in its no-battery mode setup, allow it to operate for at least 30 minutes.

Integrate the energy consumed over a time period of at least 10 minutes,

Record the power factor and the crest factor of the input current at some time during or after the 10-minute period.

Divide the energy (Wh) by the integration time (in hours) to get the No-battery Mode Power (W).

Off Mode Test

If there is not an "on/off" control which turns the battery charger off, the Off Mode Test is not applicable. In this case, report the Off Mode power, power factor, and crest factor as "not applicable" (N/A). If there is an "on/off" control for the charger, perform the following steps:

1) After completion of the No-Battery Test, if applicable, set the "on/off" control in the "off" setting.
2) Allow the charger to operate for at least 30 minutes.
3) Integrate the energy consumed over a time period of at least 10 minutes,
4) Record the power factor and the crest factor of the input current at some time during or after the 10-minute period.
5) Divide the energy (Wh) by the integration time (in hours) to get the Off Mode Power (W).

V. Reporting Requirements

The following information shall be recorded about each UUT and each test performed. Quantitative values shall be reported to the precision of the measurement, not rounded by technician.

General

1) Name of technician performing the test
2) Organization performing the test
3) Location of the test (physical address)
4) Time and date of each test
5) Make and model of measurement equipment
6) Input power voltage (V)
7) Input frequency (hertz), if ac
8) Manufacturer and model number of battery charger
9) Other functionality of battery charger, if any (see section V.D for more details)
10) Manufacturer and model number of battery
11) Standard size or type of battery (AA, C, D, etc.) if applicable
12) Number of batteries employed in the test
13) Battery chemistry

14) Rated battery voltage (V)
15) Rated battery capacity (Ah or mAh)
16) Any information provided by the manufacturer regarding access to the battery, particular safety requirements, etc.
17) Whether the battery charger system is detachable, integral, swappable, or does not meet any of these definitions.
18) Whether the battery charger system includes a cradle.

Charge and Maintenance Mode Test

1) Total charger input energy (Charge and Maintenance Energy) accumulated over the entire duration of the test (Wh)
2) The total time duration of the charging test (at least 24 hours)
3) Average power during maintenance mode (W)
4) The time duration used for the maintenance mode power (at least 4 hours)
5) True power factor at beginning and end of the charge test
6) The crest factor of the input current at the beginning and end of the charge test
7) The length of the rest period before charging (hr:min) and, if applicable, the electrolyte temperature at the beginning of charging (°C).
8) Sample rate used during test(s)
9) The steps taken, if any, to turn off or reduce the power consumption of other functionality and a description of the other functionality that could not be turned off, if any.

Battery Discharge Test

1) Energy delivered during discharge (Wh)
2) Starting battery voltage (V)
3) Ending battery voltage (V)
4) The length of the rest period before discharge (hr:min) and, if applicable, the electrolyte temperature at the beginning of discharge (°C)
5) Sample rate used during test(s)
6) A brief description of the steps taken, if any, to gain access to the battery terminals.

No-Battery Mode and Off Mode Tests

1) Category of product
2) Average no-battery mode power (W)
3) No-battery mode power factor and input current crest factor
4) Average off mode power (W)
5) Off mode power factor and input current crest factor

Additional Information

1) Any observations, notes or comments by the lab technician, in general or as required for certain special cases and exceptions.

PART 2:

I. Standard Test Conditions:

A. Measuring Equipment

The following test equipment is required.

1) Power meter (AC and DC) with kWh integration and with a sampling rate of at least 128 samples per 60 Hz cycle.
2) Power analyzer integrated with data logger (for continuous recording of Total Harmonic Distortion & Power Factor).
3) An Ah counter or meter on the battery side.
4) A device to discharge a battery at a specified rate and duty cycle down to a specific depth of discharge. This can be a battery cycler or load bank.
5) Personal computer.
6) Thermometers – for ambient and battery conditions.
7) Barometer – for environmental pressure.
8) Hygrometer – for environmental humidity.
9) Temperature compensated specific gravity meter – used to verify condition and state of charge of a flooded, lead-acid battery.
10) Volt meter.
11) Timer.

Note: the state of health of the battery must be ascertained. The battery must be in a state of condition to provide a minimum of 80% of nameplate capacity at the nominal rate in order to be used in this test procedure, and must maintain that level of health throughout the procedure. To determine state of health, have the battery certified by a qualified agency, or perform the state of health verification per BCIS-14 (see References). A test battery used for a series of tests by a lab over an extended period shall be tracked for state of health and tested appropriately to ensure that it is above 80% of nameplate capacity.

B. Equipment Tracking and Accuracy

All equipment used to conduct the tests must be identified and recorded by tracking or serial number. It is required that equipment be calibrated. The calibration should meet the National Institute of Standards and Technology's (NIST) calibration policy and meet the intent of ANSI/NCSL Z540-1-1994. The NIST's calibration policy requires the reporting of calibration results, with measurement results accompanied by the associated measurement uncertainties.

Each (voltage, current, temperature, etc.) measurement shall be made with an uncertainty of ≤ 1%.

Total uncertainty with calculated data (energy, power, etc.) shall be ≤ 2%.

Equipment data of all devices used in the test will be recorded, along with test equipment ID and calibration date. The information that shall be recorded includes:

1) ID number
2) Calibration date
3) Calibration expiration date
4) Type of instrument (power meter, battery discharger, etc.)
5) Comments on sample rate

C. Input Reference Source: Input Voltage and Input Frequency

In order to help separate the local infrastructure effects on the readings, follow these guidelines to ensure accurate power quality assessment:

1) Test voltage harmonic distortion: Must be less than 2% total under normal operating conditions, from no load to full load. Measure AC source THD after AC input power meter and before UUT.
2) Voltage (RMS) Tolerance: ± 3%
3) Frequency: 50 or 60 Hz ± 1%

II. Battery Charger System Setup Requirements

A. Outline of Test Procedure

1) Assure compatibility and effectiveness of charger/battery combination (II.B)
2) Receive certified battery to be used for the procedure (I.A)
3) Record nameplate and equipment data (I.B)
4) Set-up test (I.A,B,C)
5) Prepare battery with preliminary cycles (II.C,D)
6) Discharge battery – 3 scenarios (II.D, III.A.1)
7) Charge battery – 3 scenarios (II.E, III.A.2)
8) Monitor Battery Charge Maintenance – 72 hours (III.B)
9) Monitor "No-Battery" state – 1 hour (III.C)
10) Compile data and analyze (IV)
11) Report (IV)

B. Charger/Battery Selection and Qualification

A battery and charger combination to use for the test must be selected and qualified. The battery shall be matched to the charger capabilities.

If the charger is capable of charging a range of battery sizes, test both the highest and lowest capacity values, as well as the highest and lowest voltage levels for the battery, if applicable. If the charger has multiple charging profile options, each charging profile shall be tested. This means if the charger is capable of charging multiple battery capacities for each charge profile, each profile shall be tested with both the highest and lowest battery capacities, as well as the highest and lowest voltage levels for the battery if applicable.

Determine that the charger/battery system performs in a way that charges the battery properly and maintains the health of the battery by reading the specifications and operational parameters and verifying with the manufacturers of both the battery and the charger that they are compatible and effective as described in BCIS-16 (see References Section).

Report the specifications and operational parameters, of both the battery and the charger, regarding periodic equalization, as published by the manufacturers.

For the charger, the information that shall be recorded includes:

1) Manufacturer
2) Model name
3) Model number
4) Serial number
5) Electronics type (silicon controlled rectifier, ferroresonant, etc.)
6) Rated input voltage and current
7) Rated battery size(s)
8) Rated output voltage and current
9) Charge method (fast, pulse, intelligent, inductive, trickle)
10) Number of ports

Pertinent charger observations, or accompanying instructional manual descriptions shall also be recorded on the test forms.

For batteries, the information that shall be recorded includes:

1) Manufacturer
2) Model name
3) Serial or ID Number
4) Chemistry
5) Construction (flooded lead acid, value regulated lead acid, gel, etc.)
6) Number of cells
7) Rated Voltage
8) Rated Ah
9) Discharge rate for above
10) Manufacturer approved for charger under test?
11) BCI-14 Capacity

Verify from the information provided by the BCS manufacturer, that the charger, or charger/battery system, performs regular equalization in a way that maintains the health of the battery, i.e. verify that the battery used in the test is appropriate for the BCS being tested according to the manufacturer. Have the battery certified, or perform the state of health verification per BCIS-14 (see References).

C. Battery Conditioning

After receiving a qualified battery (see the note in Part 2, Section I.B, above) conduct some preparatory cycles on the battery and charger if it has not been used in testing within 24 hours. This is for battery conditioning in the test environment, as the performance can change for various reasons. The battery shall be depleted to roughly 80% depth of discharge, and then recharged with the charger under test. Do this two times. If available per manufacturers instructions, one of those times shall include the equalization cycle. Rest time shall be included to avoid overheating the battery (according to battery specifications). The final full charge must be completed within 24 hours of beginning the discharge test procedure. Record environmental parameters at the beginning and end of each charge and discharge. The following information shall be recorded for each conditioning cycle:

1) Start Date and time for each cycle
2) End Date and time for each cycle

D. Battery Preparation

The discharge test must be begun no sooner than 3 hours, and no more than 24 hours after the last full charge.

Verify full charge of the battery using one of two methods:

1) Flooded batteries – At least one hour after the full charge is completed, and before beginning the discharge test, take temperature-compensated specific gravity measurements of the electrolyte in each cell, and ensure that the specific gravity corresponds to full charge according to the battery manufacturer's specifications.
2) Valve regulated batteries (VRLA) – At least one hour after the full charge is completed, take voltage measurements and ensure that the voltage corresponds to full charge according to the battery manufacturer's specifications.

Measure the temperature of the electrolyte (preferred, for flooded batteries, or negative terminal post for VRLA batteries). The battery temperature at the start of discharge must be between $17^{o}C$ and $33^{o}C$. Configure the battery (or pack) with the appropriate data acquisition equipment to record voltage and current at 1 minute intervals.

E. Charger Preparation

The charger shall be in proper working condition, and connected and adjusted properly for the battery and the utility, as verified in the battery preparation process. Configure the data acquisition equipment on both the input and the output side of the charger to measure AC and DC power and power quality. Set up to record the DC power for the entire charge to view the charge profile.

It is important to locate the PQ monitoring device as close as possible to the tested charger, but avoid being too close to service entrance equipment such as step-down transformers or UPS equipment. The monitoring device must see the same electrical variations the charger does. Harmonic content, in particular can be significantly different if there is a large separation between the monitor and the charger. The monitoring equipment shall be placed after any circuit protection device, and as close as possible to the charger.

III. Test Procedure: Part 2

A. Battery Discharge/Recharge Sequence

The discharge/recharge sequence is completed at three different levels of battery discharge: fully discharged (100% DOD), 40% depth of discharge (DOD), and 80% DOD. After the proper amount of rest and within temperature limits, according to Part 2, Section II.D, proceed with the battery discharge. After each discharge (as in Part 2, Section III.A.1), recharge the battery (as in Part 2, Section III.A.2.).

<u>Battery Discharge</u>

Using a battery cycler or load bank, discharge the battery pack at a constant nominal current rate ± 3%. The discharge rate shall be:

> **C_6/6** for batteries used in industrial equipment like lift trucks, airport ground support equipment, port cargo handling equipment, tow tractors, sweepers, scrubbers, and material handling equipment;
>
> **C_5/5** for batteries used in personnel carriers like golf carts and neighborhood electric vehicles.

The battery shall be discharged at a rate specified above, unless this rate conflicts with manufacturer's recommendations. In that case, the technician may choose either C_6/6 or C_5/5 and this shall be noted on the test sheet. No other discharge rate may be used.

Discharge the battery to 100% DOD (measured with an accuracy of 1%), or until reaching the cutoff voltage (as specified in Part 1, Section III.F. "Table D" of this Test Procedure). Measure and record the following data:

1) Discharge Test Date
2) Start Time
3) Maximum and Minimum Ambient Temperature
4) Start Pressure
5) Start Humidity
6) Starting Voltage
7) Starting Battery Temp Avg (Near Center of Cell)
8) Total Ah Delivered
9) Total Energy Delivered (Wh)
10) End Time
11) End Pressure
12) End Humidity
13) End Voltage
14) End Battery Temp Avg (Near Center of Cell)
15) Actual Depth of Discharge (Not Nominal)

After recharging according to Part 2, Section III.A.2., repeat this Battery Discharge Test sequence by discharging the battery to each of the following levels and then recharging:

- 40% DOD of measured charge capacity (within ± 10%) as determined by voltage meter, Ah counter, specific gravity measurements, or discharge meter reading of Ah capacity.
- 80% DOD of measured charge capacity (within ± 10%) as determined by voltage meter, Ah counter, specific gravity measurements, or discharge meter reading of Ah capacity.

Each of the measurements made above with respect to the state of discharge are required to be recorded for each battery discharge cycle.

Battery Recharge

During the recharge test, the ambient environment shall be maintained between 18^{o}C and 27^{o}C. The battery recharge must start within 1 to 6 hours of the completion of the discharge, depending on the temperature of the battery. If the charger is capable of charging a range of battery sizes, test both the highest and lowest capacity values, as well as the highest and lowest voltage levels for the battery, if applicable. If the charger has multiple charging profile options, each charging profile shall be tested. This means if the charger is capable of charging multiple battery capacities for each charge profile, each profile shall be tested with both the highest and lowest battery capacities, as well as the highest and lowest voltage levels for the battery if applicable.

Start the charge and measure and record the following data:

1) Date
2) Start Time
3) Maximum and Minimum Ambient Temperature
4) Start Pressure
5) Start Humidity
6) Starting Battery Voltage
7) Starting Battery Temp Avg (Near Center of Cell)
8) Input Voltage
9) Input Frequency
10) Instantaneous input and output current (as described below)*
11) Instantaneous input and output voltage (as described below)*
12) Power Factor*
13) Current THD*
14) Voltage THD*
15) Power Conversion Efficiency[†]
16) Total Ah Delivered
17) Total Energy Delivered (Wh, AC)
18) Total Energy Delivered (Wh, DC)
19) End Time
20) End Pressure
21) End Humidity
22) End Battery Voltage
23) End Battery Temp Avg (Near Center of Cell)
24) Average End Specific Gravity
25) Average Temp of All Cells at Specific Measurement
26) Specific Gravity Measurement Date
27) Charge Return Factor [‡]

*Power quality measurements reported for the first full recharge from 100% DOD only.
† Power conversion efficiency reported for the three performance reporting points below and reported for first full recharge from 100% DOD only.
‡ The charge return factor is obtained by dividing the number of Ah returned to the battery pack during the charge cycle (but not an equalization charge) by the number of Ah delivered by the battery pack during discharge.

The discharge/recharge sequence is completed at three different levels of battery discharge, as described in this Section III.A.1 of Part 2. Data 1-24 shall be recorded for the 100% DOD recharge cycle. Data 1-11 and 16-24 shall be recorded for the 80% DOD and 40% DOD recharge cycles. When the charging current reaches 2% of the charging current capacity the charge is complete.

Power Quality Measurements

For the power quality data, set up the power meters and power analyzer sampling at 128 samples per 60 Hz cycle, and recording, at 1-minute intervals. Report the required data using rms values of the sampled data.

After charge completion, select three performance reporting points as follows:

1) High-power: select the highest AC power data point, excluding the first three minutes after the start of the charge; this avoids initial transients.
2) Low-power: select the lowest AC power data point recorded during the last two hours of charge.
3) Mid-power: select the median power between the low and high power data points.

For each performance reporting point, look at two adjacent data points:
1) one point preceding that point by one minute
2) one point following that point by one minute.

Both adjacent points must be within 4% in absolute value of the central point. If the selected point meets this requirement, report the required performance data point.

If the adjacent points are not within 4% of the central point, reexamine the data to find the next point that most closely matches the specification for that data performance point: high, low, or mid-power. When a new performance point is found, repeat the 4% deviation procedure for the adjacent points. This should be repeated until a suitable point is found.

This process shall serve to ensure power stability prior to reporting a performance point. The 4% tolerance provides a method to distinguish between pulse phenomena and a point representative of the charger's operation.

Electrolyte Temperature Measurements
The average electrolyte temperature, or average terminal post temperature (in the case of sealed batteries), must remain in the range of $18^{o}C$ to $46^{o}C$ during charging for a valid test. Temperature is to be recorded at the start of charge and again within 10 minutes of the termination of charge.

The average temperature is assumed to change linearly during the charge, so that the limits are defined by the starting and ending values. If the range is exceeded, the test results are invalid, and the test must be repeated. Start the next test with a starting battery temperature at the lower end of the acceptable range. If the results again exceed the temperature window, consult with the battery and charger manufacturers to determine if there are any malfunctions, or problems with the health of the battery. If there is no problem identified, then record the results on the data sheet and mark the block indicating a test anomaly.

Equalization Phase Disabled

The equalization phase of the charger shall be disabled, if possible. If it is not possible to manually disable equalization, the technician shall plot the battery charging profile, with dc charging voltage and current vs. time to ensure the charger is not performing equalization. This plot is not a required reporting element. If the technician determines that the equalization phase is carried out by the charger, then the data are invalid and the test shall be repeated.

B. Battery Maintenance Charge Test

After completing the battery charger test, leave the battery connected and leave test equipment recording data for a 72-hour period and record data at 1-minute intervals. Determine the power and amount of AC kWh drawn by the battery charger and the amount of DC kWh delivered by the battery charger to the battery pack, and the frequency and duration of any intermittent activity over the period. Note energy consumption by any auxiliary systems, such as a thermal management system maintaining the temperature of the battery. Measure and record the following data:

1) Start Date
2) Start Time
3) Maximum and Minimum Ambient Temperature
4) Start Battery Temperature
5) Record input and output voltage and current at one minute intervals
6) Average AC Power (kW)
7) Output Power Cycle Frequency
8) Total AC energy over period (kWh)
9) Total DC energy over period (kWh)
10) End Date
11) End Time
12) End Battery Temperature
13) Maintenance Charging Behavior Parameters: magnitudes and frequency of maintenance events*
14) Comments

* Determine and report the character of maintenance mode by evaluating the ac and dc charge behavior with respect to the amplitude and frequency of maintenance charging periods. The maintenance charging behavior shall be characterized by length, magnitudes, and frequency of maintenance events. For example: 1 hour charge at 5 kW every 4 hours.

C. Charger No-Battery Test

With the battery disconnected from the charger, and the charger connected to AC power, measure the demand of the charger on the AC side for a period of up to one hour, depending on the nature of the demand (or some time long enough to characterize demand if intermittent). Measure and record the following data:

1) Date
2) Start Time
3) Maximum and Minimum Ambient Temperature
4) Start Battery Temperature
5) Record input voltage and current at one minute intervals
6) Average AC Power (kW)
7) Total AC energy over period (kWh)
8) End Time
9) End Battery Temperature
10) Comments

IV. Reporting Requirements

Reporting requirements are embedded in test instructions above. For a comprehensive list, see the Excel Test Data Template for part 2.