Draft Energy Efficiency Battery Charger System Test Procedure

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As part of the Energy Commission PIER research process, the authors are seeking comment and suggestion on this test procedure from industry members and other stakeholders. In order to ensure your comments are considered, please send them to Ms. Suzanne Foster Porter at sfoster@ecosconsulting.com no later than December 20, 2005. Comments received by this date will be compiled and posted anonymously at www.efficientproducts.org in early January 2006, and the final draft of this test procedure, which will consider those comments, will be completed in late January 2006. Please visit the battery charger section of www.efficientproducts.org for ongoing updates to this process.

I. Scope

The purpose of the test procedure is to measure the energy efficiency of chargers coupled with their batteries, which we refer to collectively as ***battery charger systems***. Battery charger systems include those electronic devices with a battery that are normally charged from line voltage ac through an internal or external power supply and a dedicated battery charger. This includes 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) as well as dedicated battery systems primarily designed for electrical or emergency backup (such as emergency egress lighting and small-scale uninterruptible power supply (UPS) systems).

The charging circuitry may or may not be located within the housing of the functional 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 and runs on power from the battery. Examples of battery charger systems included in this scope are: cellular and cordless telephones, cordless power tools, laptop computers, cordless shavers, battery powered forklifts, emergency egress lighting, golf carts, portable lawn tools, and rechargeable toys.

This scope also includes those devices whose primary function is to charge batteries. These units include replacement chargers for power tools and chargers for AA, AAA, C, D, and 9 V rechargeable batteries.

This scope is meant to cover those battery charger systems that are used in the residential sector (private households) and commercial sector (generally defined as businesses; federal, state, and local governments; and other private and public organizations, such as religious, social, or fraternal groups; institutional living quarters; and sewage treatment facilities).[1] Some battery charger systems may be used in both industrial and commercial arenas (e.g. battery powered fork lifts), and therefore some battery charger systems that are also found in the industrial arena may be included under this scope.

This test procedure is not intended to cover laboratory testing equipment used to test and analyze batteries. This test procedure applies only to whole battery charger systems, not components of that system. In other words, this test procedure does not specify how to test a charger in the absence of a battery, nor a battery in the absence of a charger. Furthermore, this document does not specify safety requirements, nor does it specify limits on energy consumption or efficiency, though policy-making bodies may choose to reference this test procedure in proposing such limits.

II. References

The following list includes documents used and/or referenced in the development of this test method:

1) International Electrotechnical Commission, *Household Electrical Appliances - Measurement of Standby Power,* IEC 62301, 2005.
2) International Electrotechnical Commission, *International Electrotechnical Vocabulary- Electrical and Electronic Measurements and Measuring Instruments*, IEC 60050.
3) International Electrotechnical Commission, *Primary batteries – Part 1:General*, IEC 60086-1.
4) 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.
5) 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.
6) International Electrotechnical Commission, *Secondary cells and batteries containing alkaline or other non-acid electrolytes –Secondary lithium cells and batteries for portable applications*, IEC 61960.
7) 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.
8) Institute of Electrical and Electronics Engineers, *The Authoritative Dictionary of IEEE Standards Terms*, IEEE 100.
9) Buchmann, Isidor, *Batteries in a Portable World: a Handbook on Rechargeable Batteries for Non-Engineers*, Cadex Electronics Inc., 2001.

III. Definitions

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[1] For a more complete definition of energy sectors, as defined by DOE, please see http://www.eia.doe.gov/neic/datadefinitions/sectors25B1.htm

A. Active Power (P)

The rms value, taken over one period, of the instantaneous power. Most measuring instruments average active power over a number of periods (ac cycles); readings from such instruments are equally valid for this measurement.

B. Ambient Temperature

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

C. Apparent Power (S)

The total or *apparent power* (S) is the product of rms voltage and rms current (VA).

D. Battery Maintenance Mode

Refers to a condition in which the battery charger system is connected to line voltage ac, and the battery charger may be delivering current to the battery in order to counteract self discharge of the battery. The battery is, in this state, at or near 100% capacity.

E. Battery Chemistry

The chemistry of the battery, usually Nickel Cadmium, Nickel Metal-Hydride, Lithium Ion, or Sealed Lead Acid. The chemistry of the battery is typically printed on the label of the battery itself or can be found in product literature.

F. Charge Mode

Refers to a condition in which the battery charger system is connected to line voltage ac, 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.

G. C-Rate

C-rate (in amperes) refers to the rate of charge or discharge. A discharge rate of one C draws a current equal to the rated capacity of the battery (in ampere-hours or milliampere-hours) over one hour.

H. External Power Supply

External power supplies are designed to convert line voltage ac into low voltage output (either ac or dc) and are contained in a separate housing from the product they are powering. For further clarification, see *Test Method for Calculating the Energy Efficiency of Single-Voltage External Ac-Dc and Ac-Ac Power Supplies,* August 11, 2004 at www.efficientpowersupplies.org.

I. End-of-Discharge Voltage

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

J. Instantaneous Power

The product of the instantaneous voltage and instantaneous current at a port (the terminal pair of a load).

K. No-Battery Mode

The battery charger system is connected to ac line voltage, but there are no batteries connected to the dc output. It is the lowest possible power mode that cannot be switched off (influenced) by the user and may persist for an indefinite time when the battery charger is connected to ac line voltage and used in accordance with the manufacturer's instructions.

L. Measured Battery Capacity

The capacity or amount of storable charge in a battery measured with the test procedure detailed in section VII of this document. It is equal to the product of the measured current during constant current discharge (in ampere-hours or milliampere-hours) and the battery voltage during discharge. Measured battery capacity is in units of energy (watt-hours (Wh)), and should be distinguished from rated battery capacity, defined in this document below.

M. Power Factor (True)

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

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

This definition of power factor includes the effect of both distortion and displacement.

N. Rated Battery Capacity

This 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. In general, it is the quantity of electric charge the manufacturer declares the battery can store under particular pre-specified test conditions.

O. Rated Battery Voltage

The voltage of the battery, specified by the manufacturer and typically printed on the label of the battery itself. If not printed on the battery, it can be derived if the electrical configuration and chemistry of the battery is known.

P. Rated 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.

Q. Rated Voltage

Range of ac input voltage designed to operate the UUT; assigned by the manufacturer and usually printed on the housing of the charging device.

R. UUT

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

Authors' comment on operational modes: *The operational modes considered by this test procedure are meant to be comprehensive, reflecting all of the ways in which a battery charger system may be used. The authors recognize that some battery charger systems are charged and discharged infrequently and spend the majority of their lifecycle in battery maintenance mode. The purpose of this procedure is to measure all ways in which a battery charger system may be used to provide manufacturers and policymakers with comprehensive data. Particular policymakers may not reference all battery charger tests outlined in this document, especially for devices that rarely enter certain modes of operation, but at this early stage, this approach does not include exceptions for certain battery charger systems.*

IV. Standard Test Conditions

A. General

The test sequence detailed below is designed so that the test of one UUT easily can be completed in a twenty-four hour period. Although not required, the test sequence in Table A is suggested for efficient use of technician and lab equipment time:

Table A: Suggested Test Sequence

Step	Description	Data Taken?	Approx. Technician Time	Equipment Needed	Approx. Lab Equip. Time	Total Test Time
1	Record general data on UUT	Yes	15 min	battery(ies) and charger	0	15 min
2	*Battery conditioning according to IEC (optional)*	*No*	*variable*	*battery(ies) and battery analyzer*	*variable*	*variable*
3	Charge the batteries with associated charger in preparation for test	No	5 min	Battery(ies) and charger	0	16 h
4	Store battery(ies) between charge and Battery Discharge Energy Test	No	5 min	battery(ies)	0	1 h
5	Discharge battery(ies) according to section VII (Battery Discharge Energy Test)	Yes	15 min	battery(ies), battery analyzer	5.25 h	5.25 h
6	Store batteries between Battery Discharge Energy Test and Charge and Battery Maintenance Mode Test	No	5 min	battery(ies)	0	1 h
7	Conduct Charge Mode and Battery Maintenance Mode Test as specified in section VIII	Yes	15 min	charger, battery(ies), ac power meter	16 h (test runs overnight)	16 h
8	Remove battery(ies) and conduct No-Battery Mode Test detailed in section VI	Yes	10 min	charger, ac power meter	5 min	10 min
9	Compile data into report	No	25 min	none	0	25 min
	Approximate Test Times:		2 h		21.25 h	40 h

Unless otherwise specified, measurements shall be made under the test conditions and with the equipment specified below.

B. Ac Measuring Equipment

Ac power measurements shall be made with a suitably calibrated power analyzer. As in IEC 62301, measurements of active power of 0.5 watts 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 watts at the. As specified in IEC 62301, the power measurement instrument shall have a resolution of:

- 0.01 W or better for power measurements of 10 W or less;
- 0.1 W or better for power measurements of greater than 10 W up to 100 W;
- 1 W or better for power measurements of greater than 100 W.

For appliances connected to more than one phase, the power measurement instrument shall be equipped to measure total power of all phases connected.

In addition, ac voltage should be made with an uncertainty of = 2%. Power factor should be measured with an accuracy of = 2%. Frequency should be measured with an accuracy of = 2%.

C. Battery Analyzer Equipment

As is specified in IEC 61951 and IEC 61960, the overall accuracy of controlled or measured values associated with discharging the battery, relative to the specified or actual values, shall be within the following tolerances:

- ±1 % for voltage;
- ±1 % for current;
- ±1 % for capacity;
- ±2 °C for temperature;
- ±0.1 % for time.

These tolerances comprise the combined accuracy of the measuring instruments, the measurement techniques used and all other sources of error in the test procedure. For assistance in selecting instrumentation, see the IEC 60051 series for analogue instruments and IEC 60485 for digital instruments. The details of the instrumentation used shall be provided in each report of results.

D. Test Room

As sections of IEC 62301 specify, the tests shall be carried out in a room that has an air speed close to the UUT of = 0.5 m/s, and the ambient temperature shall be maintained at 23°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 tested on a thermally non-conductive surface. Products intended for conditions outside of 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.

E. Ac Input Reference Source: Voltage and Frequency

As is specified in IEC 62301, an ac reference source shall be used to provide input voltage to the UUT; the input to the UUT shall be the specified voltage ± 1% and the specified frequency ± 1%. Where this test method is referenced by an external standard or regulation that specifies one or more test voltages and frequencies, these test voltage(s) and frequency(ies) as defined shall be used for all tests. Where the test voltage and frequency are not defined by an external standard, the test voltage and the test frequency shall be the nominal voltage and the nominal frequency of the country for which the measurement is being determined +1 % (refer to Table B below from IEC 62301).

Table B: IEC 62301 Input Voltage and Frequency

Country / Region	Nominal Voltage and Frequency [a]
Europe	230 V, 50 Hz
North America	115 V, 60 Hz
Japan [b]	100 V, 50/60 Hz
China	220 V, 50 Hz
Australia and New Zealand	230 V, 50 Hz

[a] Values are for single phase only. Some single phase supply voltages can be double the nominal voltage above (centre transformer tap). The voltage between two phases of a three-phase system is 1.73 times single phase values. (e.g. 400 V for Europe). Thus these multiples of the listed nominal voltage are also the nominal voltage for some appliances (e.g. ovens and clothes dryers) in some markets.
[b] "50 Hz" is applicable for the Eastern part and "60 Hz" for the Western, respectively.

***Authors' comment on UUT input voltage:** Although California units will be tested at 115 V and 60 Hz, the reference to other voltages above is meant to address the needs of international stakeholders who could potentially reference this test method in their own battery charger initiatives.*

F. Ac Input Reference Source: Other Specifications

The THD of the supply voltage when supplying the UUT in the specified mode shall not exceed 2%, up to and including the 13th harmonic (as specified in IEC 62301). The peak value of the test voltage shall be within 1.34 and 1.49 times its rms value (as specified in IEC 62301).

V. Battery Charger System Setup Requirements

As in IEC 62301, the battery charger system should be prepared and set up in accordance with the manufacturer's instructions, except where these conflict with the test procedure as stated. 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. The following parameters are of particular importance:

- 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.
- The battery charger unit shall be used with the exact external power supply packaged with the unit, if any.
- The battery charger unit shall be tested with the batteries that are commercially packaged or most commonly sold with the unit. If the unit is not packaged with batteries, then the charger should be tested in one of the following ways:

- The battery charger shall be tested with batteries that are most closely associated or typically used with the product.
- If multiple types of batteries are used with the product, such that not one battery is closely associated with the charger, then the tests specified in sections VII, and VIII of this document (Battery Discharge Test, and Charge/Maintenance Mode Test) shall all be conducted twice, once with the highest capacity battery that is sold or associated with the charger, and once with the lowest capacity battery that is sold with or associated with the charger. Measurements from both tests shall be recorded.
- For chargers with multiple charging ports, the tests specified in sections VII, and VIII of this document (Battery Discharge Test, and Charge/Maintenance Mode Test) shall all be conducted twice with battery configurations list below:
  - The maximum number of identical batteries of maximum capacity that the charger is meant to accommodate shall be used
  - The minimum number of identical batteries of minimum capacity that the charger is meant to accommodate shall be used

  Data from both tests shall be recorded.

- Any optional functions controlled by the user and not associated with the battery charging process shall be turned off. If it is not possible to turn them off, they should be set to their lowest power-consuming mode during the test.

VI. No-Battery Mode Test

This test should be made on devices that contain battery charger systems from which the battery itself or a component housing the battery can be readily removed from the charger during normal operation while the charger remains connected to line voltage ac. Examples include:

1) A cordless phone with the handset off of the base unit. The base unit remains connected to line voltage ac.
2) A cordless power tool battery charger, from which the batteries are removed while the charger remains connected to line voltage ac.

NOTE: *A few devices (e.g. some electric razors and some desk size uninterruptible power supplies (UPSs)) do not normally operate in such a no-battery condition and may not be appropriate for this test.*

The No-Battery Mode power may be measured in two ways, depending on the stability of the power measurement.

A. Where the selected mode is stable

This method, modified from IEC 62301, may only be used where the mode and measured power are stable. A variation of less than 5 % in the measured ac power over 5 minutes is considered stable for the purposes of this standard. Instrument power readings may be used in this case. The following steps apply:

1) Remove the battery from the battery charger
2) Connect the power metering equipment to the battery charger
3) Confirm the battery charger is in no-battery mode and is in its lowest power state in that mode (this might require switching off other functionality of the device).

4) After the product has been allowed to stabilize for at least 5 min, monitor the power consumption for not less than an additional 5 minutes. If the power level does not drift by more than 5 % (from the maximum value observed) during the latter 5 minutes, the load can be considered stable and the power can be recorded directly from the instrument at the end of the 5 minutes.

B. All other cases

This method, modified from IEC 62301, shall be used where either the no-battery mode or measured power is not stable. However, it may also be used for all stable modes and is the recommended approach if there is any doubt regarding the behavior of the battery charger or stability of the mode. [If we're integrating in the other modes anyway, we're effectively integrating in all modes, no?]

Average power readings or accumulated energy over a user-selected period are used in this case. The following steps apply:

1) Remove the battery from the battery charger
2) Connect the power metering equipment to the battery charger
3) Confirm the battery charger is in no-battery mode and is in its lowest power state in that mode (this might require switching off other functionality of the device).
4) Determine average power using either the average power or accumulated energy approaches outlined below.

Average power approach: where the power metering equipment can record a true average power over a user-selected period, the period selected shall not be less than 5 minutes (except if there is an operating cycle – see below).

Accumulated energy approach: where the power metering equipment can accumulate energy over a user-selected period, the period selected shall not be less than 5 minutes (except if there is an operating cycle – see below). The integrating period shall be such that the total recorded value for energy and time is more than 200 times the resolution of the meter for energy and time.[2] Determine the average power by dividing the accumulated energy by the time for the monitoring period.

NOTE: *To ensure consistent units and simplify calculations, it is recommended that measurements be made in watt-hours and hours, to give average power in watts.*

If the power varies over a cycle (i.e. a regular sequence of power states that occur over several minutes or hours), the period selected to measure average power or accumulated energy shall be one or more complete cycles in order to get a representative average value.

In case of accumulated energy the integrating period shall be as described above.

[2] Example 1: if an instrument has a time resolution of 1 s, then a minimum of 200 s (3.33 minutes) is required for integration on such an instrument. Example 2: if an instrument has an energy resolution of 0.1 mWh, then a minimum of 20 mWh is required for an integration on such an instrument (at a load of 0.1 W this would take about 12 minutes, at 1 W this would take 1.2 minutes). Note that the reading should satisfy both the time and energy resolution requirements.

VII. 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 tests specified in section VI, Charge/Maintenance Mode Test. If multiple batteries are being used in this test (see section V, Battery Charger System Setup Requirements), then each battery should separately undergo this discharge test to determine its capacity.

For this test, the following steps apply:

1) The battery is charged with its associated battery charger (not with a battery analyzer).
2) As is specified in IEC 61951 and IEC 61960, the cell or battery shall be stored, in an ambient temperature of 20 °C ± 5 °C, for not less than 1 hour and not more than 4 hours.
3) The battery shall be discharged at a constant current of 0.2 C, until its voltage is equal to the specified end-of discharge voltage (in Table C below).
4) The total energy extracted during the period of discharge should be recorded as well as the voltage and current values as a function of time. Voltage and current shall be sampled at once per minute.

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

Battery Chemistry	Discharge Rate	End-of-Discharge
Sealed Lead Acid (SLA) or Vent Regulated Lead Acid (VRLA)	0.2 C	1.75 volts per cell
Flooded Lead Acid	0.2 C	1.75 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	3.0 volts per cell
Rechargeable Alkaline	0.2 C	0.9 volts per cell

Similar to IEC 61951, 5 cycles of discharge are permitted, although not required for the test. The cycle with the best capacity may be used as the measured capacity. Prior to the discharge test, the battery may also be conditioned through a cycling process specified by IEC 61951.

NOTE: If a conditioning sequence precedes the battery discharge test specified above, then the final charge prior to the discharge test must be completed with the battery charger associated with the UUT, not a battery analyzer (see step 1 above).

Authors' comment on discharge rates chosen: *0.2 C was chosen because it is referenced in the IEC test procedures reviewed and because it provides the most favorable representation of battery capacity without placing an undue time burden on testing organizations. (One discharge can easily be performed in a workday.) We are, in particular, seeking input from stakeholders on this test procedure parameter.*

VIII. Charge Mode and Battery Maintenance Mode Test

The Charge/Battery Maintenance mode test measures the ac power profile and energy consumed during one charge and a significant portion of the maintenance cycle of the UUT. Functions required for battery conditioning that happen only with some user selected switch or other control should **not** be included this measurement. As is specified in IEC 61951 and IEC 61960, the battery(ies) used in this test shall be stored, in an ambient temperature of 20 °C ± 5 °C, for not less than 1 hour and not more than 4 hours after the Battery Discharge Energy Test, VII.

The following steps apply:

1) Connect the metering equipment to the battery charger.
2) Ensure that user-controllable device functionality not associated with battery charging is turned off.
3) Record the start time of the measurement period, and begin recording the energy and power values associated with the measurement period.
4) Connect battery(ies), which have been fully discharged and conditioned according to section VII of this method, to the battery charger.
5) At the end of the measurement period, record the final time, power, and power factor values.

If the charge rate of the device is reported in the product literature, specification sheet, or is otherwise available from the manufacturer, the standard measurement period shall be whichever is the longer of the two scenarios listed below:

- sixteen hours
- one C divided by the manufacturer-specified charge rate plus 5 hours

For example, a UUT with C over 4 charge rate would be tested for 16 hours $16 > [(\frac{1C}{C/4}) + 5]$, while a UUT with a C over 20 charge rate would be tested for 25 hours $[(\frac{1C}{C/20}) + 5] > 16$.

In the case where the charge rate cannot be obtained, but the total reported charge time is reported in the product literature, specification sheet, or is otherwise available from the manufacturer, then the standard measurement period shall be whichever is the longer of the two scenarios listed below:

- sixteen hours
- the total reported time to charge plus 5 hours

For example a UUT with reported charge time of 16 hours would be tested for 21 hours, whereas a UUT with reported charge time of 15 minutes would be tested for 16 hours.

In the case where charge rate or charge time is unavailable, then the measurement period shall be 16 hours.

During the measurement period, power and power factor values shall be recorded at least every minute. After the measurement period is complete, the average power over the last 4 hours of the test shall be computed to give the average battery maintenance mode power.

IX. Reporting Requirements

The following information shall be recorded about each UUT:

General:

1) Name of technician performing the test
2) Organization performing the test
3) Time and date of each test
4) Manufacturer and model number of battery charger
5) Manufacturer and model number of battery
6) Battery chemistry
7) Rated battery voltage (volts)
8) Rated battery capacity (milliampere-hours)
9) Ac input voltage (volts)
10) Ac input frequency (hertz)

No-Battery Mode Test:

1) Average no-battery mode power (watts)
2) True power factor (expressed as a percent)

Battery Discharge Test:

1) Energy during discharge (watt-hours)
2) Starting battery voltage (volts)
3) Ending battery voltage (volts)
4) Starting cell voltage (millivolts per cell)
5) Ending cell voltage (millivolts per cell)
6) The dc voltage and dc current at regular one-minute intervals during the test period, taken in the following format: (time interval (minutes), dc voltage (volts), current,(milliamps)). Because data are taken once per minute, the number of data sets should be sixty times the number of hours in the test period.

Charge /Maintenance Mode Test:

1) The power and power factor at regular one-minute intervals during the test period, taken in the following format: (time interval (minutes), power (watts), true power factor (expressed as a percent)). Because data are taken once per minute, the number of data sets should be sixty times the number of hours in the test period.
2) Total duration of the test period (hours)
3) Average power during maintenance mode (watts)