SIZING, SPECIFYING AND TESTING HIGH RATE BATTERIES FOR UPS APPLICATION

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The key to delivering a satisfactory complex electrical system is to clearly define the performance expected. The battery specification for a UPS system typically is heavy on manufacturing details and light on system performance requirements.

SIZING FACTORS

A battery is considered properly sized when it fulfills its expected function. Sizing a high rate UPS battery involves a number of factors not associated with long duration battery with direct connection applications. These factors include inverter efficiency, inverter output characteristics, and battery end of discharge voltage.

Efficiency

Since the inverter is placed between the battery and the test load, inverter characteristics are a crucial factor in evaluating the battery performance. An inverter will have a different efficiency depending on the load magnitude, load power factor, load linearity, and battery voltage. Since the battery AH is evaluated by measuring the inverter kWh, battery testing is also inevitably inverter testing. For example, if the inverter efficiency changes significantly when the load is nonlinear, not that unusual, the in-service operating time on battery will not be the same as is demonstrated during testing with a resistive load. The design engineer should define the performance during operation on the critical load and separately define how the system will operate during commissioning.

Inverter Output Characteristics

As the UPS inverter converts DC voltage to pulses that form the AC output voltage waveform, it must deal with decreasing battery discharge voltage. The UPS inverter has a voltage operating range which is limited by the capacity of the inverter to produce sufficient AC output voltage and handle the increase in current as the battery voltage decreases (constant output power). The battery voltage will eventually be too low for the inverter to maintain full output voltage and, as the battery voltage continues to decline, the inverter output voltage will also drop until the UPS shuts down. This is a significant issue in inverter designs that demand high instantaneous battery currents to provide high peak currents to maintain output voltage for non-linear loads. A good way to specify the limits of battery discharge voltage is to define the resulting inverter output voltage limits.

Battery End Of Discharge

Battery watt tables are developed by the manufacturer by using the constant current table and an average battery voltage curve. This results in curves that predict the average battery voltage after a given discharge time with a constant power load. When the battery is chosen based on a minimum discharge voltage value, it may be at a higher voltage than the inverter minimum operating battery voltage, but it should never be lower.

HIGH RATE (UPS) BATTERY SPECIFICATION

A system performance specification for a high rate battery used with a UPS should include:

Battery Type

- Absorbed glass mat valve regulated lead acid
- Flooded calcium lead acid

Critical Load Definition

- 50% of inverter continuous output rating at 0.9 lagging power factor linear load and 50% of inverter continuous output rating with load crest factor of 2

Inverter Operation Time at Full Critical Load

- 15 minutes minimum at the initial battery capacity
- 10 minutes minimum at 80% of the initial battery capacity

Inverter Output Voltage During Battery Operation at Full Load

- ±3% of nominal output voltage during the specified battery operating time

Minimum Inverter DC Operating Voltage

- 1.67 volts per cell times the nominal number of cells plus 2V for voltage drop between the battery system connection points and the inverter, including all field supplied cabling.

Battery Discharge Protection

- Not less than 1.75 volts per cell times the actual number of installed cells for any discharge greater than 60 minutes

Battery Test Requirements

Prior to any discharge test, the battery must be prepared to the requirements of IEEE standard 450 or 1188.
Commissioning test

- 15 minutes at 100% of inverter continuous output rating, with a resistive load bank to minimum average battery voltage of 1.67 volts per cell. Inverter output voltage during battery test within 2% RMS of nominal output during any continuous ten cycle period

Maintenance test

- 10 minutes at 100% of inverter continuous output rating, with a resistive load bank to minimum average battery voltage of 1.67 volts per cell. Inverter output voltage during battery test within 2% RMS of nominal output during any continuous ten cycle period

Battery Replacement

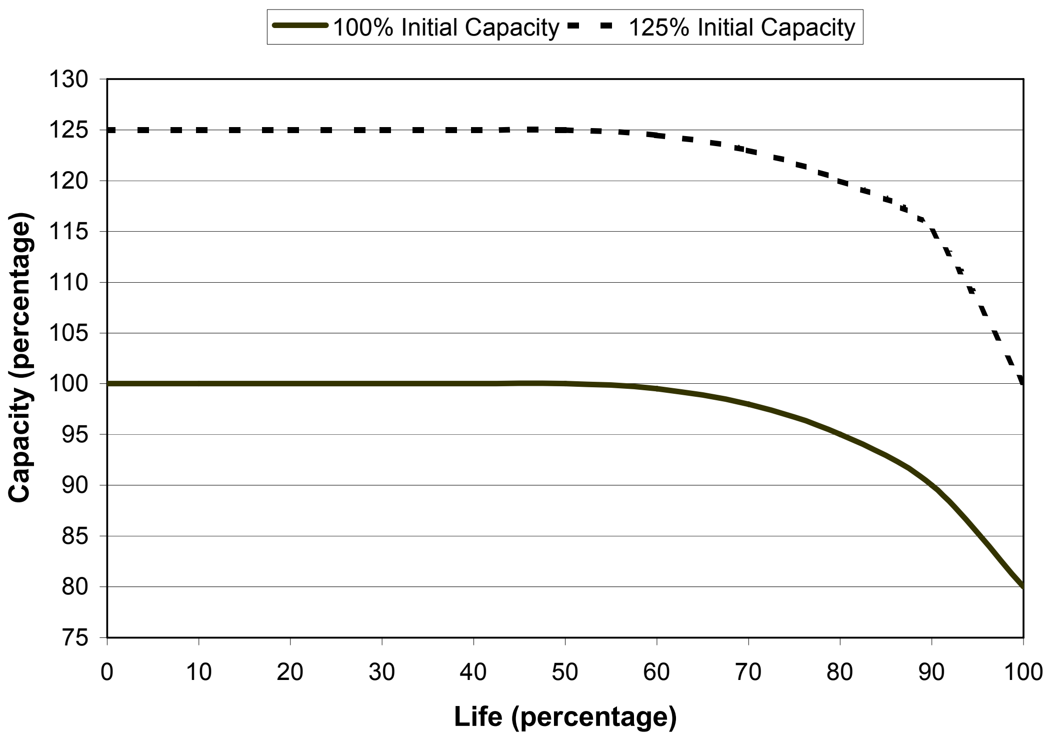
- State the capability of continued operation and operating time on battery when the smallest connected unit is bypassed

SPECIFYING OPERATING TIME FOR AGE DERATED BATTERIES

Age Derating

Often overlooked is the battery capacity at the end of useful battery life. The end of useful life is based on 80% of initial capacity for the initial operating time. As the battery ages and the battery load remains the same, the operating time will decrease at a rate greater than the rate of capacity decrease.

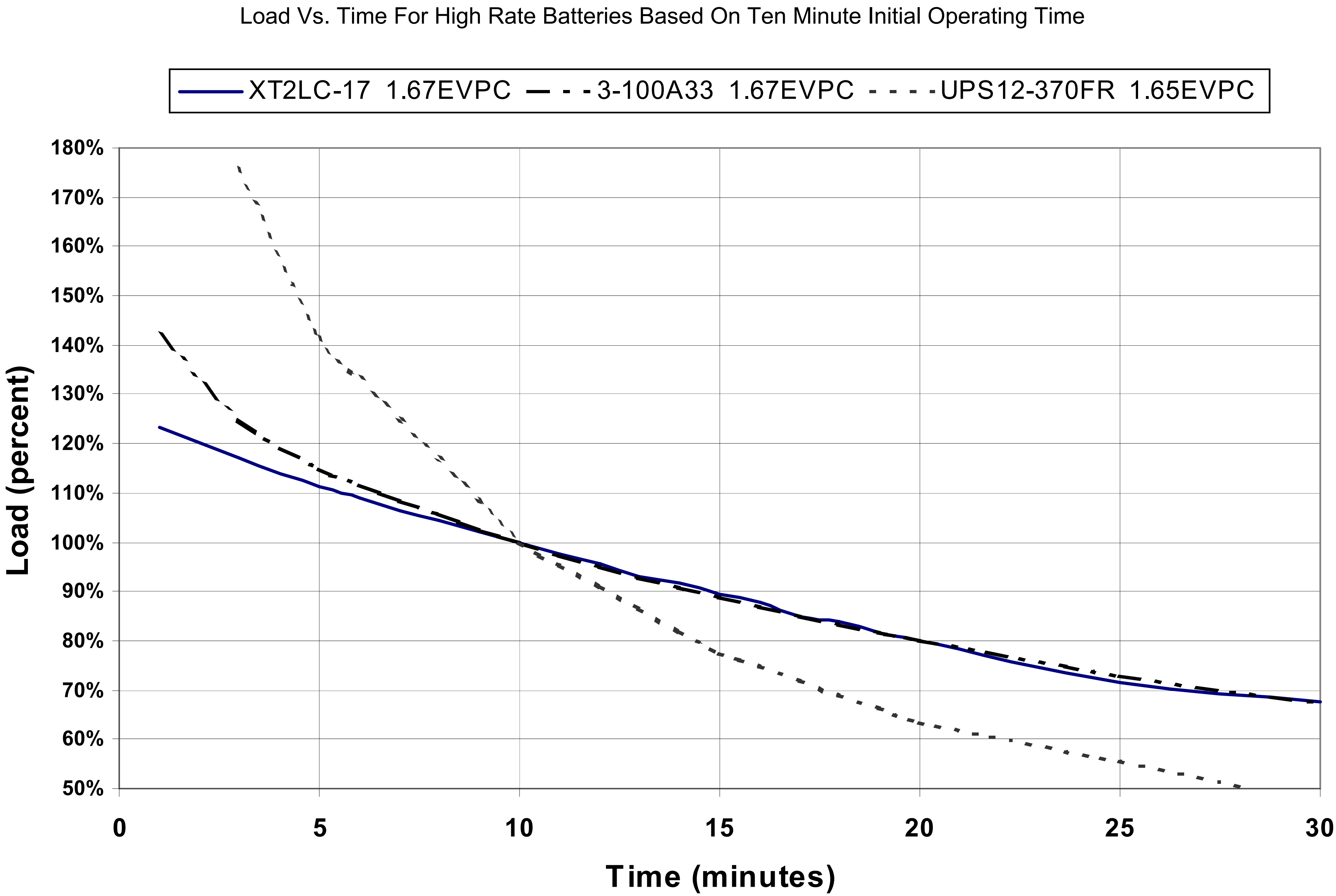
The best way to ensure sufficient operating time at the end of life is to select the battery based on using 125% initial load. It is not practical to commission the battery by loading the inverter to 125% of nominal load. The best method is to test at the nominal load, but for the longer initial time.



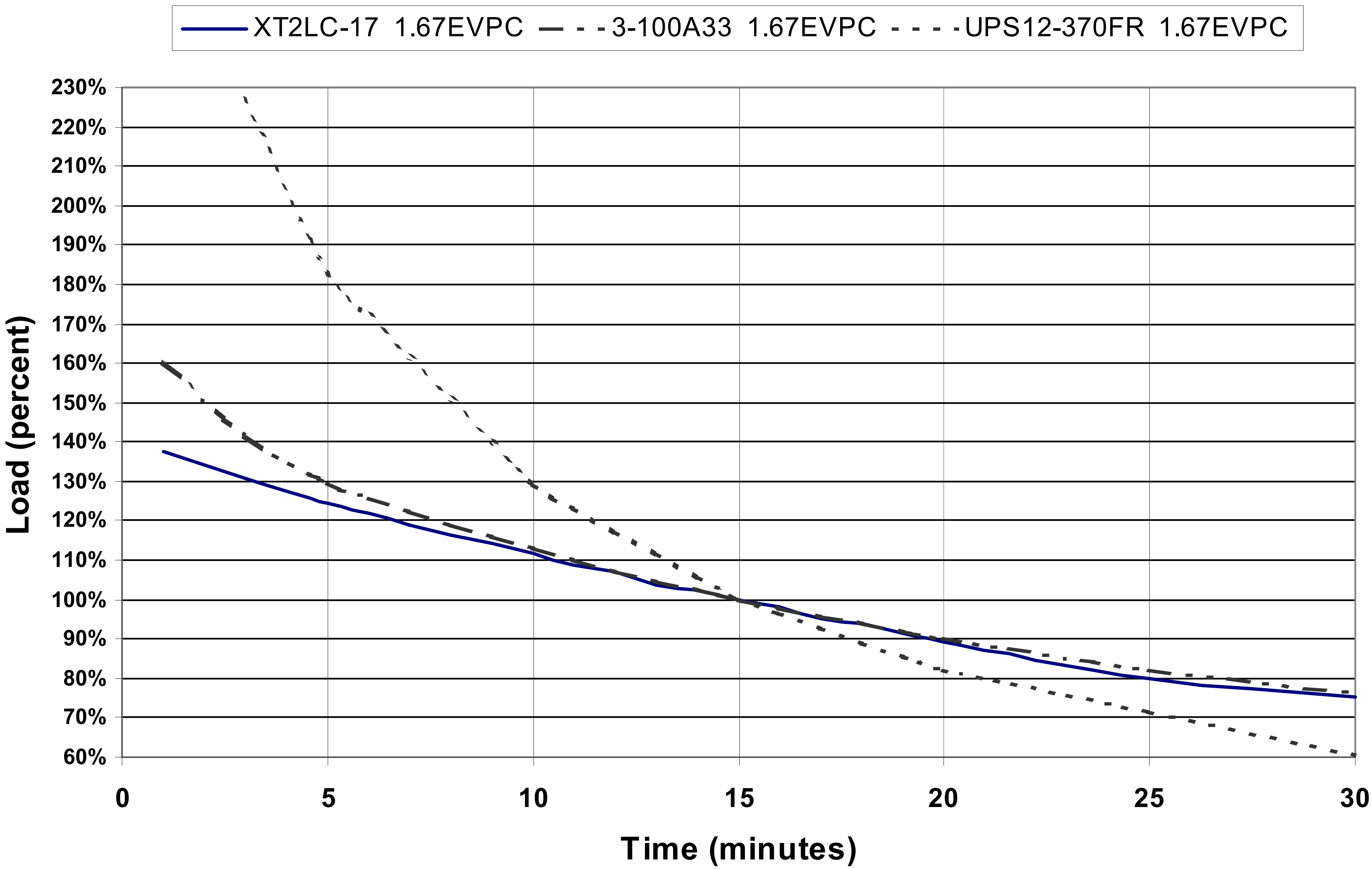
Identifying Capacity for a Derated Battery

To select the initial capacity that a battery must display, the following table shows the adjustment factor that must be used. Multiply the battery capacity needed to supply the normal inverter load by the selected adjustment factor, and that will be the initial capacity needed.

FINAL CAPACITY AS % OF FULL CAPACITY	INITIAL CAPACITY ADJUSTMENT
100%	1.0
95%	1.05
90%	1.11
85%	1.18
80%	1.25
75%	1.33


Load Vs. Time For High Rate Batteries Based On Ten Minute Initial Operating Time
XT2LC-17 1.67EVPC
3-100A33 1.67EVPC
UPS12-370FR 1.65EVPC
Load (percent)
180%
170%
160%
150%
140%
130%
120%
110%
100%
90%
80%
70%
60%
50%
0
5
10
15
20
25
30
Time (minutes)

Load Vs. Time For High Rate Batteries Based On Fifteen Minute Initial Operating Time



TESTING

As applied with a UPS, the battery is isolated from the load by an inverter. Therefore, any evaluation of battery performance must be made with full information about the inverter characteristics available. Battery capacity is evaluated by placing a load on the inverter. This load is usually an adjustable resistive load bank. Sometimes an inductive load bank is also used. Usually the load bank will not match the nominal critical load, so an adjustment factor will be needed to determine the expected operating time. The UPS manufacturer should supply a curve or table for loads within 5% of nominal load per the test criteria.

Calculating Battery Load

Calculating the battery percentage of capacity is at its base determining the number of ampere hours that can be removed without the battery voltage dropping below a predetermined value versus the same value for a full capacity battery. Unfortunately, this value can not be directly determined, and numerous averages, assumptions and errors creep into the process.

The first part of the process is to translate inverter load into battery load. This is accomplished by dividing the inverter load kilowatts by the inverter efficiency. The questions that must be answered include, "What is the load and the efficiency?"

- Inverter Load
  Measure the inverter load. The UPS metering might be accurate to within three to five percent. The load bank metering might be accurate to within three to ten percent. If you bring in metering equipment, you might be able to achieve two percent accuracy.
- Inverter Efficiency
  The manufacturer of the UPS is the best source of an efficiency value. The problem is, the manufacturer doesn’t really know the efficiency. The reason for uncertainty about the actual efficiency is that it changes for each of these situations: load kW, load kVA, load linearity, temperature, DC voltage at inverter; variations in inverter components. Therefore, the best efficiency value that can be expected is an “average” value and, even then, it may not be appropriate for the installed machine.

Now that you have determined the power delivered to the input terminals of the inverter, it is necessary to determine the power delivered by the battery. Other losses in the circuit between the battery and the inverter include the power lost in the connections, cabling, battery breaker, and anything else in the DC power current path. These losses are accounted for in the voltage drop between the battery and the inverter.

EXAMPLE OF CALCULATIONS NEEDED TO DETERMINE PASS/FAIL CRITERIA OF TEST

Calculations are based on the following data tables and graphs.

When you calculate for a 500kW inverter load and a 90% inverter efficiency, the battery load is 555.55kW.

Next calculate the kW per battery cell by dividing the battery load by the number of cells.

When you calculate for a 555.55kW load on 240 cells the per cell, load is 2.135kW.

Determine rating value changes based on battery temperature. Use the temperature measurement method and the battery capacity adjustment factor recommended by the battery manufacturer. In this case, divide the required battery kW by the correction factor. Remember, the battery will demonstrate a higher than nominal value when the temperature is above 77°F and lower than nominal value when the temperature is below 77°F.

When you adjust for 85°F with a 96% cell size correction factor and a 2.135kW load, the adjusted per cell kW is 2.224.

Next, determine the desired battery cell end of discharge voltage. I would recommend reviewing the battery manufacturer's "kW charts," trying to find the closest match between the per cell load and a value on the chart. You can linearize the values between closely coupled values.

When you pick the closest match to 2.224kW per cell, the best selection is 19 minutes to 1.68 volts per cell. A battery operating to 403V for 19 minutes demonstrates full capacity.

If the battery is fully charged and its condition recorded, it is now time to run the test.

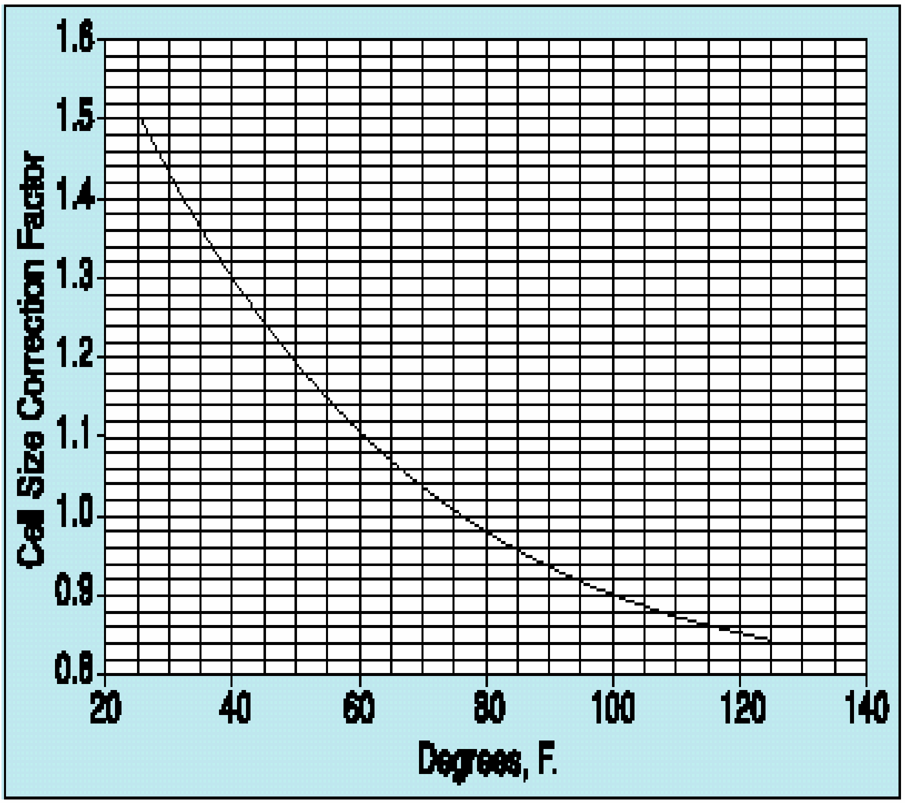
Start the clock when the battery is placed on load. Stop the clock when the desired battery voltage is reached.

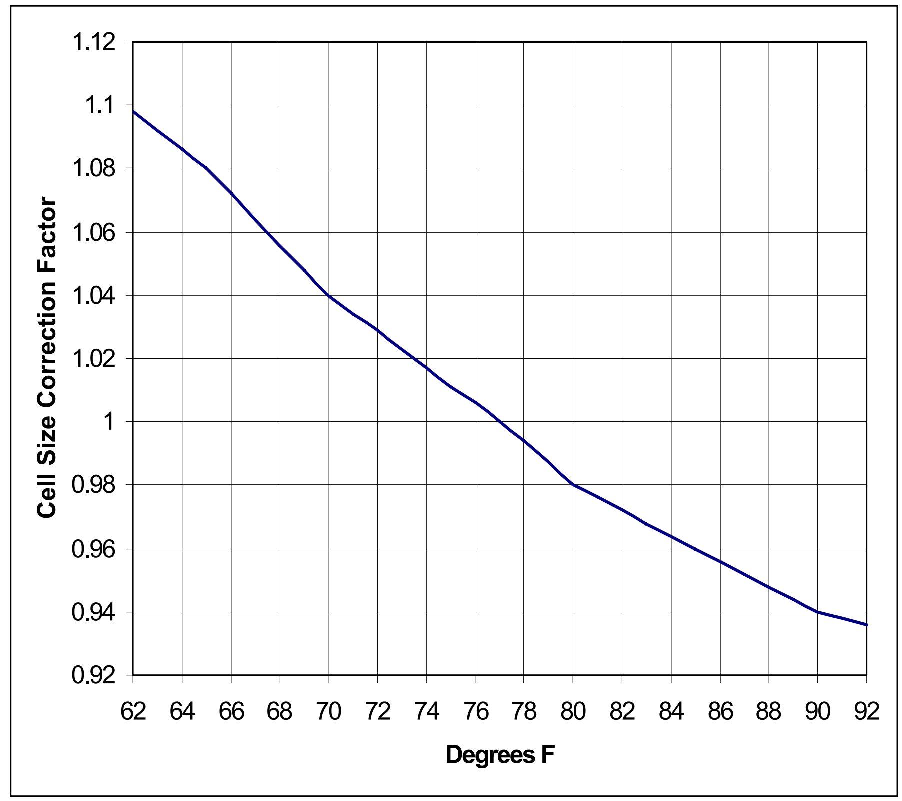
If the battery operating time is greater or equal to the calculated value, finish the paperwork and send the bill. If the operating time is less the calculated operating time, determine the percent of initial capacity. Return to the battery manufacturer's "kW charts" and find the operating time that matches the tested battery cell kW value. Divide the actual battery kW based on the actual operating time by the battery kW at the expected time. This value will be the percent of full capacity.

When the actual operating time is 10 minutes, the table kW is 2.703 and the calculated full capacity is 2.224kW. The percent of full capacity is 82.3.

XT2LC-17

Avg/ VPC	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	24	25
1.72	2.768	2.712	2.656	2.603	2.542	2.488	2.429	2.394	2.328	2.296	2.250	2.213	2.165	2.128	2.082	2.048	1.986	1.925	1.894
1.70	2.898	2.835	2.775	2.716	2.647	2.588	2.528	2.491	2.417	2.378	2.327	2.291	2.242	2.203	2.148	2.114	2.048	1.982	1.950
1.69	2.956	2.893	2.830	2.771	2.705	2.646	2.583	2.541	2.466	2.429	2.375	2.335	2.277	2.242	2.183	2.145	2.070	1.996	1.959
1.68	3.013	2.951	2.886	2.826	2.763	2.703	2.638	2.592	2.515	2.481	2.423	2.380	2.313	2.281	2.219	2.175	2.093	2.010	1.969
1.67	3.071	3.009	2.941	2.881	2.821	2.761	2.693	2.642	2.564	2.532	2.471	2.424	2.348	2.320	2.254	2.206	2.115	2.024	1.978
1.66	3.145	3.080	3.005	2.939	2.870	2.806	2.736	2.690	2.611	2.574	2.507	2.461	2.385	2.352	2.289	2.246	2.145	2.045	1.995
1.65	3.218	3.151	3.069	2.997	2.920	2.851	2.779	2.737	2.658	2.616	2.543	2.497	2.422	2.383	2.324	2.285	2.176	2.067	2.012





TEN THINGS THAT CAUSE TEST FAILURE

10. **Improperly chosen battery.** Yes, a UPS or battery manufacturer will pick the usual battery from a selection guide and ignore the specification. All parties should sign off on the test procedure. Don't get caught in the middle when the manufacturer took exception to the specification and the purchasing agent is proud of the money he saved.

9. **Improperly calculated DC voltage drop.** During discharge, the voltage at the battery is based on the battery manufacturer's design. The DC voltage at the inverter is a function of the cabling installed between the battery and the inverter, including all "cross-aisle" "around the piller/post" connections!!! (Total cable MCM determined by total loop feet.) Voltage at the inverter is the key to maintaining output voltage and inverter operation.

8. **Improper load.** Accurate three phase power measurements are difficult to take.

7. **Insufficient instrumentation or manpower during testing.** Testing is prime time to gather data. Do not ask one person to take thermal readings, watch the time, and monitor voltages for 240 cells during a ten minute test.

6. **The battery has low capacity due to temperature.** Everyone remembers it was cool in the battery room during the test, but nobody measured the temperature. How does the manufacturer instruct that temperature be taken? Battery capacity can also be affected if some of the batteries have cold air blowing on them from an improperly designed cooling scheme.

5. **The battery is improperly connected.** Follow the battery manufacturer's instructions for properly preparing and tightening and testing all power terminations.

4. **The battery is not fully charged.** Follow the battery manufacturer's instructions for charging. It will take at least 5 days of uninterrupted charger operation prior to battery capacity testing. Everyone is in a hurry at the end of the project, but if the test has to be repeated, it will take at least 7 more days and may include additional load bank rental expenses.

3. **Pass fail criteria is not understood.** Nobody was responsible for developing a test plan. Who would want to? It's a pain.

2. **Inexperienced testing personnel are used.** "I've never seen a battery this big before. How many of these would I need to run my trolling motor?"

1. **Instruction manuals remain in the shipping container.** Real men don't ask for directions or read instructions. Heck, we don't even like to follow instructions.