TSEWG TP-4: STATIONARY BATTERY AND CHARGER SIZING

BATTERY SIZING FOR APPLICATIONS WITH A DUTY CYCLE.

The designer of a backup power system has to determine the battery size. The battery can carry more load or perform longer as it is made larger, but a larger battery is also more expensive, requires more floor space, and increases the life cycle cost. For these reasons, provide a technical basis for the battery size.

The classic method of sizing a battery is based on determining the specific load requirements and selecting a battery size capable of supplying that load for the specified time. ANSI/IEEE 485 is the best industry reference for this type of cell sizing and should be reviewed as part of a battery sizing evaluation. ANSI/IEEE 1115, *IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications*, provides equivalent sizing information for nickel-cadmium batteries.

The battery duty cycle is the load that the battery is expected to supply for a specified period of time. Generally, the duty cycle is described in terms of the worst-case load that the battery is expected to supply. The battery would have to carry all or part of the connected load under any of the following conditions:

- System load exceeds the battery charger capability.
- Battery charger output is lost (could be by charger failure or loss of ac input).
- All ac power is lost in the facility.

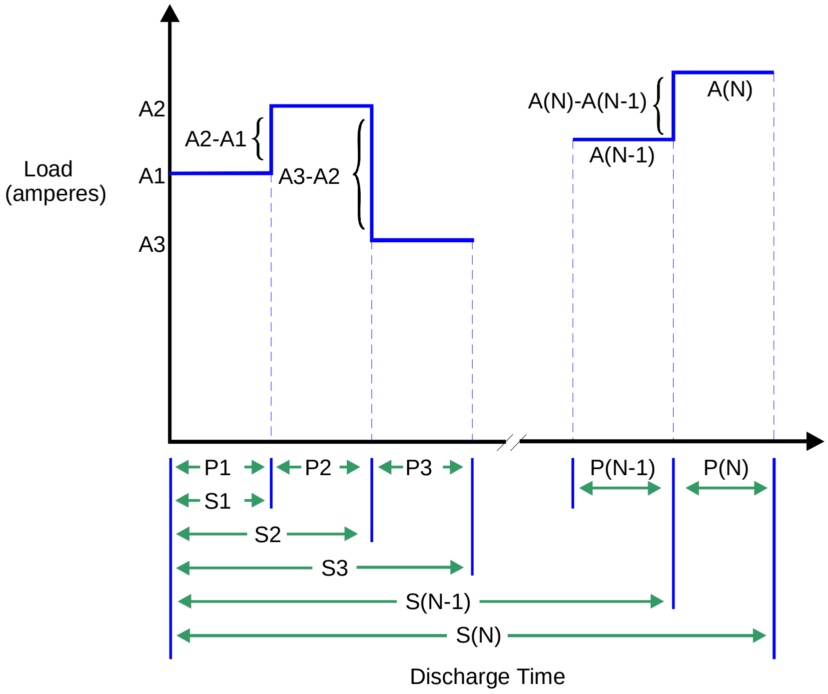
The worst case load usually occurs when all ac power is lost because other emergency loads might be energized in addition to the normally-energized loads. For example, loss of all ac power might require the additional energization of emergency lighting, circuit breaker components such as trip coils or spring charging motors, and emergency diesel engine cranking power. The duty cycle must consider all of these loads.

The following design inputs are needed to determine a battery size:

- Discharge capability of selected battery type.
- Load requirements, including duration.
- Minimum and maximum system voltage limits.
- Temperature, aging, and design margin allowances.

Evaluate the duty cycle, section by section, to determine which section of the duty cycle is limiting in terms of battery size. The cell size is selected based on the most limiting portion of the duty cycle. A generalized representation of a duty cycle is shown in Figure 1.

Figure 1 Generalized Duty Cycle



The battery sizing analysis of a duty cycle determines the required cell size for each section. Depending on the load profile, it is not guaranteed that the last section containing all periods will be limiting. For example, the cell size might be established by the first minute of the duty cycle if many loads are energized at once. ANSI/IEEE 485 provides worksheets to assist with the calculation process. Battery manufacturers provide similar worksheets.

The battery sizing methodology determines the cell size for the defined duty cycle when the battery capacity is 100 percent and at the reference temperature of 25 °C (77 °F). For most batteries, end-of-life occurs when capacity falls to 80 percent of the rated capacity. Also, depending on the installation, the actual battery temperature might be well below 25 °C (77 °F), and battery capacity decreases as temperature decreases. Apply correction factors to the calculated cell size to account for these effects. The net result is that the selected cell size must be larger so that it can meet its design requirements at end-of-life at the design low temperature.

Under ideal conditions, a battery can have 90 percent to over 100 percent capacity when new. As the battery ages, its capacity will eventually fall to 80 percent, which is the commonly accepted point at which the battery should be replaced. Below this capacity, the rate of degradation can increase rapidly. As part of the battery sizing process, size the battery so that it can fulfill the duty cycle requirements at its end of life. Apply the following correction factor to the calculated cell size; the calculated cell size is made 25 percent larger to ensure that it can supply the required load at end of life:

$$\text{Aging Correction Factor} = \frac{1}{0.8} = 1.25$$

The manufacturer specifies battery performance at the reference temperature of 25 °C (77 °F). As the battery temperature falls below 25 °C (77 °F), battery capacity decreases. As the battery temperature rises above 25 °C (77 °F), battery capacity increases. If the expected operating temperature will be less than 25 °C (77 °F), adjust the cell size to account for the reduced capacity at the lower temperature. Table 1 shows the correction factors for different battery temperatures. This table is based on vented lead-acid cells with a nominal 1.215 specific gravity. For a different specific gravity, consult the manufacturer to confirm the applicability of these correction factors. VRLA cells can have a completely different temperature response; consult the manufacturer for the appropriate temperature correction factors. Nickel-cadmium cells also require a manufacturer-provided temperature correction factor for low temperature operation, but the correction factor is not as large as for lead-acid batteries.

Table 1 Temperature Correction Factors for Vented Lead-Acid Cells (1.215 Specific Gravity)

Electrolyte Temperature		Cell Size Correction	Electrolyte Temperature		Cell Size Correction	Electrolyte Temperature		Cell Size Correction
(°F)	(°C)	Factor	(°F)	(°C)	Factor	(°F)	(°C)	Factor
25	-3.9	1.520	71	21.7	1.034	85	29.4	0.960
30	-1.1	1.430	72	22.2	1.029	86	30.0	0.956
35	1.7	1.350	73	22.8	1.023	87	30.6	0.952
40	4.4	1.300	74	23.4	1.017	88	31.1	0.948
45	7.2	1.250	75	23.9	1.011	89	31.6	0.944
50	10.0	1.190	76	24.5	1.006	90	32.2	0.940
55	12.8	1.150	77	25.0	1.000	95	35.0	0.930
60	15.6	1.110	78	25.6	0.994	100	37.8	0.910
65	18.3	1.080	79	26.1	0.987	105	40.6	0.890
66	18.9	1.072	80	26.7	0.980	110	43.3	0.880
67	19.4	1.064	81	27.2	0.976	115	46.1	0.870
68	20.0	1.056	82	27.8	0.972	120	48.9	0.860
69	20.6	1.048	83	28.3	0.968	125	51.7	0.850
70	21.1	1.040	84	28.9	0.964			

The aging and temperature correction factors account for inevitable aging and temperature effects. The battery is sized for a particular duty cycle and, depending on the facility, load growth can occur over time. A design margin correction factor can be applied to provide additional assurance that the battery will meet its future design requirements. The design margin correction factor also adds a capacity margin to allow for less-than-optimum battery operating conditions due to improper maintenance, recent battery discharge, lower than expected operating temperatures, or other effects. Simply stated, the design margin correction factor is an additional margin to help ensure the battery has adequate capacity to perform its job. A design margin of 10 percent to 15 percent is typical.

EXAMPLE: Suppose the sizing calculation for a vented lead-acid battery determined that 5 positive plates per cell were required for the specified duty cycle. What size cell is needed to account for aging and an expected low operating temperature of 15.6 °C (60 °F)? Also, the designer would like to add a 10 percent design margin.

The aging correction factor is 1.25 to ensure adequate capacity when the battery is at end of life. From Table 1, the temperature correction factor is 1.11 for an operating temperature of 15.6 °C (60 °F). The design margin correction factor is 1.10. The required cell size is as follows:

$$\textit{Corrected Cell Size} = (5\ \textit{positive plates}) \times 1.25 \times 1.11 \times 1.10 = 7.63\ \textit{positive plates}$$

In this case, round up to 8 positive plates. If the application of design margin causes the calculated cell size to slightly exceed the next size cell, for example, 7.05 positive plates, the designer should, in this case, determine if 7 positive plates are adequate. Rounding up to the next cell size results in a larger and more expensive battery. The battery must be big enough to do its job throughout its service life, but a grossly oversized battery is not desirable either.

In summary, size the battery for the limiting portion of the duty cycle, including corrections for performance at end of battery life and for the minimum expected operating temperature. If needed, include an additional design margin.

BATTERY SIZING FOR UPS APPLICATIONS.

Compared to duty cycle sizing, UPS applications often involve a different approach to battery sizing. If the UPS is the only load placed on the battery (which is common for many UPS systems), the battery can be sized more easily based on the UPS constant power requirements. Battery manufacturers also provide sizing charts based on a constant power discharge. The method of analysis is particularly straightforward, consisting of the following steps:

- Determine total load (and duration) the UPS will place on the battery. The duration can be the most difficult design factor to specify. If additional backup power such as a diesel generator is not available, the UPS battery has to be large enough for the staff to place the system in a safe state in response to a power outage. If diesel generator backup is available, a 5-minute backup time might be adequate if the diesel system operates properly. If the designer allows for diesel starting difficulties, a backup time of over 30 minutes might be needed.

- Apply cell sizing correction factors so that the battery can provide the required load at end of life and the design low temperature.

- Determine the minimum and maximum system voltage. Select the number of cells based on the minimum and maximum voltage limits.

- Calculate the load on each cell and select a cell size capable of supplying the required load.

As a battery discharges, the battery voltage declines in a predictable manner. For a constant power discharge, the current will increase in direct proportion to the voltage decrease in accordance with the following relationship:

$$Power = Voltage \times Current$$

EXAMPLE: The easiest way to discuss battery sizing for a UPS application is with an example. Assume the UPS specifications applicable to the battery are as follows:

Size: 7.5 kVA @ 0.8 power factor (6.0 kW)

Inverter efficiency: 0.92 at full load

Maximum input dc voltage: 140 volts

Low voltage cutout: 105 volts

The user specifies that the UPS must power critical loads for a minimum of 30 minutes following a loss of normal power. The user believes that the UPS will be almost fully loaded for the entire discharge duration.

First, calculate the total battery load. Assume the UPS is fully loaded at 7.5 kVA. The power required from the battery is the real power produced by the UPS including efficiency losses. The real power produced by the inverter is 6.0 kW (7.5 kVA x 0.8 PF). Thus, the required battery load is:

$$Battery\ \ Load\ \ (kW) = \frac{Power}{Efficiency} = \frac{6.0\ \ kW}{0.92} = 6.52\ \ kW$$

This is the nominal load that the battery must be capable of providing when the battery has 100 percent capacity at 25 °C (77 °F). As discussed previously, the battery will have less than rated capacity if the temperature is less than 25 °C (77 °F). Also, a lead-acid battery is normally sized to be capable of fulfilling its design load requirements at end of battery life (80 percent capacity). Apply the appropriate correction factors to ensure the battery can meet this load requirement at end of battery life at the lowest expected temperature. The correction factors are as follows:

Aging: 1.25 (corresponding to 80 percent capacity)

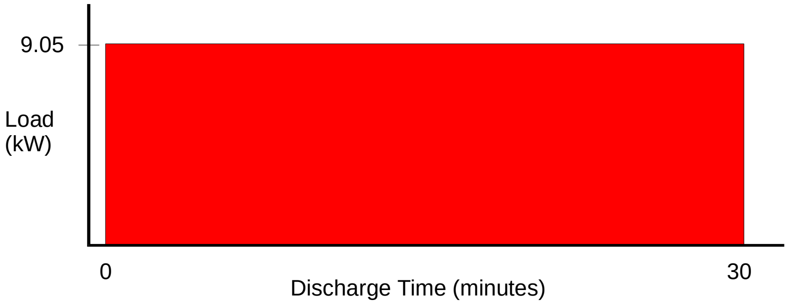
Temperature: 1.11 (assume lowest expected temperature is 15.6 °C or 60 °F)

The corrected battery load is:

$$Corrected\ Battery\ Load\ (kW) = \frac{6.0\ kW}{0.92} \times 1.25 \times 1.11 = 9.05\ kW$$

Notice that the designer chose not to add design margin because the UPS is already assumed to be fully loaded.

For this typical example, the duty cycle consists of the above constant load for 30 minutes.



The UPS maximum dc input voltage was specified as 140 volts. This voltage is the maximum allowed voltage on the system. Also, assume that the manufacturer recommends a maximum battery equalize voltage of 2.33 volts per cell. The maximum number of cells is given by:

$$Maximum\ Number\ of\ Cells = \frac{Max\ System\ Voltage}{Equalize\ Voltage} = \frac{140}{2.33} = 60.09\ \ cells$$

In this case, choose 60 cells. Next, determine the minimum allowed voltage per cell based on the system minimum voltage requirement of 105 volts:

$$Minimum\ \ Cell\ \ Voltage = \frac{Minimum\ \ System\ Voltage}{Number\ of\ Cells} = \frac{105}{60} = 1.75\,volts$$

The designer needs 60 cells capable of providing 9.05 kW for 30 minutes without allowing voltage to drop below 1.75 volts per cell. Each cell must deliver:

$$\frac{9.05\ kW}{60\ cells} = 0.151\,kW\ \ per\ \ cell$$

This is the information needed to select a cell from the manufacturer's data sheets. Each cell must be capable of providing 0.151 kW for 30 minutes without individual cell voltage falling below 1.75 volts.

Refer to IEEE 1184, *IEEE Guide for the Selection and Sizing of Batteries for Uninterruptible Power Supply Systems*, for additional information regarding sizing of UPS batteries.

BATTERY SIZING FOR ENGINE STARTING APPLICATIONS.

Depending on the design, a diesel engine might be started by an air system or an electric motor (starting motor). Electric starting is the most convenient to use, is usually the least expensive, and is the most adaptable method for remote control and automation. The ambient temperature and lubricating oil viscosity affect the starting ability of a diesel engine. The diesel relies on the heat generated by compression to ignite the fuel. When first starting, this compression and heat is created by the diesel cranking (starting) process, which is a function of the cranking speed and cranking time. When the engine is cold, longer cranking periods are required to develop ignition temperatures. The battery powers an electric starting motor to accomplish this cranking process. Lubricating oil imposes the greatest load on the cranking motor; oil viscosity varies with oil type and temperature. For example, Society of Automotive Engineers (SAE) 30 oil viscosity approaches that of grease below 0 °C (32 °F).

Either lead-acid or nickel-cadmium batteries can be used for engine starting. The nickel-cadmium type is often used so that the battery can be located very near the engine, which is usually a higher ambient temperature environment. Also, nickel-cadmium batteries are capable of very high-rate discharges for the few seconds needed for an engine cranking application.

In many cases, the associated battery's only purpose is to provide cranking power to start the diesel engine. In these cases, battery sizing is performed differently than described in the previous sections. The primary considerations for sizing a diesel engine battery are:

- The lowest temperature at which the engine might be cranked. Oil viscosity increases with decreasing temperature and affects how long the starter motor must turn before fuel ignition temperature is reached. Note also that lower temperatures affect the battery's capacity. At lower temperatures, the battery's capacity requires adjustment for both oil viscosity and decreased battery capacity. For very cold applications, consider engine heaters or glow plugs to minimize the battery size requirements.

- How many start attempts will be allowed. Select a battery that can provide at least four 30 second cranking periods (total of 2 minutes of cranking). Engines are often rated for up to 30 seconds of cranking before the starter motors begin to overheat. Confirm the starter motor limitations with the manufacturer.

EGSA 100B provides guidance for sizing a diesel engine starting battery. This performance standard should be used for battery sizing; it recommends providing the following information to the battery manufacturer as part of a battery sizing evaluation:

- Nominal volts needed for the starter motor.

- Starting current of starter motor.

- Engine model and make.

- Cubic inches displacement. Some battery manufacturers have sizing guidelines based on the cubic inches displacement.

- Number of cranks and possible duration of each crank.

- Rest period for battery recovery, if needed.

- Worst case low battery temperature.

- Worst case low engine temperature and oil viscosity.

- Battery type and desired life.

- Seismic or vibration requirements.

As part of the sizing process for a diesel engine battery, consider voltage drop between the battery and the starter motor. The starter motor usually draws significant current from the battery. For this reason, batteries are often located very near the diesel engine to minimize the voltage drop caused by the high current. Typical connecting devices between the battery and the starter motor include:

- Cable—resistance varies with cable size and length.
- Contactors (relays, solenoid, switches)—resistance less than 0.002 ohms is typical.
- Connections—each connection resistance less than 0.001 ohms is typical.

The diesel engine manufacturer usually specifies the minimum system requirements, including the maximum connection resistance between the battery and the starter motor. Ensure these minimum requirements are met by the installation.

BATTERY CHARGER SIZING.

Size each battery charger to be large enough to power the normal system loads while recharging a discharged battery within a reasonable amount of time. Manufacturers recommend a recharge time of 8 to 12 hours. Shorter recharge times require larger battery chargers and might result in excessive current flow into the battery during the recharge process. For this reason, 8 hours is usually the minimum recharge time for a discharged battery. On the high end, 12 hours is often recommended for an upper limit; however, this recharge time is somewhat arbitrary and 14 hours or 16 hours might be acceptable, depending on the application and how the recharge is controlled. The primary consideration is that the charger should be sized to recharge the battery within a reasonable amount of time.

Size the charger to be large enough to supply the normal continuous loads while also recharging the battery within a reasonable time period. The charger sizing formula is as follows:

$$A = \frac{kC}{H} + L_c$$

where

A = Output rating of the charger in amperes.
k = Efficiency factor to return 100 percent of amperhours removed. Use 1.1 for lead-acid batteries and 1.4 for nickel-cadmium batteries.
C = Calculated number of amperhours discharged from the battery (calculated based on duty cycle).
H = Recharge time to approximately 95 percent of capacity in hours. A recharge time of 8 to 12 hours is usually recommended.

L_c = Continuous load (amperes).

The above sizing method is recommended, but tends to provide an optimistic recharge time. The actual recharge time is usually longer than indicated above because the charging current tends to decrease as the battery voltage increases during recharge.

EXAMPLE: Determine the charger rating if a) the continuous load is 100 amperes, b) 300 amperhours are discharged from a lead-acid battery, and c) the battery is to be recharged within 10 hours.

$$A = \frac{1.1 \times 300}{10} + 100 = 133 \; amperes$$

EXAMPLE: Suppose that the above system has 50 amperes of noncontinuous loads that can be energized at any time. In this case, the total charger load is the sum of the continuous and noncontinuous load before consideration of battery recharge requirements. At any time, the charger load can be as high as:

$$A = L_c + L_n = 100 + 50 = 150 \; amperes$$

If the charger in the previous example was selected to have a capacity of 133 amperes, the battery would have to supply the additional load whenever the noncontinuous load is energized. So, the charger should instead be sized to provide the expected system loads, or 150 amperes in this example. Note that this assumes the noncontinuous loads will not be energized for long periods when the battery is being recharged.