Selection and Sizing of Batteries for UPS Backup

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Abstract

Until only a few years ago, the types of batteries for use with Uninterruptible Power Systems (UPS) were limited to perhaps two or three. This made the selection rather simple. Over the past few years, a number of different types of batteries have appeared on the market. They exhibit varied specifications, environmental requirements, are available in a wide price range, require varying degrees of maintenance and have different warranty periods and life expectancies from two or more than twenty years.

Choosing the proper battery for the application then becomes one of examining these various parameters and choosing the one most suitable for the particular application. The following paper is a comprehensive analysis of various battery types and methods for sizing these batteries utilizing the various battery manufacturers' data available for sizing.

Introduction

As a UPS manufacturer, SCI often supplies batteries with a UPS and aids customers with their decision on battery selection. The following types of batteries are generally selected for use with a UPS:

1) Lead Acid/Plante'

2) Lead Acid/Antimony

3) Lead Acid/Calcium

4) Lead Acid/Calcium, Maintenance-free Liquid Electrolyte

5) Lead Acid/Calcium, Maintenance-free Gelled Electrolyte, Sealed

6) Lead Acid (Special Alloy), Suspended Electrolyte, Maintenance-free, Sealed

7) Nickel Cadmium, Pocket Plate Liquid Electrolyte

An understanding of the various operating parameters, maintenance requirements and cost is vital in choosing the most advantageous battery for the application. This paper does not favor one battery type over another, but only presents alternatives for consideration. Sizing information charts which show manufacturers' names are used for illustrative purposes only. Where an example of various types are referenced, some of the suitable sized batteries available are reflected for a moderately sized UPS (In the range of 10 - 200 kVA.)

Battery Type

Lead Acid Plante' This battery is manufactured by utilizing a lead grid framework into which lead oxide paste or pure lead is applied. The plates are then formed by applying an electric current (charging) which forms lead dioxide on the positive plate and sponge (porous) lead on the negative plate. Since lead paste and the grid framework is rather soft, special care must be exercised in the construction of these batteries. As a result, these batteries are more expensive than some other types (For example 2-2 1/2 times the cost of lead acid/calcium battery). Note: Since the lead acid/calcium battery is the most commonly used battery for UPS back-up in the U. S. today, this battery will be used as a reference for comparing the other battery types.

The Plante' battery is both mechanically and electrically durable. It is able to provide approximately 1,000 - 1,200 full discharges during its 25 year warranted life. This battery will also likely deliver its full rated capacity after 25 years of operation. Maintenance, especially watering, is low and the Plante' battery can tolerate operation at high temperatures better than the various lead acid alloyed types, i.e., calcium, antimony, etc. (Note: Batteries are normally rated at the nominal temperature of 77° F (25°C). Because this type of battery generates hydrogen gas when charging and because the sulfuric acid electrolyte does evaporate to some extent, these batteries must be used in a room which is well ventilated to the outside and kept away from delicate electronic equipment. Examples of some available types include Chloride type YAP, YCP, YHP, Yuasa-Exide type, Manchex DMP, EMP.

Lead Acid/Antimony This battery is manufactured by utilizing a lead antimony allow in the grid construction which increases the strength of the plates. Thus, special and expensive mechanical construction is not necessary. This lead acid/antimony battery is able to provide approximately 1,000 - 1,200 full discharges during its 15 year warranted life. Hydrogen gas generation and consequential water usage is approximately ten times that of the lead acid/Plante' and the lead acid/calcium battery. Adequate ventilation becomes more important. The frequency of maintenance, water addition, also increases. There is also a need for periodic monthly equalization. At the end of 15 years, the lead acid antimony battery will have lost approximately 20% of its original capacity. This battery may be selected where frequent discharging is expected. Initial cost is approximately the same as the lead acid/calcium battery. Examples of some available types of lead acid/antimony batteries include Chloride type FAP, FCP; C&D type DU, KC, KCW LCW, LC; Yuasa-Exide type CA, ET, EA, GT, GA; GNB type MAT, NAT, DS, DKR, MAX, NAX.

Lead Acid/Calcium The lead acid/calcium battery is manufactured by utilizing a lead calcium alloy grid in the grid construction to increase the strength of the plates. Hydrogen gas generation and consequential water consumption is the same as the lead acid/Plante' battery. This battery, when maintained at a float voltage of 2.25 volts/cell, does not require routine equalization and it is capable of only approximately 100 full discharges during its 20 year warranted life. As with most UPS applications, the battery will be floating on the charger most of the time, and even when discharged, may not normally be fully discharged. This battery offers an excellent cost versus service reliability advantage. It is, in fact, the most popular battery in the United States for UPS back-up. At the end of 20 years, it will have lost approximately 20% of its original capacity. Examples of some available types of lead acid/calcium batteries include: GNB type DSC, MCX NCX PDQ; C&D type DCU, XT; Yuasa-Exide type CC, KU, EC, DX, FTC, GU, GC.

Lead Acid/Calcium Maintenance-Free Liquid Electrolyte The lead acid/calcium battery is designed for 3-5 years of maintenance-free operation. It utilizes a high specific gravity electrolyte with a large electrolyte capacity. This battery carries one year full replacement warranty and a five year expected life when used in a float application such as a UPS back-up. This battery will gas the same as the lead acid/calcium battery, consequently, ventilation is required. Initial cost compared to an equal size lad acid/calcium (20 year life) battery is approximately 35 - 50%. This battery is presently manufactured in only a limited number of sizes; therefore, it becomes necessary to parallel banks for longer back-up times or for larger UPS equipment. Since it is more expensive to parallel smaller battery banks than to supply a single large bank, the price advantage is quickly lost when a system would require a large number of parallel banks. Example of an available type of maintenance-free lead acid/calcium batteries is: Delco-Remy.

Lead Acid/Calcium Gelled Electrolyte (GellCell) Sealed The gelled electrolyte sealed lead acid/calcium maintenance-free battery is designed for up to 20 years of operation requiring no routine maintenance and carries a one-year full replacement warranty. Because this battery is sealed, it vents no gas into the atmosphere under normal operating conditions. The batteries will vent to release pressure as a safety precaution when a specific internal pressure is reached. Because the battery is sealed, the hydrogen and oxygen gas generated during charging recombines immediately within the cell. This sealed battery can safely be used in an unventilated room making it suitable for applications where ventilation would be expensive or impractical. Since it is sealed and has a gelled electrolyte, it can be used in any position and will not leak electrolyte even if the case becomes cracked. Cost is approximately 60-70% of the standard lead acid/calcium battery of equal size. This battery also has a high energy density, meaning it is physically smaller than an equal lead acid (liquid electrolyte) battery. Examples of some available types of gelled electrolyte sealed lead acid/calcium batteries include: Johnson Controls type UPS.

Lead Acid (Special Alloy), Suspended Electrolyte, Sealed The lead acid (special alloy) battery is the newest sealed battery appearing on the market utilizing an electrolyte that is suspended in porous material. There is no liquid to spill. It is completely sealed venting gas only as a safety precaution under high internal pressure. This battery can be used in an office environment or in an unventilated room. It is totally maintenance-free battery with a warranted life of up to 20 years and an expected life of approximately 10 - 14 years. It has a high energy density and is physically smaller than an equal lead acid battery. Its cost is approximately 1 to 1.2 times that of the lead acid/calcium battery. Examples of this type of battery include: (Hawker) Chloride type VA, VC, VB.

Nickel Cadmium - Pocket Plate, Liquid Electrolyte Nickel cadmium or NICAD batteries are the most expensive of the various types of batteries previously discussed. Initial costs are approximately three times that of the lead acid/calcium battery. Although 92 cells of nickel cadmium are required to equal 60 cells of lead acid, this battery still has the advantage of being smaller in size and weight for a given capacity. These batteries do not experience the severe shortening of life when operated at elevated temperatures and performs better at low temperatures than do the lead acid batteries. NICAD batteries do emit hydrogen and oxygen gas, products of electrolysis, but there are no corrosive gases as it true with lead acid types. Consequently, they can be installed directly next to delicate electronic equipment. When maintained at the recommended float voltage, periodic equalization is not required. Water consumption is relatively low and, consequently, so is maintenance. Normal service life should extend beyond the warranted 20 years. Examples of some available types of NICAD batteries include: Chloride type VHP, MP, EP, LP; Saft/Nife type H, M, L.

Figure 1 summarizes the features of the various types of batteries discussed in this paper. Remember that these batteries require routine maintenance and have costs associated with that maintenance over the life of the battery. Maintenance can range from none at all for maintenance-free types, to monthly visual checks and quarterly measurements of voltages and specific gravity, all of which must be completed and recorded in order to maintain the warranty.

FIGURE 1

Battery Type	Typical Warranty	Life Expectancy	Hydrogen Gas Evolution	Approximate Number of Deep Discharges	Initial Cost Comparison to Lead Calcium
Lead Calcium-Flooded Cell	20 Years	20 years	Low To Moderate	100	100%
Lead Calcium-VRLA	10 Years	5 years	None	200	30-50%
Lead calcium-VRLA	20 years	12-15 Years	None	200	80-120%
Lead Antimony-Wet Cell	15-20 Years	15 Years	High	400	100%
Nickel Cadmium-Wet Cell	20-25 Years	20-25 Years	Low	1000	200-300%

It should be noted that in the same installations, for example an EDP installation, a four or five year life may be all that is required with the thought in mind that in four years the entire computer system may be outdated and replaced with a new “state-of-the art” device requiring a different size UPS and battery.

Battery Sizing

Battery manufacturers provide various types of information for sizing batteries. All battery sizing calculations in this paper have assumed a standard room temperature of 77° (25°C). Batteries which will be operated at higher or lower temperatures continuously should be calculated specifically for that temperature. Your UPS or battery supplier can assist you with these calculations. Generally, this information is supplied in one of three ways:

1. Kilowatts per cell

2. Kilowatts per bank

3. Ampere per cell

Normally information supplied for lead acid batteries designed for short discharge times (5-120 minutes) is in the form of kilowatts per cell tabulated for various back-up times. Therefore, it is important to first calculate the total kilowatts required to operate the particular UPS at a given load (usually assuming full load).

Equation 1

$$\text{KW/cell} = \frac{\text{KVA x PF}}{\text{EFF x Number Of Cells}} + \text{AL}$$

KVA	=	KVA of the load
PF	=	Power factor of load
EFF	=	Efficiency of the UPS at the given load
No. Cells	=	Number of cells required. The number of cells required will be specified by the UPS manufactured.
AL	=	Any additional loads on the battery expressed in kilowatts.

Example Calculation:

Determine the battery required for a 20 kVA UPS operating at full load with an efficiency of 86%, a load power factor of 0.8 and no additional DC loads. The UPS is a 130 VDC system requiring 60 cells of lead acid batteries and requiring 30 minutes of back-up time. Utilizing the preceding formula, the kW / cell equals .310.

Equation 2

$$\text{kW / cell} = \frac{20 \times .8}{.86 \times 60} = .310 \text{ kW}$$

The UPS manufacturer will also recommend the battery be discharged to a specific end voltage per cell. For a 60 cell lead acid battery, this will normally be 105V per bank or 1.75 volts/cell.

Utilizing the battery manufacturer's supplied information, such as that in Figure 2 for this 20 kVA UPS, 60 cells of either 3CX-11 are required which will supply 19.4 kW (0.324kW x 60 cells) for 30 minutes.

FIGURE 2

AVERAGE CELL PERFORMANCE DATA (Discharge Rates in KW**)*

Specific Gravity 1.215

TYPE	3 HR	2 HR	1.5 HR	1 HR	45 MIN	30 MIN	25 MIN	20 MIN	19 MIN	18 MIN	17 MIN	16 MIN	15 MIN	14 MIN	13 MIN	12 MIN	11 MIN	10 MIN	5 MIN
	TO 1.75 END VOLTS PER CELL																		
CX-5	0.041	0.052	0.062	0.086	0.100	0.129	0.144	0.159	0.163	0.167	0.171	0.175	0.180	0.185	0.191	0.197	0.204	0.212	0.244
CX-7	0.061	0.078	0.094	0.129	0.151	0.194	0.216	0.239	0.245	0.250	0.256	0.262	0.270	0.278	0.286	0.296	0.307	0.318	0.367
CX-9	0.082	0.105	0.125	0.172	0.201	0.259	0.288	0.319	0.326	0.334	0.342	0.350	0.360	0.370	0.382	0.395	0.409	0.424	0.489
CX-11	0.102	0.131	0.157	0.215	0.252	0.324	0.360	0.399	0.408	0.417	0.427	0.438	0.450	0.463	0.478	0.494	0.512	0.530	0.612
CX-13	0.123	0.157	0.188	0.258	0.30[illegible]	0.389	0.432	0.479	0.490	0.501	0.513	0.525	0.540	0.555	0.573	0.593	0.614	0.636	0.734
CX-15	0.143	0.184	0.220	0.302	0.353	0.453	0.503	0.559	0.571	0.584	0.598	0.613	0.630	0.648	0.669	0.692	0.717	0.742	0.857

Long term discharge lead acid batteries and most nickel cadmium batteries are sized using charts expressed in available amps for specified periods of time. The battery supplying a UPS will be delivering less current when the batter is at 120" than will be necessary as the battery discharges down to a lower voltage. Consequently, one must determine an “average current for the particular UPS. For these calculations, it is recommended that one calculate battery current based upon 104% of the final end voltage of the battery bank. For example, 60 cells with an end voltage of 1 .75V/cell will equal 105V/Bank. Consequently, 104% of 105V equals 109V. An average current will be calculated at this voltage.

Equation 5

$$\text{DC Amp} = \frac{\text{KVA x PF x 1000}}{\text{EFF x DCV}} + \text{AL}$$

KVA	=	KVA of the load
PF	=	Power factor of the load
EFF	=	Efficiency of the UPS at the given load
DCV	=	Average Discharge Voltage - For a 130 VDC system, this is 109V
AS	=	Additional loads expressed in amperes

Example Calculation:

Determine the battery required for a 20 kVA operating at full load with an efficiency of 86%, a load power factor of 0.8 and 30 amps of additional DC loads. The UPS is 130 VDC system requiring 92 cells of nickel cadmium batteries and requiring three hours of back-up time. Utilizing the preceding formula:

Equation 6

$$\text{DC Amps} = \frac{20 \text{ x } .8 \text{ x } 1000}{.86 \text{ x } 109} + 30 = 200.68 \text{ Amps}$$

The UPS manufacturer has recommended an end voltage of 105V per bank or 1.14V per cell for the 92 cell bank. Using Figure 3 for this 20 kVA UPS and additional 30 amp DC load, 92 cells of HB705P are required which will supply 213 amps for three hours.

<u>Figure 3</u>

Final voltage: 1.14 Volts per cell

Cell type	C_5 Ah	HOURS				MINUTES								SECONDS		
		8 h	5 h	3 h	2 h	90 min	60 min	30 min	20 min	15 min	10 min	5 min	1 min	30 s	5 s	1 s
HB560P	560	65.5	104	169	248	320	421	564	651	712	779	950	1412	1619	1905	1972
HB615P	615	72.0	114	186	272	352	462	619	715	782	856	1043	1551	1778	2092	2166
HB640P	640	74.9	118	193	283	366	481	645	744	814	890	1085	1614	1850	2177	2254
HB705P	705	82.5	130	213	312	403	530	710	820	897	981	1196	1778	2038	2399	2483
HB765P	765	89.5	142	231	338	438	575	770	890	973	1064	1297	1929	2212	2603	2694
HB865P	865	101	160	261	382	495	650	871	1006	1100	1203	1467	2181	2501	2943	3046
HB920P	920	108	17[illegible]	278	407	526	692	927	1070	1170	1280	1560	2320	2660	3130	3240

Battery Charger Sizing

Once a battery has been discharged, it is important to restore the battery to full charge as quickly as possible in order to be prepared for the next power outage and, in the case of all lead acid batteries, to prevent permanent damage to the battery. In general, a short term discharge battery can be recharged to 85% capacity in 8-10 times the discharge time. A long term discharge battery can be recharged to 85% capacity in a minimum of 8 hours provided the charger is sized properly.

The following formula can be used to calculate battery charger size. Assuming the UPS is a float configuration where the charger also supplies the inverter with DC power.

Equation 7

$$\text{Charger size in Amps} = \frac{I_B \times T_D \times K}{TR} + I_I + I_A$$

Where:

$$I_B = \text{Battery Current Required} = \frac{\dfrac{\text{Inverter VA x Power Factor}}{\text{DC to AC Efficiency}}}{\text{DCV}}$$

$$I_I = \text{Inverter Current Required} = \frac{\dfrac{\text{Inverter VA x Power Factor}}{\text{DC to AC Efficiency}}}{\text{Float Voltage}}$$

I_A = Any additional DC Loads in amperes

T_D = Battery Discharge (Run) Time in hours

T_R = Battery Recharge Time in hours

Example Calculation:

Determine the charger required for a 20kVA UPS with a 60 cell lead acid battery, no additional DC loads, 1 Hour backup and 8 hour recharge time.

$$I_B = \frac{\dfrac{\text{20,000VA x 0.8 PF}}{0.86}}{\text{109V}} = \text{171A}$$

$$I_I = \frac{\dfrac{\text{20,000VA x 0.8 PF}}{0.86}}{\text{130V}} = \text{143A}$$

Then: $$I_C = \frac{\text{171A x 1Hr x 1.15}}{\text{8Hr}} + \text{143A}$$

$$I_C = 24.6 + 143 = 167.6\text{Amps}$$

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