VRLA Sizing for UPS

White Paper

Introduction

An uninterruptible power supply (UPS) is an electrical device that protects critical loads such as computers, data storage, telecommunication equipment and other electronics where unexpected power interruptions could cause serious business disruption, data loss, injuries and even fatalities.

A UPS system includes a backup energy storage device, which is typically a battery. The purpose of a battery is to store energy and discharge it at a desired time.
For more than 30 years, VRLA (Valve Regulated Lead-Acid) batteries have been commonly used and dominate the UPS market. VRLA batteries are well perceived as being a mature technology solution, with high availability and low price. VRLA batteries for UPS systems are available in different sizes, capacities, supported temperature ranges, lifetime, cost, and number of charging cycles.

In order to provide continuous power when you need it most and to meet the required backup time in case of a power outage, **battery sizing matters**. The battery size determines how long will a UPS provide power to your critical loads, when the AC grid is off.

This document provides the basics to determine proper battery sizing for the best performance and value for your needs.

Battery backup time considerations

The backup time will be determined based on the required load power, battery size and the number of batteries used. In addition, several other considerations need to be taken into an account.

- Power outage likelihood
- Typical power outage length
- Backup generator availability
- In the absence of a generator, whether a continues work is required or just backup and proper systems shutdown

If a generator exists then 5-10 minutes' backup, until the generator goes into operation, might be a good fit. Without a generator, 10-30 minutes backup time is typically required. When long power outages are expected and loads are required to work continuously, a few hours of backup may be needed.

Battery strings

Normally a small power UPS runs with a single battery bank. However, as power requirements increase and systems become more critical, there is a growing demand for redundancy in the battery with more battery strings, ensuring backup even in the unlikely event of battery failure. In cases of multiple battery strings, the backup time is shared between them.If one of the battery strings malfunctions due to battery failure, serial fuse or lost connection, the remaining battery strings will continue to provide the system with backup power albeit with afor a shorter duration. This method is usually more expensive but can provide a higher degree ofsystem reliability.

Choosing a battery

Battery vendors provide specifications with discharge tables, usually for two discharge types: Constant Current & Constant Power. Constant Power discharge tables should be used for battery size calculations. Battery size selection for a required backup time, requires additional information:

- Number of batteries in series
- Number of cells in a battery (6 cells in a 12V battery)
- Minimum discharge voltage, for example: 1.75 volts per cell (varies between vendors)
- UPS inverter efficiency (DC to AC efficiency)
- Total power required and desired backup time per project

Based on this data, a calculation can be made to find the appropriate battery. The calculation is done according to the following formula for obtaining the required battery/cell at the specified backup time:

$$\text{Cell Power} = \frac{\text{Total Power}}{\text{(Number of batteries)} \times \text{(Amount of cells in battery)} \times \text{(Inverter efficiency)}}$$

Once the cell power has been calculated, based on the additional requirements, a battery can be found according to specifications in battery datasheets of approved manufacturers.

Example - Battery selection for a required backup time

Parameters of UPS type (from UPS datasheet):

- Number of batteries in series: 60
- Number of cells in battery: 6
- Minimum DC voltage: ±320V
- UPS inverter (DC/AC) efficiency: 99%

Minimum discharge voltage per cell can be easily calculated –

$$\text{Min discharge voltage per cell} = \frac{2 \times (\text{Minimum DC voltage})}{(\text{Number of Batteries}) \times (\text{Amount of cells in battery})}$$

$$\text{Minimum discharge voltage per cell} = \frac{2 \times 320}{(60) \times (6)} = 1.77$$

Minimum discharge voltage is 1.77 Volts per cell.

Parameters for a specific project:

- Total power required: 100kVA
- Backup time: 15 minutes

$$\text{Cell Power} = \frac{\text{Total Power}}{(\text{Number of Batteries}) \times (\text{Amount of cells in battery}) \times (\text{Inverter efficiency})}$$

$$\text{Cell Power} = \frac{100{,}000\text{W}}{(60 \times 6 \times 0.99)} = 280\text{W}$$

The required cell power is 280W for 15 minutes at a minimum voltage of 1.77 volts.
The next step is finding a battery that meets the above cell power specification as well as other requirements such as lifetime, flammability, etc.

In this example, we use East Penn HR3000 battery type:

Discharge Rate in Watts per Cell Ratings @ 77°F (25°C)*									
Volts per Cell (VPC)	1 Min.	5 Min.	10 Min.	15 Min	20 Min	30 Min	40 Min	50 Min	60 Min
1.60	1080	610	413	316	259	190	151	124	107
1.67	972	576	400	310	254	188	149	123	106
1.70	924	559	393	305	250	185	148	122	105
1.75	830	519	373	293	243	182	145	120	104
1.80	–	466	343	277	235	176	140	116	101

*Subject to change without notice.

The nearest minimum value in the table is 1.75 volts per cell (4th row from top). Per the defined 15 minutes backup time, the cell power value (in watts per cells) is 293W. This value is about 4% more than the required calculated value.

It should be taken into an account that because of the granularity of battery capacities, it is not always possible to find a battery at the exact required power, therefore it is generally acceptable to choose a battery with the nearest value usually upwards.

When there is a demand for redundancy in the battery, the below example shows how to choose the battery for a required backup time.

Parameters of UPS type (from UPS datasheet):

- Number of batteries in series: 60
- Number of cells in battery: 6
- Minimum DC voltage: ±320V
- UPS inverter (DC/AC) efficiency: 99%

Minimum discharge voltage can be easily calculated

$$\text{Minimum discharge voltage} = \frac{(2 \times (\text{Minimum DC voltage})}{(\text{Number of batteries}) \times (\text{Amount of cells in battery})}$$

$$\text{Minimum discharge voltage} = \frac{(2 \times 320)}{(60) \times (6)} = 1.77$$

Minimum discharge voltage is 1.77 Volts per cell

Parameters as per a specific project:

- Total power required: 420kW
- Number of strings required: 3
- Backup time: 15 minutes

$$\text{Power per battery string} = \frac{\text{Total power}}{(\text{number of strings})} = \frac{420{,}000}{3} = 140\text{kW}$$

$$\text{Cell Power} = \frac{140{,}000\text{W}}{(60 \times 6 \times 0.99)} = 392\text{W}$$

The required cell power is 392W for 15 minutes at a minimum voltage of 1.77 volts.

Next steps are searching for the battery in the vendor datasheets with the above cell power and checking all the additional requirements; design life, flammability, etc.

In this example, we use East Penn HR4000 battery type:

Discharge Rate in Watts per Cell Ratings @ 77°F (25°C)*									
Volts per Cell (VPC)	**1 Min.**	**5 Min.**	**10 Min.**	**15Min**	**20 Min**	**30 Min**	**40 Min**	**50 Min**	**60 Min**
1.60	1405	832	554	428	350	257	204	168	145
1.67	1227	780	541	420	344	254	202	167	143
1.70	1125	750	532	417	342	252	201	166	143
1.75	1027	705	506	404	335	249	198	163	140
1.80	–	640	471	381	316	237	191	159	138

*Subject to change without notice.

The nearest minimum value in the table is 1.75 volts per cell (second row from bottom). Per the defined 15 minutes backup time, the cell power (in watts per cells) is 404W. This value is about 3% more than the required calculated value. The above system will consist of 3 battery strings, each containing 60 batteries of East Penn type HR4000.

Battery Longevity

Battery longevity is directly related to the level and duration of the stress inflicted, which includes charge, discharge and temperature.

The depth of discharge (DoD) of a battery equates to the percentage of the battery that has been discharged relative to the overall capacity of the battery. A higher DoD means you can use more energy stored in the battery. The more frequently the battery is charged and discharged, the shorter its service life. It is generally not recommended to completely dischargethe battery as that will greatly reduce the battery life. Many battery manufacturers specify the recommended maximum DoD for the best battery performance.

The number of charge/discharge cycles in a battery lifecycle depends on how much battery capacity will typically be used. If the battery is regularly discharged with a lower percentage of charge, it will have more useful cycles compared to repeatedly draining the battery to its maximum DoD. For instance, a battery with 85% capacity retention may have 1,250 cycles at a DoD of 30%, or 400 cycles at a DoD of 50%, but only 250 cycles at a DoD of 80%.

Battery shelf life is the period a battery can remain in storage without losing itscapacity. During storage, when a battery is not in use, it will age and will self-discharge.

This aging is generally affected by three factors:

1. Battery type or the battery's cell chemistry (Lead-acid, Nickel-cadmium, Lithium-ion, etc.)
2. Storage temperature – higher temperatures increase the battery's self-discharge rate, and coolertemperatures decrease the self-discharge rate.
3. Period of time battery remains idle. Among rechargeable batteries, VRLA has one of the lowest self-discharge rates. It loses about 5% per month

Summary

When designing a backup solution of uninterruptible power supply system along with a battery bank, it is critical to ensure a continuous operation and a maximum power availability during a power outage. Inaccurate battery selection may cause the system not to meet the required backup specification, mainly in terms of delivering the desired backup time or battery longevity. Both could be risky to organizations and should be avoided.

All relevant battery factors for a certain project must be taken into consideration during the initial stages, such as required backup time, required energy and frequency of charging and discharging the battery.