Battery Charging Terminology

Battery Charging Topology

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There are three main categories of rechargeable batteries available.

Automotive batteries
Used to supply primary power to start engines on cars, boats and other vehicles. They provide a short burst of high current to get the engine started.

Standby/industrial batteries
Designed to be permanently connected in parallel with a critical load and a rectifier/charger system, where the rectifier/charger forms the primary source of power for the load and the battery provides the secondary source in the event of a primary source failure.

Portable batteries
Designed to power portable equipment such as consumer products and tools such as drills, mobile phones, laptop computers and so on.

The latter two categories can be further broken down by the chemistries used in the construction of the battery.

> **Nickel-cadmium (NiCd) (vented & semi-sealed)** - mature but have moderate energy density. Nickel-cadmium batteries have generally been used where long life, high discharge rate and extended temperature range is important. Nickel-cadmium batteries contain toxic metals and are generally being phased out.
>
> **Nickel-metal-hydride (NiMH)** - have a higher energy density compared to nickel-cadmium at the expense of reduced cycle life. Contain no toxic metals.
>
> **Lithium-ion (Li-ion)**- fastest growing battery technology offering high energy density and low weight. Requires protection circuits to limit voltage and current for safety reasons.
>
> **Lead-acid (vented & valve-regulated) batteries**
> Most economical for larger power applications where weight is of little concern.

One of the main differences between the above battery types is the initial purchase cost of the battery. However, when selecting a battery, the initial cost can give a very misleading impression of the total cost to the user during the system's lifetime.

The selection of a battery based on cost alone can have a major impact on the life cycle cost of the system being supported due to such factors as installation, replacement, maintenance, testing and downtime cost.

In many instances, the selection of the most suitable battery for a particular application can be a very complex calculation that can only be performed by the end user as a number of the factors relating to life cycle cost are outside the control of the battery supplier maintenance for example. However, some basic logic can be applied by the supplier assuming some data has been provided, including location and access to site, site ambient temperature and the nature of the application. It would be logical to select a nickel-cadmium battery for a remote unmanned site in the Middle East with an ambient temperature of 45°C during the day and 5°C at night, where the load being supported is vital to the production of oil. However, if the equipment was to be housed within an air-conditioned room in a well-maintained oil production facility it would be reasonable to utilize valve-regulated lead acid batteries.

Terms Associated with Standby Batteries

Cell A cell comprises a number of positive and negative charged plates immersed in an electrolyte that produces an electrical charge by means of an electrochemical reaction. Lead acid cells generally produce an electrical potential of 2V while Nickel-cadmium cells generally produce an electrical potential of 1.2V.

Battery A battery is a number of cells connected together.

String/bank A battery string or bank comprises a number of cells/batteries connected in series to produce a battery or battery string with the required usable voltage/potential e.g. 6V, 12V, 24V, 48V, 110V.

Ah The Ah or Ampere/hour capacity is the current a battery can provide over a specified period of time, e.g. 100Ah @ C10 rate to EOD of 1.75V/cell. This means the battery can provide 10 Amps for 10 hours to an end of discharge voltage of 1.75V per cell.

Different battery manufacturers will use different Cxx rates depending on the market or application at which their batteries are targeted. Typical rates used are C3, C5, C8, C10 and C20. Because of this it is important, when comparing batteries from different manufacturers having the same Ah rate, to confirm on what Cxx rate this figure is based.

Example:
An application requires a 100Ah battery at the C3 rate, based on a load profile of 33 Amps for 3 hours to an end discharge of 1.8V per cell. However, when two battery manufacturers are asked to tender for this project, the only data they are given is that a 100Ah battery is required.

		Standby Time (Hrs)							
		1	**2**	**3**	**5**	**8**	**10**	**12**	**20**
Manufacturer 'A'	**Current**	80.9	47.4	**35.0**	23.2	16.2	13.57	11.4	5.9
	Ah (Cxx rate)	80.9	94.8	**105.0**	116.0	129.6	135.7	136.8	138.0
Manufacturer 'B'	**Current**	66.9	38.5	27.7	18.2	12.3	**10.2**	8.6	5.77
	Ah (Cxx rate)	66.9	77.0	83.1	91.0	98.4	**102.0**	103.2	115.4

As can be seen above, both manufacturers can offer a 100Ah battery based on the limited specification provided, but only the battery from manufacturer A is capable of supporting the intended load profile.

Manufacturer A - 105Ah @ C3 Rate to 1.8V/cell (i.e. 3 hour discharge rate)
Manufacturer B - 102Ah @ C10 Rate to 1.8V/cell (i.e. 10 hour discharge rate)

EOD voltage End of discharge voltage is the level to which the battery string voltage or cell voltage is allowed to fall to before affecting the load i.e. 1.75V or 21V on a nominal 24V system.

End of life factor This is a factor included within the battery sizing calculation to ensure the battery is able to support the full load at the end of the battery design life, calculated by multiplying Ah by 1.25.

Temperature derate factor As the energy stored within a battery cell is the result of an electrochemical reaction, any change in the electrolyte temperature has an effect on the efficiency or rate of reaction. i.e. an increase in temperature increases the efficiency/rate whereas a decrease in temperature reduces the efficiency/rate of reaction. As a result of this, all battery manufacturers' discharge data will be specified at a recommended temperature (typically 20-25°C) with temperature corrections provided for operation above and below these values.

Typical temperature correction factors for Valve Regulated Lead Acid (VRLA) batteries

Discharge/ charge rate duration	Temperature Correction Factors to be applied to 20°C data at:								
	0°C	**5°C**	**10°C**	**15°C**	**20°C**	**25°C**	**30°C**	**35°C**	**40°C**
5 minutes to 59 minutes	0.800	0.860	0.910	0.960	1.000	1.037	1.063	1.085	1.100
1 hour to 24 hours	0.860	0.900	0.930	0.970	1.000	1.028	1.050	1.630	1.070

Typical reduction in design life against temperature

	Temperature						
	20°C	**25°C**	**30°C**	**35°C**	**40°C**	**45°C**	**50°C**
% Expected Float Life	100%	100%	80%	60%	40%	20%	10%

High temperatures will reduce the service life of VRLA batteries dramatically and can, in extreme cases, cause thermal runaway, resulting in high oxygen or hydrogen gas production and battery swelling. Batteries will not recover from this condition and must be replaced.

Temperature compensation As previously detailed, the energy stored within a battery cell is the result of an electrochemical reaction, so any change in the electrolyte temperature has an effect on the rate of reaction provided all other factors (charge voltage and current) relating to the reaction remain constant.

Therefore, if we alter these factors to compensate for the effect of temperature, we can minimize the effect of temperature on battery life by maintaining the amount of gas evolved within a VRLA or semi-sealed nickel cadmium battery to approximately the normal operating limit.

The simplest way of maintaining the rate of reaction within design parameters is to alter the charge voltage at a rate proportional to the change in temperature, i.e. decrease the charge voltage with an increase in temperature above 20-25°C and increase the charge voltage with a decrease in temperature below 20-25°C. The typical change in charge voltage is 3 mV / °C.

Boost charge Charge given to a battery to correct voltage imbalance between individual cells and to restore the battery to fully charged state.

Charge The process of replenishing or replacing the electrical charge in a rechargeable cell or battery.

Cycle life The number of cycles (charge/discharge) a battery provides before it is no longer usable. A battery is considered non-usable if its nominal capacity falls below 60 to 80 percent.

Electrolyte A non-metallic conductor of electricity between the positive and negative electrodes of a battery. The current is carried by the physical movement of ions.

Equalize charge *See Boost charge.*

Fast charge Term generally associated with NiCd batteries. The typical fast charge time is between one and three hours. The fast-charger detects the state of charge and switches to trickle charge when full charge is reached.

Float charge Similar to trickle charge. Compensates for the self-discharge of a lead acid battery.

Memory Reversible capacity loss in NiCd and NiMH batteries. The modern definition of memory commonly refers to a change in crystalline formation from the desirable small size to a large size. Memory is often used to describe any reversible capacity loss on nickel-based batteries.

Nominal voltage The cell voltage that is accepted as an industrial standard. (Cell voltages of 1.20 and 1.25V are used for NiCd and NiMH batteries).

Quick charger A charger that charges a battery in three to six hours.

Rapid charger Same terminology as quick charger.

Self-discharge	Capacity loss during storage due to the internal leakage between the positive and negative cell plates.
Slow charge	Typically an over-night charge lasting 10 to 16 hours at a charge current of 0.1CA (0.1 x Ah capacity in Amps). The battery does not require instant removal when fully charged.
Thermal runaway	A condition whereby an electrochemical cell will overheat and destroy itself through internal heat generation. This may be caused by overcharge or high current discharge and other abusive conditions.
Trickle charge	Maintenance charge to compensate for the battery's self-discharge.

Minimum information required to select and size a battery

In order to size a standby battery the following data is generally required:

System nominal voltage. The nominal voltage that the load requires e.g. 24V, 48V.

Load rating. Either current or power taken by the load during normal & primary power source failure. If load rating is given in Watts, the battery should not be sized by dividing the nominal voltage to convert to Amps as the specified battery will be too small to support the load for the required standby period.

Battery standby or autonomy time.

Load voltage limits. The voltage range over which the load will safely operate. Load voltage limits need to be evaluated to determine whether the system will need some form of DC/DC converter/regulator between the load and battery to protect the load from over or under voltage due to the voltage range of battery.

Normal operating or ambient temperature in which the battery will be operating.

Battery type.

Battery Sizing Constant Current Method

The following example demonstrates how a battery is sized using the constant current calculation method. This method is not recommended where DC-DC converters are utilized as the load.

A 24V control system requires 50 Amps constant current and operates satisfactorily down to a minimum of 21V. The battery is required to support the load in the event of a mains failure for 2 hours in an ambient temperature of 20°C.The battery will be housed within the main equipment panel, which will be located within the site’s main control room.

As the battery is to be used in a controlled environment, the most cost-effective solution would be to use twelve VRLA cells. The following calculation can be used:

Minimum allowable volts per cell = minimum voltage/number of cells
= 21V/12 cells
= 1.75V/cell

Cell performance required is 50 Amps constant current to 1.75V/cell.

By referring to the sample constant current performance table below relating to 1.75 Volts per cell, it can be seen that cell type “F” is the smallest available to perform the standby duty required.

If the specification is now modified so that the system is operating in an outdoor enclosure where the ambient temperature during the winter is known to fall to 0°C and the sizing is checked again using the temperature correction factor table, it is found that:

At 0°C the current available from cell type ‘F’ is reduced to 55 A x 0.86 = 47.3 A, and hence too low.

The next cell size “G” at 0°C has available 75.2 A x 0.86 = 64.6 A. The revised battery selection should comprise 12 x “G” cells.

Discharge Currents (Amperes Per Cell) at 20°C to 1.75V/Cell

Cell Type	Standby Time (Hrs)							
	1	2	3	5	8	10	12	24
A	12.70	7.40	5.40	3.50	2.40	1.97	1.66	0.85
B	25.30	14.80	10.70	7.00	4.80	3.90	3.30	1.70
C	38.00	22.30	16.10	10.50	7.00	6.00	4.80	2.54
D	71.30	41.40	30.40	20.00	14.00	11.80	9.80	5.10
F	95.00	55.10	40.40	26.80	18.70	15.50	13.20	6.80
G	131.00	75.20	55.50	36.60	25.40	21.40	18.10	9.40
H	143.00	82.70	60.80	40.30	28.10	23.40	19.80	10.20

Discharge/ charge rate duration	Temperature Correction Factors to be applied to 20°C data at:								
	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
5 minutes to 59 minutes	0.800	0.860	0.910	0.960	1.000	1.037	1.063	1.085	1.100
1 hour to 24 hours	0.860	0.900	0.930	0.970	1.000	1.028	1.050	1.630	1.070

Battery Sizing Constant Power Method

The following example demonstrates how to size a battery using the constant power calculation method. Recommended for DC-DC converter loads.

Example A

A 110V sub-station control system requires 5kW constant power and operates satisfactorily at a minimum voltage of 94.2V. Under full load conditions there is approximately 3V drop between the battery and the control panel input terminals due to cable resistance. A battery is required to support the load in the event of a mains failure for an eight hour standby period in an ambient temperature of 20°C. The batteries will be housed within a separate battery room.

Based on the above, either VRLA or vented lead acid cells could be used.

Minimum allowable volts per cell	**=**	**min Voltage/no. cells**
	=	**(94.2+3V)/54 cells**
	=	**1.8V/cell**
Watts per cell	**=**	**total Watts/no. cells**
	=	**5000/54 cells**
	=	**92.59W/cell**

Cell performance required is 92.59 W/cell constant power to 1.8 V/cell.

By referring to the sample constant power performance table below relating to 1.8 Volts per cell, it can be seen that cell type 'F' is the smallest available to perform the standby duty required.

Discharge Power (Watts Per Cell) at 20°C to 1.8V/Cell

Cell Type	Standby Time (Hrs)							
	1	2	3	5	8	10	12	24
A	194.0	115.0	85.0	57.7	40.1	32.2	27.5	14.5
B	266.0	158.0	115.0	77.1	54.0	45.0	38.1	19.8
C	361.0	212.0	154.0	103.0	73.0	60.0	51.0	26.0
D	390.0	234.0	170.0	117.0	82.0	68.0	58.0	31.4
F	439.0	263.0	191.0	131.0	93.0	77.0	66.0	35.0
G	541.0	330.0	239.0	163.0	124.0	96.4	82.1	44.1
H	563.0	356.0	264.0	180.0	125.0	103.0	87.0	48.0

Battery Charging

The time taken to recharge any battery is dependent on the voltage and current applied. If the recharge current or voltage is too low, then the recharge time will be relatively long; if the current or voltage is high then the recharge time will be short.

However, as all batteries involve an electrochemical reaction, care must be taken to ensure the charging characteristics of both battery and charger are matched correctly.

These unique needs must be met to obtain reliable service and long life. The table below summarizes the general need of each battery type and advises proper handling of each battery type.

Optimal handling may not always be practical. Deviations from the ideal are acceptable but will lower the life expectancy of the battery to some degree, heat being the greater detrimental factor.

Charging
Nickel-cadmium (NiCd) Fully discharge the battery before charging. Do not leave battery in charger for more than two days because of memory effect. Avoid getting battery too hot during charge. **Charge methods:** Constant current, followed by trickle charge when full. Fast-charge preferred over slow charge. Slow charge = 16h, Rapid charge = 3h, Fast charge = 1h+
Nickel-metal-hydride (NiMH) Discharge every three months. Over-cycling is not advised. Do not leave battery in charger for more than two days because of memory effect. Avoid getting battery too hot during charge. **Charge methods:** Constant current, followed by trickle charge when full. Slow charge not recommended. Battery will get warm towards full charge. Rapid charge = 3h, Fast charge = 1h+
Lithium-ion (Li-ion) Charge the battery often. The battery lasts longer with partial rather than full discharges. Do not use if the pack gets hot during charge. **Charge methods:** Constant voltage to 4.20V/cell (typical). No trickle-charge when full. Li-ion may remain in the charger (no memory). Battery must remain cool. No fast-charge possible. Rapid charge = 3h
Lead-acid (Sealed or flooded) Charge the battery immediately after use. Lead-acid must always be kept in a charged condition. The battery lasts longer with partial rather than full discharges. Over-cycling is not advised. **Charge methods:** Constant voltage to 2.40/cell (typical), followed by float held at 2.25V/cell. Battery must remain cool. Fast charge not possible; can remain on float charge. Slow charge = 24h, Rapid charge = 10h

Discharging
Nickel-cadmium (NiCd) NiCd is one of the most hardy and durable chemistries and is not harmed by a full discharge cycle.
Nickel-metal-hydride (NiMH) Avoid too many full discharge cycles because of wear. Use 80% depth-of-discharge. NiMH has higher energy density than NiCd at the expense of shorter cycle life.
Lithium-ion (Li-ion) Avoid full cycle because of wear. 80% depth-of-discharge recommended. Recharge more often. Avoid full discharge. Low voltage may cut off safety circuit.
Lead-acid (Sealed or flooded) Avoid full cycle because of wear. 80% depth-of-discharge recommended. Low energy density generally limits the use of lead-acid batteries to automotive and fixed standby applications.
Service needs
Nickel-cadmium (NiCd) Discharge to 1V/cell every 1 to 2 months to prevent memory.
Nickel-metal-hydride (NiMH) Discharge to 1V/cell every 3 months to prevent memory.
Lithium-ion (Li-ion) No maintenance needed. Loses capacity due to aging whether used or not.
Lead-acid (Sealed or flooded) Apply topping charge every 6 months. Occasional discharge/charge may improve performance.
Storage
Nickel-cadmium (NiCd) Best to store at 40% charge in a cool place. Open terminal voltage cannot determine state-of charge. 5 years and longer storage possible. Recharge battery if stored longer than 6 months.
Nickel-metal-hydride (NiMH) Store at 40% charge in a cool place. Open terminal voltage cannot determine state-of-charge. Recharge battery if stored longer than 6 months.
Lithium-ion (Li-ion) Store at 40% charge in a cool place (40% state-of-charge reads 3.75-3.80V/cell at open terminal). Do not store at full charge and at warm temperatures because of accelerated aging.
Lead-acid (Sealed or flooded) Store fully charged. Apply topping-up charge every 6 weeks.
Disposal
Nickel-cadmium (NiCd) Do not dispose of; contains toxic metals; must be recycled.
Nickel-metal-hydride (NiMH) Should be recycled. Low volume household NiMH may be disposed of.
Lithium-ion (Li-ion) Should be recycled. Low volume household Li-ion may be disposed of.
Lead-acid (Sealed or flooded) Do not dispose of; must be recycled.

Contact Amtex for battery chargers