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Rechargeable Batteries used in Portable Electronic Devices

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Abstract: Technological advancement and need have produced number of widely used Portable Electronic Devices (PEDs) such as mobile phones, laptops, tablets and wearable electronic devices. Ability of these devices to collect, process and disseminate information, has brought great convenience in every field of life. For their working, these PEDs require stable operating, safe, efficient, large capacity and long-life energy sources for which rechargeable batteries are used. Rapid development and higher requirements of PEDs have led to progress of battery technology from lead acid to nickel cadmium (NiCd), to nickel metal hydride (Ni-MH), to lithium-ion (Li-ion) batteries. This paper reviews various parameters and development of these rechargeable batteries over the time.

Keywords: PED, rechargeable battery, lead acid, NiCd, Ni-MH, Li-ion.

I. INTRODUCTION

Nowadays, information is playing vital role in every aspect of life. Individual person as well as organizations are having information which is required to be collected, stored, processed and transmitted in timely and efficient manner. To meet these requirements, a number of portable electronic devices (PEDs) such as mobile phones, laptops, tablets and wearable electronic devices have been developed. With the development and innovation in electronic technology, these devices are rapidly growing. Ability of these devices to integrate and interact with a human, have brought great convenience, epoch-making changes and even becoming indispensable part for almost every person.

To guarantee desired performance of PEDs; use of stable operating, safe, efficient, large capacity and long-life energy sources is strongly recommended in PEDs. Electrochemical energy storage systems, especially rechargeable batteries have been widely used as energy sources in PEDs for decades [1]. To support rapid development and high requirements of PEDs, rechargeable batteries have also been gone through significant improvements leading to increase in specific energy and specific power.

Rapidly developing and multifunctional PEDs requires batteries with larger capacity, smaller volume, lighter weight and longer operational time. However due to limited energy storage capacity, short cycle life and high self-discharge of present batteries, it is challenging to satisfy the ever-increasing demands of PEDs. To improve performance of batteries, great efforts have been made. Considering the critical role of battery technologies for development of PEDs, study of rechargeable batteries is important. In this connection; section 2 deals with important parameters related to battery; section 3 reviews four types of representative rechargeable batteries and section 4 concludes the paper.

II. BATTERY PARAMETERS

Following are the various parameters related to rechargeable batteries [2-4].

- Energy storage capacity-
  It determines the number of hours for which the battery can be discharged at a constant current to a defined cut-off voltage. The value of this capacity depends on the ambient temperature, the age of the battery, and the discharge rate. The higher the discharge rate, the lower the capacity and vice versa. It is defined in Watt-hours (Wh)
- Specific energy-
  Specific energy is the amount of electrical energy stored for every kilogram of battery mass. It has units of Wh.kg−1.

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- Specific power-
  Specific power is the amount of power obtained per kilogram of battery. It is a highly variable and rather anomalous quantity, since the power given out by the battery depends far more upon the load connected to it than the battery itself.
- Energy density-
  Energy density is the amount of electrical energy stored per cubic metre of battery volume. It normally has units of Wh.m−3.
- Self-discharge rate-
  This parameter defines the reduction in energy capacity of the battery under no-load conditions (e.g., open circuit), as a result of internal short-circuits and chemical reactions. This is important as it means some batteries cannot be left for long periods without recharging. The rate varies with battery type, and with other factors such as humidity, temperature; higher temperatures greatly increase self-discharge.
- Cycle life-
  The cycle life determines the number of charge/discharge cycles that the battery can experience before it reaches a predetermined energy capacity or other performance criteria. The current rate at which the battery is charged/discharged as well as environmental conditions (e.g., temperature and humidity) can affect this number.

III. RECHARGEABLE BATTERIES

PEDs have developed rapidly along with progressive improvement of rechargeable batteries. PEDs have incorporated several different types of rechargeable batteries including lead acid, nickel cadmium, nickel-metal hydride and lithium-ion batteries. Table 1 shows key characteristics of these four types of batteries. Each type of these batteries is discussed in following sections.

A. Lead acid battery

The lead-acid is the oldest type of rechargeable battery. It was invented by French physicist Gaston Planté in 1859 [1]. In lead acid battery lead, lead dioxide and concentrated sulphuric acid are used as anode, cathode and electrolyte respectively. The sulphuric acid combines with the lead and the lead oxide to produce lead sulphate and water, electrical energy being released during the process. The overall reversible reaction is:

$$Pb + PbO_2 + 2\ H_2SO_4 \leftrightarrow 2\ PbSO_4 + 2\ H_2O$$

When lead acid battery is fully discharged, anode and cathode become lead sulphate and electrolyte becomes water. In fully charges state, anode and cathode become lead and lead dioxide and electrolyte turns back to concentrated sulphuric acid. Lead acid batteries are of two types, sealed lead acid battery and valve-regulated lead acid battery.

Energy density of lead acid batteries is low so they have large size and heavy weight. However specific power of these batteries is relatively large which makes it possible to supply high discharge currents [5]. Though these are oldest types of batteries, due to low cost, low self-discharge rate, these batteries are till used widely not only in PEDs but also automobiles, forklifts and other vehicles. Limitations of lead acid batteries include short lifetime, slow charge rates and toxic for human and environment. Lowest specific energy limits their use in PEDs.

TABLE I Characteristics of Rechargeable Batteries used in PEDs [1]

Characteristics	**Lead acid battery**	**Nickel Cadmium battery**	**Nickel-Metal Hydride battery**	**Lithium-ion battery**
Volumetric Energy density (Wh/L)	60-110	150-190	140-300	350-700
Specific energy (Wh/Kg)	30-50	40-60	60-120	170-250
Battery voltage (V)	2.0	1.2	1.2	3.7
Cycle life (to 80% initial capacity)	300	1500	1000	500-2000
Self-discharge per month (%)	5	20	30	<10
Fast charging time (h)	8-16	1	1-4	1 or less
Toxicity	High	High	Low	Low
Overcharge tolerance	High	Moderate	Low	Low
Operating temperature range (^{0}C)	-20 to 60	-40 to 60	-20 to 60	-20 to 60
In use since	Late 1800s	1950	1990	1991

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B. Nickel Cadmium Batteries

The Ni-Cd battery was invented by Waldemar Jungner in 1899 [1]. In this battery cadmium is used as anode, nickel hydroxide is used as cathode and potassium hydroxide is used as electrolyte. It operates on the principle of redox reaction between cadmium and nickel hydroxide. The overall reversible reaction is:

$$2\ NiO(OH) + Cd + 2H_2O \leftrightarrow 2\ Ni(OH)_2 + Cd(OH)_2$$

Due to their low internal resistance and the very good current conducting properties, NiCd batteries can supply extremely high currents and can be recharged rapidly [6]. These cells are capable of sustaining temperatures down to -20°C. The advantages of NiCd batteries over lead acid battery include longer lifetime, attractive low-temperature performances, higher charge-discharge rates, and versatile in size. Small sealed portable types to large vented cell types NiCd batteries are available. Due to these advantages, NiCd batteries were used earlier in PEDs like mobile phones, video camera, radio laptop flash lights [1].

Limitations of NiCd batteries are high self-discharge rate; cadmium is expensive, heavy metal and highly toxic which raises significant environmental concerns. One more major drawback is dreaded memory effect where battery is not fully discharged before recharging or battery is not used for some time, battery loses its maximum energy capacity gradually. This limits their use in applications where battery is frequently recharged after being partially discharged. After development of nickel-metal hydride and lithium-ion batteries, use of NiCd batteries decreased significantly.

C. Nickel-metal hydride batteries

Like NiCd batteries, in Ni-MH batteries nickel hydroxide is used as cathode and potassium hydroxide is used as electrolyte. However, instead of cadmium, hydrogen absorbing alloy is used as anode in Ni-MH batteries. The overall reversible electrochemical reaction in Ni-MH battery is

$$NiO(OH) + MH \leftrightarrow Ni(OH)_2 + M$$

Since cadmium is not used, NiMH batteries are less expensive and eco-friendly than NiCd batteries. As compared to NiCd batteries, Ni-MH batteries have superior cycle life, excellence performance over larger operating temperature range, high energy density, high charge rates, minimal memory effect. Ni-MH batteries have fast charging ability. Due to these advantages, NiCd batteries were replaced by Ni-MH batteries.

The major drawback of Ni-MH batteries is high self-discharge rate. Ni-MH would lose nearly 30% of charge in a month. This self-discharge rate increases further at increasing operating temperatures. In recent years, due to development of lithium-ion batteries, usage of Ni-MH batteries is decreased drastically.

D. Lithium-ion batteries

Nowadays Li-ion batteries are most widely used in PEDs. In Li-ion batteries, the anode is made of graphite; while for cathode metal oxides such as Lithium cobalt oxides, Lithium iron phosphates, and Lithium manganese oxides are used as main components. In conventional Li-ion batteries, liquid electrolyte used are lithium salts like Lithium perchlorate, Lithium tetrafluoroborate, or Lithium hexafluorophosphate dissolve in organic solvents, such as diethyl carbonate, ethylene carbonate, or dimethyl carbonate [1]. In Li-ion polymer batteries, liquid electrolyte is replaced by polymer electrolytes. A high-conductivity gel containing lithium salts is used as polymer electrolyte. When lithium cobalt oxide (LiCoO2) and graphite (C) are used as cathode and anode, the overall reversible electrochemical reaction is given by

$$LiCoO_2 + C \leftrightarrow Li_{1-x}CoO_2 + Li_xC$$

During discharge process, lithium ions move from the anode to the cathode and are intercalated (inserted) into voids in the crystallographic structure of the cathode. The ions reverse direction during charging process. Since lithium ions are intercalated into host materials during charge or discharge, there is no free lithium metal within a lithium-ion cell.

The Li-ion batteries have number of advantages such as high specific energy, low self-discharge rate, high voltage, maintenance free, lightweight, good safety and excellent cycling performance. These advantages have made Li-ion batteries as best option for PEDs like mobile phones, laptops, digital cameras. These batteries are also used in military, electric vehicle and aerospace applications. Also, thin and customizable shape of Li-ion polymer batteries makes them suitable for ultra-slim laptops, mobile phones, tablets and wearable electronic devices.

Drawbacks of Li-ion batteries include higher prices due to higher manufacturing costs, additional protection circuit required to limit voltages and currents to ensure safe operations, and decrease in capacity and cycle life when stored in

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temperatures over 300C for an extended period. Significant efforts are going on to address these drawbacks of Li-ion batteries.

IV. CONCLUSION

Today PEDs are used in every aspect of life to collect, process and disseminate information which brings great convenience in everyday life. The performance and development of PEDs is becoming more sensitive to their energy consumption which depends on energy storage components that is batteries. The increasing demand for high performance batteries have witnessed progress of commercial batteries from lead acid to Ni-Cd, to Ni-MH to Li-ion batteries. The development in battery technology promoted rapid growth of PEDs. To satisfy higher requirements of rechargeable batteries in PEDS, significant research efforts are being carried to improve existing battery technology using new materials, advanced techniques as well as research in exploring new battery systems is also going on.

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