Recharging Batteries for Autonomous Sailboat System

Introduction

Motivated mainly by latest energy sources such as the wave and the wind, autonomous sailboat system explores the viability of types of supply resource that are both economical and environmental-friendly. The electrical energy is the direct supply for motor and controller. Transforming other types of energy into electricity requires several storage elements that are highly efficient, environmental-friendly and lightweight. Chemical batteries, such as NiMH, Li-ion, and simple sea batteries, are the most appropriate choices for sailboat system. This technical review briefly summarizes some commercial and research battery choices for autonomous sailboat system, illustrates underlying technologies applied, and provides approaches of implementation for ideal operation.

Commercial and Research Choices of Batteries

The traditional Nickel-metal hydride (NiMH) and Lithium-ion (Li-ion) batteries are the most appropriate choices for the small sailboat system. Both of them are environmental-friendly and have no memory effect that refers to holding less charge after repeatedly recharging while being only partially discharged. They are perfect for storing energy supplied from the wind and the sun. Another type, broadly used in small projects for research, is the seawater battery that can store and transfer energy from seawater immediately. Therefore, it can be used to transform wave energy when the boat is moving.

NiMH Battery

Most small-sailboat teams used NiMH battery due to its simple implementation and low price [1-3]. It can be directly utilized through the connection, and has a voltage of 1.2 V, efficiency of 65-70%, typical specific energy of 60-120 Wh/kg, and a volumetric energy density of 140-200 Wh/L [4]. Panasonic "Eneloop" series battery can have a lifetime up to 2100 cycles [5]. The problem of high self-discharge was solved by Sanyo in 2005 with low self-discharge NiMH (LSD NiMH), and therefore it could be a competitor with Li-ion for boat system. Besides, the price has an advantage, typical 8-piece C-size NiMH rechargeable cell with 1.2 V and 5 Ah costs $30, while the 4-piece LiFePO4 with 3.6 V and 650 mAh costs $40 with protected circuit components [6-8].

Li-ion Battery

Li-ion battery is chosen due to stronger characteristics than those of NiMH. It has a voltage of 3.6-3.7 V, efficiency of 90-95%, specific energy of 100-265 Wh/kg, and higher energy density [9-11]. Among various types of Li-ion batteries, $LiCoO_2$ has the highest energy density of more than 200 Wh/kg, and it is the most popular cell used in the market. However, it is unsafe without protection circuit (PC) and has a relatively low life cycles around 500. $LiFePO_4$ is another type of Li-ion battery that has more than 2000 cycles of life, but it has relatively lower energy density of 120 Wh/kg [10]. The $LiFePO_4$ cells are still in developing, and most of them are required to be industrial used only [12].

Seawater Battery

Some research teams have found seawater battery, which could draw electricity from seawater for free [13,14]. It is composed of magnesium as the anode, graphite as the cathode, and seawater as the electrolyte. The battery drives the output as long as it is in the sea. It has the simplest set-up, and provides constant propulsion for the boat. The cost is low for building one with basic connection. A one-foot magnesium anode with 0.5 inch diameter costs $4.03, and a one-foot graphite rod with 0.4 inch diameter costs $4 [15,16]. Thus, the seawater battery is the best approach for the sea-wave energy transformation.

Technology of basic batteries

Functionality

The basic recharging batteries transform the electrical to chemical energy during charging, and the process is reversed while discharging. During discharging, the positive active material is oxidized, while the negative material is reduced. Electrons constitute the current flow in external circuit, while the electrolyte serves as a bridge for ion-flow between electrodes. The process for both electrodes reverses while recharging.

Structure and Protection

In NiMH battery, the cathode is nickel oxyhydroxide (NiOOH), and the anode is a hydrogen-absorbing alloy such as TiZr and $LaNi_5$ [17]. When the battery is overcharged at low rates, oxygen produced at the cathode recombines at the anode, suppressing hydrogen evolution and converting charging energy to heat. This process allows cells to remain sealed in normal operation. In Li-ion battery, the cathode is an intercalated lithium compound such as $LiFePO_4$ or $LiCoO_2$, and the anode is graphite for most cases. The electrolyte is a lithium salt in an organic solvent [18,19]. Since lithium is highly reactive with water, a non-aqueous electrolyte is applied. Therefore, it is significant to have an excellent sealed container that excludes moisture leaked by the battery for application in seawater. Particularly, the most concerned risk is that if over-charged, Li-ion battery will suffer thermal runaway and cell rupture that cause combustion, and therefore a protected circuit is required for disconnection when the voltage exceeds 3-4.2 V safety range [8,20]. The structure for seawater battery is the simplest. It is composed of magnesium alloy and graphite electrodes, while the electrolyte is the seawater.

Implementation

Due to the simplest setup and direct supply from seawater, seawater battery is an ideal choice for wave energy transformation. It can be directly connected to propeller for propulsion. The NiMH and $LiFePO_4$ batteries are both ideal choices for transformation of other types of energy sources depend on the system requirements. NiMH battery can be directly utilized and can be over-charged at low rates. Li-ion battery requires a complex protected circuit board for safety consideration, which enhances the complexity of the design. The input of batteries is connected to the conditioning circuit that transforms renewable energy into stable electrical current and voltage. Typical conditioning circuit is composed of a converter, and its output should be applicable to battery other than super capacitor. The output goes to the motor and single-board computer that controls sensors for movements of the sailboat.

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