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Research and Application of Supercapacitor Charging System

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Abstract

Based on the special power supply requirements of the project, the AD8210YRZ (current monitoring operational amplifier) monitors the charging current in real time, and its output is fed back to the detection pin of the TPS5430DDA to adjust the charging voltage of the capacitor. Combined with the charge-discharge characteristics of the super capacitor, the circuit realizes high current constant current charging at low voltage and constant voltage charging when the capacitor terminal voltage increases. This method can effectively and reasonably improve the charging efficiency of the super capacitor and meet the design requirements. The product has been put into use and achieved good results.

Subject Areas

Mechanical Engineering

Keywords

Super Capacitor, Charging Circuit, Project Verification

1. Introduction

There are four traditional rechargeable batteries [1], which include lead-acid batteries, nickel cadmium batteries, nickel hydrogen batteries and nickel cadmium batteries. Nickel-cadmium battery has obvious "memory effect" phenomenon, basically eliminated. Nickel-hydrogen battery has high self-discharge rate and poor high temperature performance. Lead acid battery life is short, and cannot be charged with high current. All above all do not satisfy the project special working condition and strict working environment. In view of the good characteristics of the super capacitor, the super capacitor is used as the power supply battery. Supercapacitors are mainly divided into two types: double layer supercapacitors, pseudo-capacitor supercapacitors and so on. This project uses pseudo-capacitor supercapacitors, that is, Farah capacitors, which has following characteristics:

1) The charging speed is fast, and it can reach more than 95% of its rated capacity after charging for 10 seconds to 10 minutes.

2) Long cycle life, depth of charge and discharge cycles can reach 1 to 500,000 times. There is no "memory effect".

3) High current discharge capability, high energy conversion efficiency, low process loss, high current energy cycle efficiency ≥ 90%.

4) The raw material composition, production, use, storage and dismantling process of the product are all free of pollution, and it is an ideal green power supply.

5) Good temperature characteristics, wide temperature range −40˚C - +70˚C; to meet the needs of the project standby power supply.

Current super capacitor conventional charging methods [2]. a) Constant voltage charging method: in the charging process, the method of charging voltage is always called the constant voltage charging method. The advantage of this method is that it can avoid the loss of the active material of the plate and the loss of electric energy due to the excessive charging current in the later period of charging. The disadvantage is that the charging current is too large at the beginning of charging, which makes it easy to bend the capacitor plate and cause the capacitor to be scrapped. b) Constant-current charging method: in the charging process, the charging current is always the same method called the constant current charging method. This method makes the capacitor charging time shortened. In the maximum allowable charging current range, the greater the charging current, the shorter the charging time. However, if the charging current is kept at the same level during the later period of charging, the electrolyte will precipitate excessive bubbles and appear boiling. This not only wastes power, but also easily causes the temperature of the battery to rise too high, causing the storage capacity of the capacitor to decline and be discarded in advance. c) Current-mode PWM control charging. This kind of charging method increases the terminal voltage of the supercapacitor in real-time and analyzes and processes the PWM signal to change the charging current. It can improve the charging efficiency, but its disadvantage is the need for MCU intervention, and the circuit is complex and costly. Therefore, a simple and practical charging scheme was designed for the project.

2. Requirements Analysis and Design

Demand Analysis

The intelligent management system of hydraulic grabs enables customers and producers to monitor the working status of the hydraulic grabs and monitor and count the operating parameters. The on-site monitoring and control system module has a built-in power supply processing circuit and outputs it to related sensors, actuators, and other monitoring and control units that require power supply. The on-site monitoring system module power supply mode is shown in Figure 1.

The external power supply is turned on when the hydraulic grapple starts to operate, and the external power supply is turned off when the grab stops working. In order to enable the continuous transfer of the grabbing operating parameters to the control room monitoring end, backup power is required. According to the site's operating conditions, complete a work cycle. Grabs complete a grab action of 30s and a stop time of 150s (Table 1).

C (F): Supercapacitor nominal capacity

ESR (Ohms): Equivalent series resistance under 1 KZ

V_{work} (V): normal working voltage V_{min} (V): Cut-off voltage;

t (s): Continuous working time is required in the circuit I(A): Load current

The approximate formula for the capacity of supercapacitors. Maintaining the required energy equals the reduced energy of the super capacitor.

$$\text{Maintaining the required energy} = \frac{1}{2}\text{It}\left(V_{work} + V_{\min}\right)$$

$$\text{The reduced energy of the super capacito} = \frac{1}{2}C\left(\left(V_{work}\right)^2 - \left(V_{\min}\right)^2\right)$$

so, $C = \text{It}\left(\text{V}_{work} + \text{V}_{\min}\right) \Big/ \left(\left(V_{work}\right)^2 - \left(V_{\min}\right)^2\right);$

According to this formula, we estimate that the specification of the required super capacitor group is I = 0.16 A, t = 150 s V_{work} = 12 V, and V_{work} = 10.5 V C = 16F. Therefore, the specification of the super capacitor group is 16 V 16F.

3. Charging Design of Super Capacitor

The super capacitor charging circuit consists of a charging power supply circuit, a charging control circuit and a super capacitor pack. The load needs a stable input voltage (3.3 V, 5 V, 12 V). The 16 V power supply is the main power supply for the charging system. When the main power supply is turned on, it

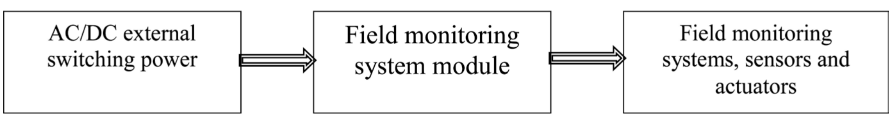

Figure 1. Schematic diagram of power supply mode of field monitoring system module.

Table 1. Main specifications of charging system for supercapacitor.

projects	index
source	16 V DC
the super capacitor pack	16 V 16F
power conditioning	Constant current 2 A charging at low voltage, constant current at high voltage and lower current
charge	charging interval ≤ 30 s
discharge	discharge current 0.16 A discharge current ≥ 150 s

supplies power to the normally operating switch voltage divider and supplies power to the super capacitor group when its voltage reaches a certain value. The value is that the main power is disconnected and the supercapacitor load is powered to maintain system operation.

1) ***Charging Circuit***

The charge circuit control circuit uses AD's current sense operational amplifier [3], which provides a high voltage interface and enables bidirectional current monitoring on the shunt resistor, thereby simplifying high-side current monitoring. It has high common-mode rejection (CMR) characteristics and excellent temperature performance to achieve the best accuracy in the application. The device amplifies the current through the shunt resistor to the load and provides a ground-referenced, output voltage that is proportional to the load current. Charging power supply circuit uses TI's step-down switching [4] integrated voltage regulator chip, input voltage range: 5.5 - 36 V. Up to 3 A continuous output current (peak current output by up to 4A). High Efficiency is up to 95% Enabled by 110-mΩ Integrated MOSFET Switch, which integrates a fixed frequency oscillator (500 Hz) and a reference regulator (1.22 V). By adjusting the VSEN pin to 1.22 V to control a wide range of output, the initial accuracy is 1.5%. And it has a complete protection circuit, including over-current protection and over-temperature protection circuits, etc. The use of this device requires very few peripheral devices to constitute an efficient voltage regulator circuit (**Figure 2**).

2) ***Circuit Analysis***

As shown in **Figure 3**, the circuit design charge current 2A, The charging current design formula is $R_3/(R_2 + R_3) = 0.6/I$. The experiment shows that the charging current is 2 A, $R_2 = 1$ K, $R_1 = 2.2$ K. In the initial stage of charge current is less than or greater than the set current, VSENSE terminal voltage is less than or greater than the reference voltage, regulator chip internal regulation 2 A. At the later stage of charging, the supercapacitor is close to Vin, and the charging current is reduced. The AD chip loses its regulating function and enters the constant voltage stage.

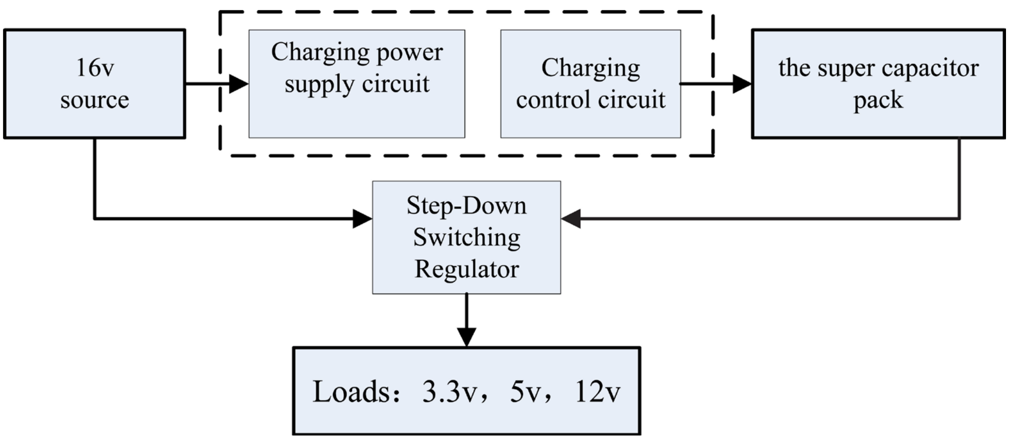

Figure 2. Super capacitor battery backup system block diagram.

4. Project Verification

Figure 4 shows the voltage and current curves during actual charging. Turn on the power switch and start charging. The capacitor charging voltage increases steadily. The ammeter values are stable at about 2 A, until 15.6 V is switched to the constant voltage stage. The current also drops suddenly until the voltage reaches 15.8 V. After charging, the whole charge takes only 24 s to meet the design requirements.

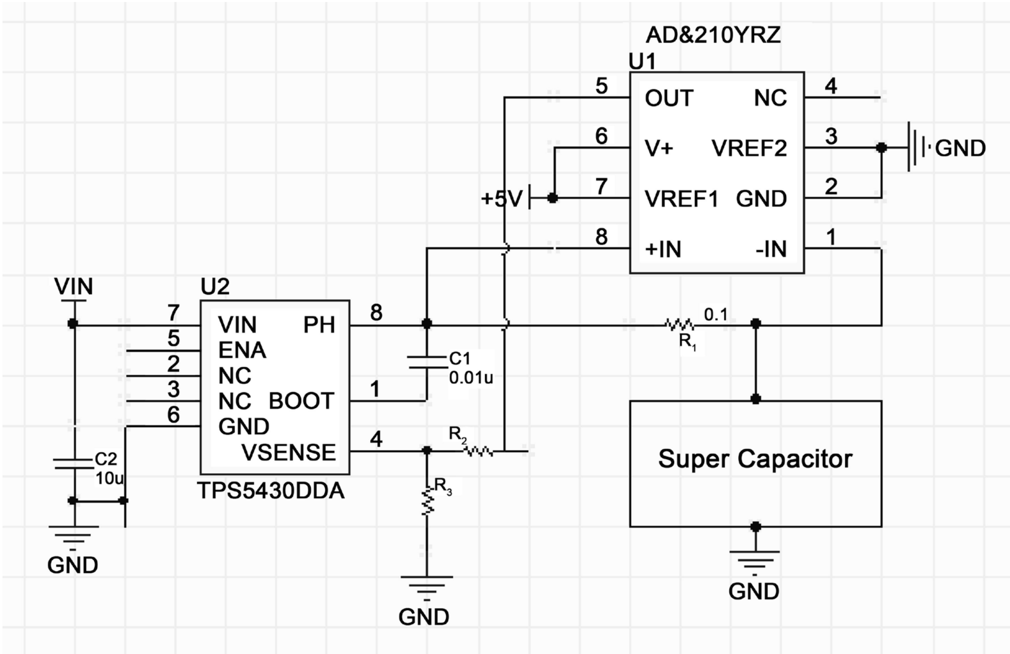

Figure 3. Circuit schematic.

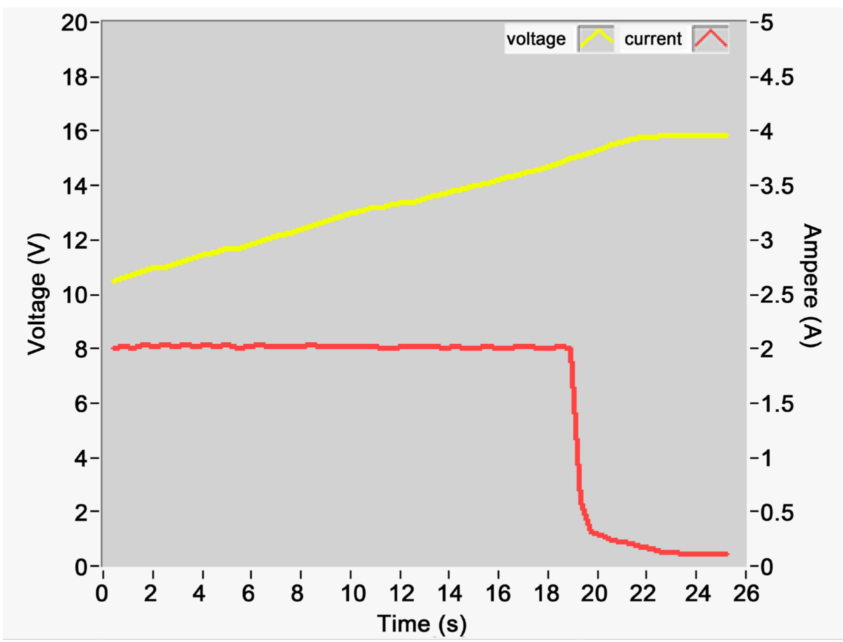

Figure 4. Super capacitor charging current/voltage waveform

5. Conclusion

This paper has done some simple research on the charging characteristics of the super capacitor to obtain the corresponding charging control strategy, changed the previous design program that needs to collect and analyze the capacitor voltage feedback through the MCU, and realized the super capacitor charging. A simple hardware circuit is adopted to solve the problem of segmented control charging of the super capacitor, and the performance of the charging circuit is tested. Each index meets the design requirements. The design circuit is simple and efficient, has strong applicability and has been widely applied.

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