Intelligent charging design for energy-saving applications

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Most portable electronic devices are developed for high efficiency and reliability, and low power consumption. This, in turn, demands of their batteries a long life and high efficiency, too.

Batteries are widely used in charging systems. Some charging systems are a bit more involved than others, and one such example is metering electricity, which in some places differs from the traditional charging methods. In China, for example, electricity prices are divided into two tariffs: daytime (8a.m. to 10p.m.), when power consumption is greater, i.e. peak electricity use; and night-time (from 10p.m. to 8a.m.). Charging electronic equipment during the night uses electricity generated at night, which helps improve the power grid's efficiency, saving energy and reducing emissions.

In addition, existing charging schemes suffer from a number of problems, such as high replacement and maintenance costs, long charging times, unstable charging temperatures (fire hazard), and under- or overcharge that can lead to early damage of the battery. Hence, we have developed an intelligent charging system, where the charger automatically selects the period of low demand on the power grid to recharge the batteries. This method also prevents overcharging the battery, thus prolonging its life. In addition, our design also displays the charge voltage, current and percentage of power left in the battery.

System Design

The main function of our design is automatic control, where the charger automatically charges the battery at a time of low electricity prices. The system comprises an MCU, a relay, power supply, sampling circuit, liquid crystal display, keypad and supporting components. Through a built-in analogue-to-digital (A/D) converter module, voltage and current are collected and converted into digital values. Charging time, determined by the MCU, controls the relay for optimal charging and protects from overcharging. Accurate time is provided by an on-chip clock.

The block diagram of the charging system is shown in Figure 1. The main control circuit of the automatic control process consists of a single C51 microcontroller, N5110 LCD, matrix button and DS1302 real-time clock module; see Figure 2.

The charger's power module mainly transforms AC to DC, and adjusts the voltage, rectifying, filtering and stabilising it. More specifically, the transformer changes the alternating current of 220V and 50Hz into the required AC voltage, and then the rectifier converts this into DC through a bridge circuit. A filter circuit filters the post-rectifier ripple and smooths the fluctuating DC, because, to that point, the DC output of the filtered circuit is still a bit unstable.

We adopted the Coulomb meter method (Figure 3) for our design (Figure 4) to display the percentage of battery power. This method measures the input and output of the net charge in the battery circuit to roughly calculate the internal residual energy. The capacity of the battery can be set up in advance or measured during a complete charging cycle. By compensating the battery's discharge and changing the battery capacity at different temperatures, this method can be fairly accurate.

In Figure 4, R_{SNS} is sampling resistance and R_L is load resistance. Voltage drop generated by the current I_0 is V_S (T) = I_0 (T) x R_{SNS}. Hence, the battery power is:

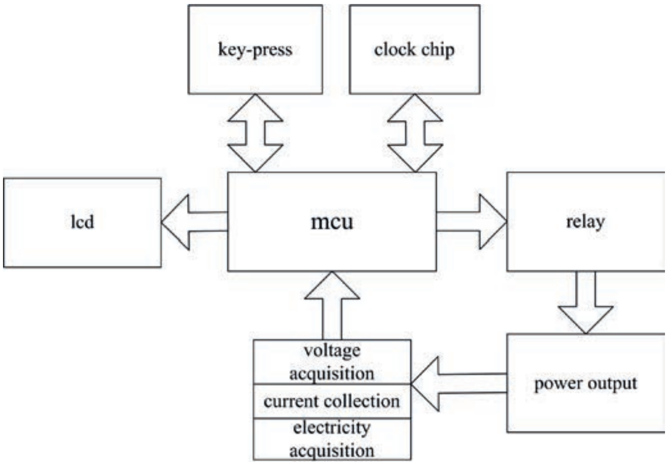

Figure 1: Block diagram of the charging system

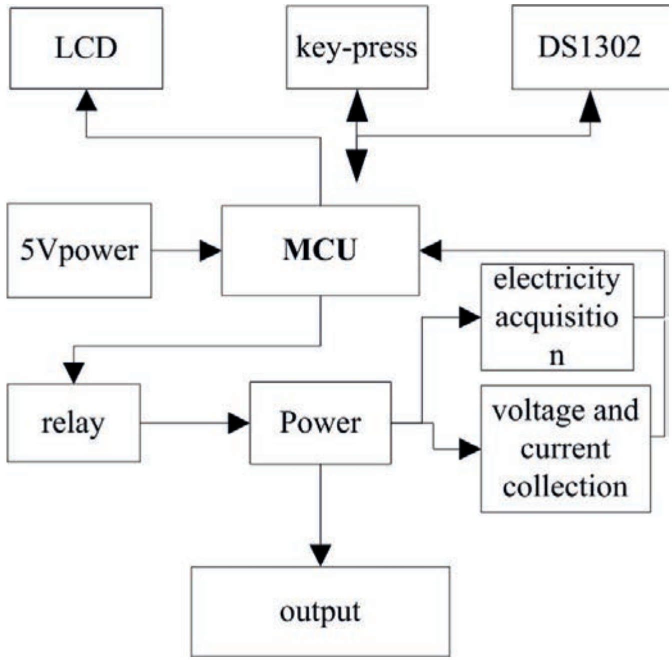

Figure 2: The system's hardware

$$Q=\int_0^t I_0(t)dt=\int_0^t \frac{V_s(t)}{R_{SNS}}dt=\frac{1}{R_{SNS}}\int_0^t V_s(t)dt \qquad (1)$$

Control Circuit

Because the charger has a large output DC voltage, and the C51 microcontroller works with 5V, high voltage will burn it out. Therefore, we use two sliding rheostats to adjust the voltage across the chip to 0-5V before passing it through LM358 as a voltage follower. The charging voltage is then calculated according to the voltage divider ratio, and the charging current using Ohm's law.

The control circuit in Figure 5 uses a relay module with optocoupler isolation. Optocouplers use light as an intermediate medium to transmit the signal, usually combining an infrared light-emitting diode and a light-sensitive semiconductor receiver. The photosensitive receiver picks up the light and produces a corresponding photocurrent,

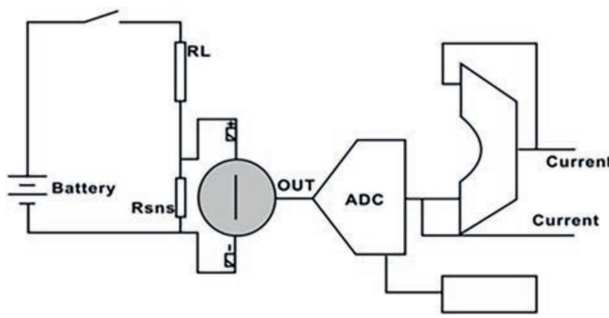

Figure 3: The Coulomb meter principle

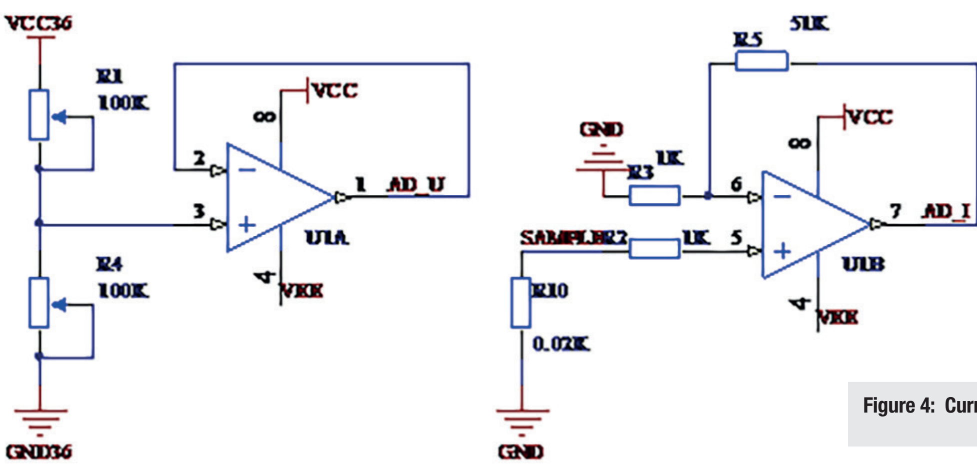

Figure 4: Current voltage measurement circuit

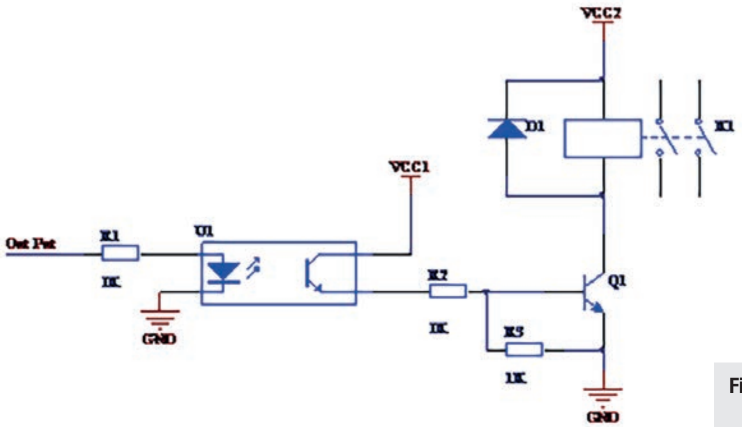

Figure 5: The control circuit

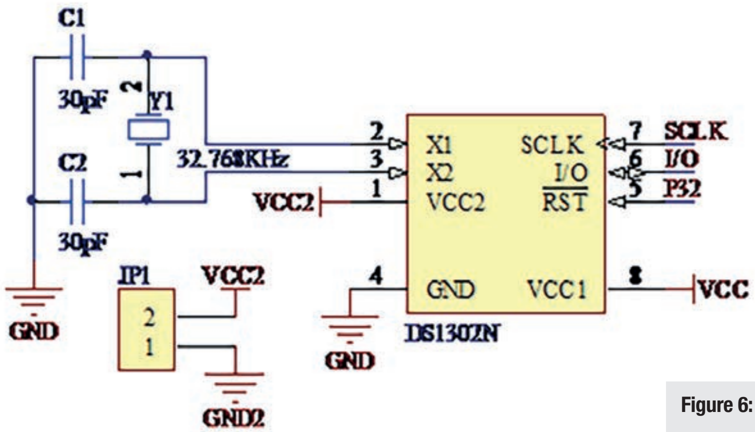

Figure 6: The DS1302 circuit

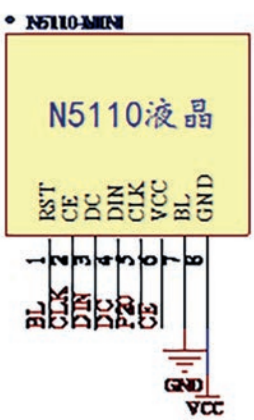

Figure 7: N5110 setup

achieving good isolation between input and output.

In our design, the optocoupler isolates the control circuit from the 220V grid voltage, preventing interference between grid and relay. We also used the DS1302 trickle-charge timekeeping chip; see Figure 6. Its connection to the C51 MCU has a reset pin (CE), SCLK clock pins and an I/O pin for data exchange between the two. DS1302's X1 and X2 connect to a 32.768kHz crystal to provide precise time-keeping.

The liquid crystal display module (N5110) is shown in Figure 7. It has eight pins: VCC, GND, CE (connected to the MCU), RST, DC (type of data transmission), DIN (serial data pin), CLK (synchronous clock pin), and BL, which indicates whether the backlight is open. The RST bit completes the N5110 reset, bringing it to a default state.

High BL lights the backlight, and low turns it off (or the opposite, depending on the setup). The design also uses a push-button matrix for interaction between keys and the LCD; there are eight I/O pins controlled by 16 keys; see Figure 8.

The Software

The software flowchart is shown in Figure 9. Its main functions include accurately assessing the time to determine the correct electricity pricing, and sending instructions to the relay to start and stop the charging. It also samples the voltage, current and power level of the charging circuit, displaying them on the N5110. In addition, it determines whether the battery is full or needs charging.

Initialisation of the N5110 is divided into several steps:

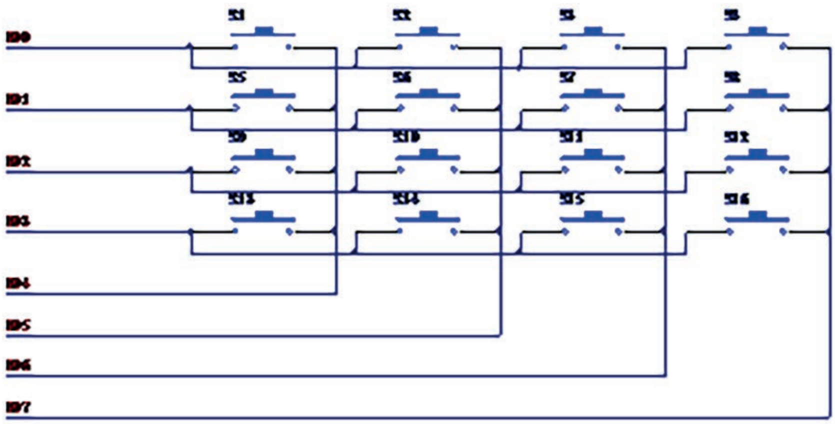

Figure 8: Matrix key setup

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1) On power-up, the reset sends N5110 to default.
2) Extension settings are chosen at this stage, including configuration of the liquid crystal display, which includes working temperature, bias coefficient and voltage. Generally, at this stage the working temperature and bias coefficient have fixed values; only the working voltage requires setting up, which influences the brightness of the LCD.
3) Selecting the general settings, which include display mode, clear screen and initialisation coordinates.
4) Time determination, mainly via data transmission between the MCU and clock.

For data acquisition, the MCU mainly uses the its A/D module. The P1 port is the MCU's A/D port, and there are eight acquisition channels. Data collection is mainly divided into:
1) I/O port initialisation and setting the I/O for data acquisition to the required mode.
2) A/D initialisation, selecting the data storage mode after A/D conversion, storing the eight high bits and eight low bits of data in the ADC_RES and ADC_RESL registers respectively, and then setting the A/D conversion mode;
3) Collecting the A/D conversion results. After A/D conversion, the collected data is processed, and the loop returns to its main function.

Relay control handles the circuit interruption. When the time condition matches the expected price, and the battery is nearly empty, the main control triggers the relay, closing the circuit. When the battery is full, the main control circuit sends a low level to the relay, which disconnects the circuit.

Our system has been tested, showing good results and suitability for energy-saving and emission-reduction applications. EW

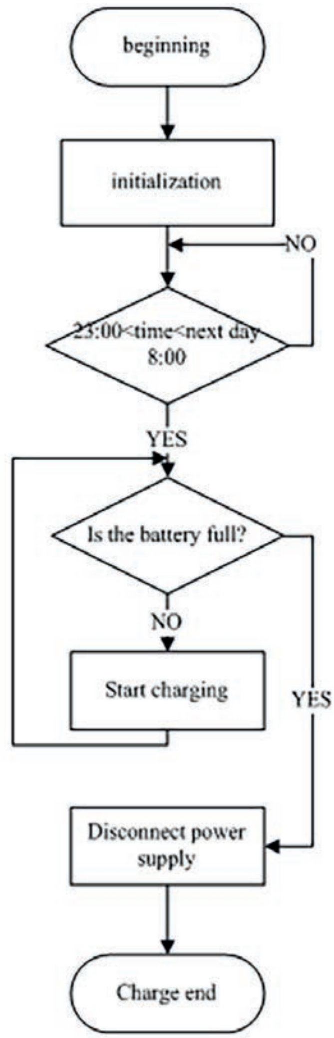

Figure 9: Software flowchart