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Design and Implementation of the Power Battery Management System of Photovoltaic Power Generation Based on Bi-Directional DCDC Equalization Control

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Abstract

This paper presents the design of the battery management system in photovoltaic power generation system based on bidirectional DCDC equalization control, More accurately measuring the temperature, current and voltage of the battery, to prevent over-charging and over-discharge, longer battery life, to ensure network security and storage, in photovoltaic power generation system the battery management system plays an important role.

Key words

DCDC control; battery management system; soc

1. Introduction

Whether from the world or from the Chinese point of view, conventional energy is very limited. China's primary energy reserves are far below the average level of the world, solar energy is a human inexhaustible renewable energy, sufficient cleanliness, security, and relative breadth, really long life and maintenance-free, adequacy of resources and potential economic advantages, an important role in long-term energy strategy [1]. The next ten years, China's photovoltaic (PV) market will turn to the grid system which consists of independent power systems, including power plants and desert city rooftop power generation system. Chinese solar PV development is potential, China solar photovoltaic attract more strategic investors into the industry in the past.

2. Technical background

PV power is directly connected to the public grid after the DC solar modules produced through grid-connected inverter into alternating current mains with requirements.

PV system consists of PV array, battery, charge controller, inverter, AC power distribution cabinets, solar tracking control system and other equipment. Action is part of its equipment: its role is battery power emitted during storage square solar cells by light and is ready to supply power to the load [2]. The basic requirement for solar power batteries is used: self-discharge rate, long service life, strong deep discharge capacity, high charging efficiency, and low-maintenance or maintenance-free, operating temperature wide range, low prices.

It can be divided with batteries and power generation systems without batteries. And power generation system with a battery is having a dispatcher, which can be incorporated into or out of the grid according to needs, but also has standby power function, when the power grid supply emergency power outage for any reason, the system used with batteries and power generation systems.

In solar energy is sufficient and power grid load is low, the energy stored by the storage battery to the power management system, when the lack of scenery, the battery pack stored energy back into the power grid through the inverter to ensure that the power system operation continuity, but also improve the utilization of solar energy [3] . In power for battery charging and discharging process, using some management technology battery charge and discharge management, since overcharging and excessive discharge will affect the performance of the battery pack, so that the energy storage efficiency decreases, due to solar power produce unstable adjustment ability worse, and ultimately affects the stability of the whole micro-grid. Therefore, advanced battery management technology in the photovoltaic is essential to protect the safe and efficient electric energy storage, the key technology of micro-grid power supply stable.

3. System Design

The system consists of two subsystems: the battery management system and bidirectional DCDC control system.

Battery management system consists of an SOC unit (SOCU), 1 personal computer interface unit (HMIU1), 3 battery measurement unit and 6 cell balancing unit compositions. Bidirectional DCDC control system consists of a high-voltage measurement unit (HVMU1) and

(HMIU2), a bidirectional DCDC converter constituted. It uses distributed architecture design; each module CAN bus connection for data transmission. System structure shown in Figure 1.

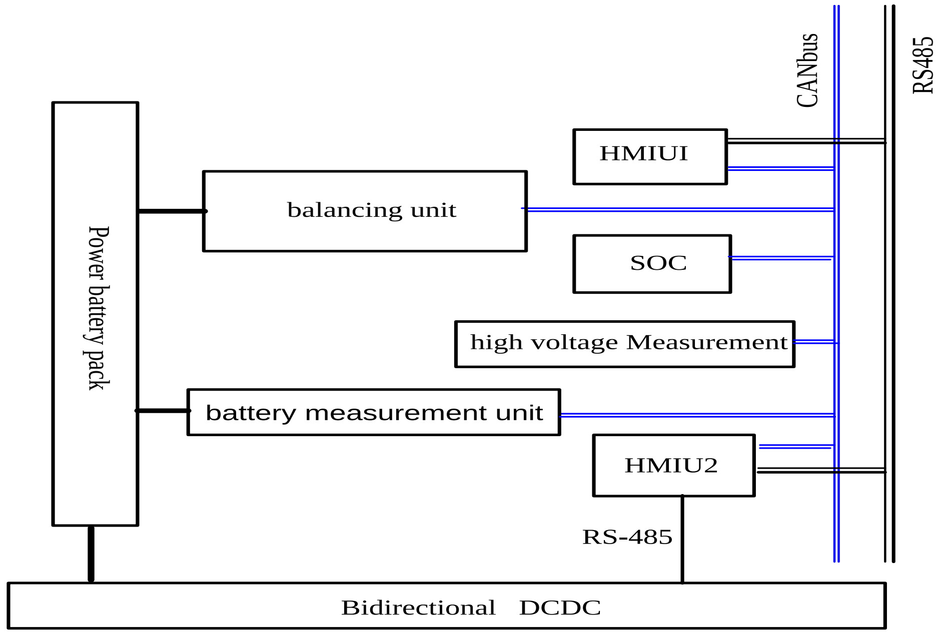

Fig.1. System structure drawing

3.1 SOC module design

SOC module uses high integration, high-performance microprocessor C8051F500 as the main controller, the processor uses Silicon Labs patented CIP-51 microcontroller core. This module uses C8051F500 MCU two AD were used to collect the bus voltage, current, internal CAN bus controller is connect to CAN transceiver for communicating with other systems, and the design of the external EEPROM memory, data storage system initialization, using the processor the SMBus bus and memory for data exchange.

After long-running, since the cumulative effect of the current signal, SOC will have a greater cumulative error, and directly use of the open circuit voltage to estimate the SOC, often affected by hold time and temperature, the effect is not very satisfactory[4]. In this issue, we are departing from the true value of the SOC, the Kalman filter based on the estimated SOC equivalent circuit model identification method is tested and validated, and achieved good results, It laid the foundation work for the further improvement SOC predicting methods

The basic process of using the Kalman filter estimate SOC:

Let y_k = SOC_k, then according to establish a current input, SOC state variables of zero-order hold sampling discrete state equation is:

$$Y_{k+1} = Y_K - \eta_{T,I} i_k \Delta t / C_M$$

Measurement equation is a mathematical model based on the battery SOC, current i, and the battery internal resistance R and other factors between the load voltage y to design, measurement equation given in the literature are the following forms: Measurement equation model obtained after the use of identification, in the state of operating conditions, regular or irregular use of recursive Kalman filter algorithm to estimate the SOC and correct with the estimated value of SOC.

The basic calculation is as follows:

$$Y_0/_0 = SOC_0, P_0/_0 = \mathrm{var}(y_0) \quad P_{K/k-1} = (I - Y_k C_k)P_{K/k-1} \quad Y_k/_{k-1} = Y_k/_{k-1} - \eta_{\tau,i} i_k \Delta t / C_M$$

$$P_k/_{k-1} = A_{k-1}P_{K-1/K-1}A_{K-1}^{\tau} + Q \quad Y_{k-1} = K_0 - Ri_{k-1} - k_1/Y_{k/k-1} - k_2Y_{k/k-1} + k_3\ln(Y_{k/k-1}) + k_4\ln(1-Y_{k/k-1})$$

$$L_{k-1} = P_{k/k-1}C_k^{\tau}(C_kP_{k/k-1}C_k^{\tau} + R)^{-1}$$

$$Y_{K/k-1} = Y_{k/k-1} + L_{k-1}(U_{k-1} - y_{k-1})$$

$$P_{K/k-1} = (I - Y_k C_k)P_{K/k-1}$$

K = 1,2,3, ……

The complex function of the system is SOC unit, we also tested this feature alone. By the case of a single pulse and compound pulse charge and discharge test or typical cycle test conditions more fully, that the next model parameter identification more accurate conditions, soc can achieve better forecast results.

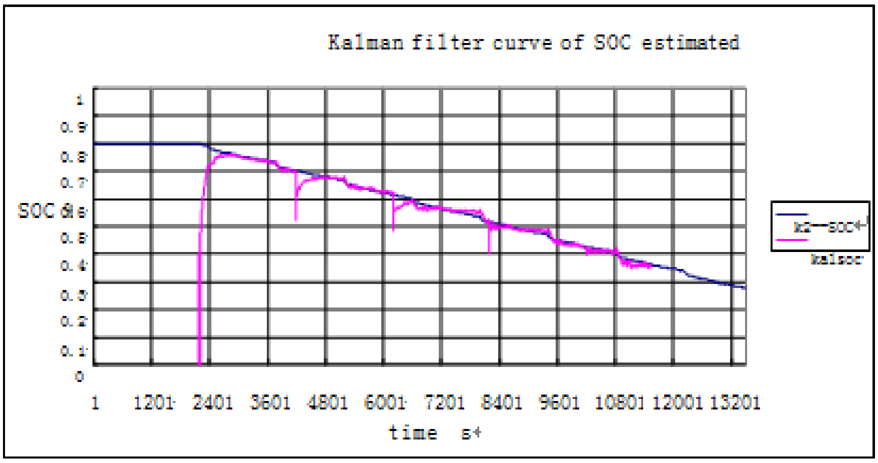

Fig.2. Kalman filter soc prediction curve

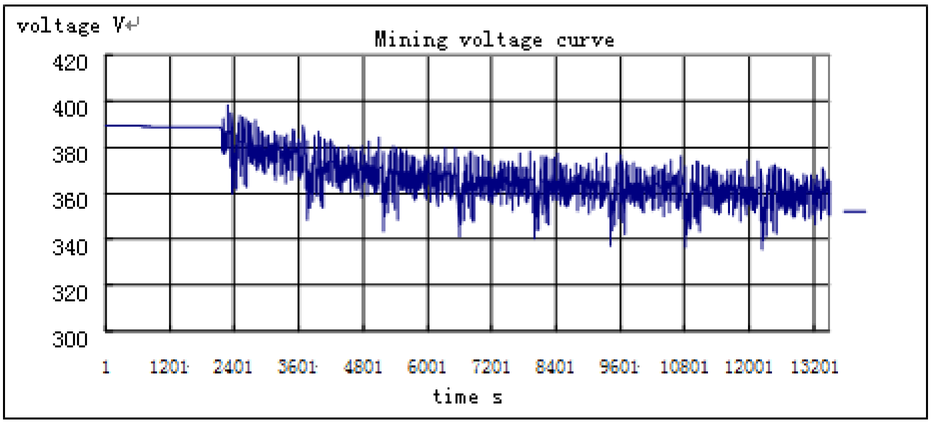

Fig.3. soc mining voltage curve

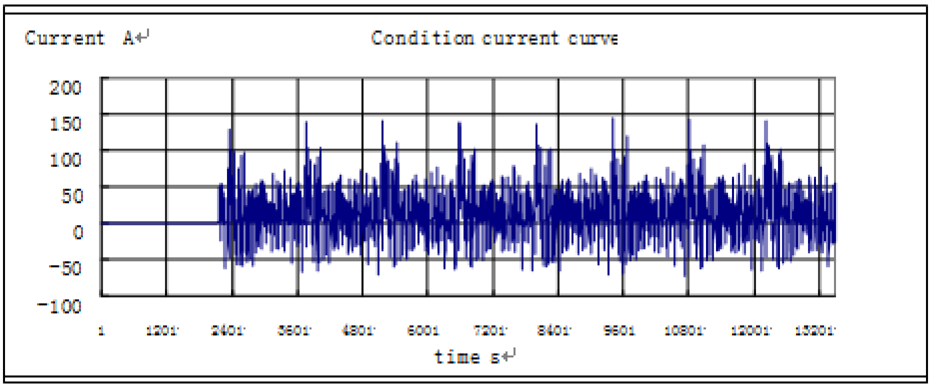

Fig.4. soc mining current curve

Figure 2 to 4 for the condition of SOC test data estimated the resulting curve. Cycle, every 30 minute intervals, using recursive Kalman filter estimated by the SOC curve can be seen, when the recursive Kalman filter SOC initial value SOC0 / 0 = 0.4 and 0.6, respectively, usually after 400 to 800 sec calculations, estimates for kalsoc can better convergence to the true SOC, estimated error is less than 2%. Thus, the Kalman filter algorithm for correcting SOC, SOC error can be controlled within the allowable range.

3.2 Acquisition bus voltage and insulation resistance testing circuit

(1) According to the design requirements of the system, low-side DC bus voltage 140V ~ 150V, high voltage terminal bus voltage 460V ~ 600V, bus voltage measured is used the partial pressure method. First test signal through the divider network, and then through the check points of the operational amplifier, isolation amplifiers into the microprocessor A / D conversion port process, and then get the bus voltage.

(2) Insulation testing is an important indicator of the battery management system. Energy storage battery group is usually consists of a large number of single cells in series, the nominal 3.6V Li-ion battery is composed of 43 sections, more than 150V DC voltage by the bidirectional DCDC boost after, bus voltage to 600V above, the entire battery system is usually affected by external factors such as the integrated temperature, humidity, mechanical vibration, external insulation of system will be greatly reduced, resulting in a significant increase in the surface conductivity, then the system may be the positive and negative power supply via an insulating layer whereby the drain circuit, which would seriously endanger the safety of the operator[5], it will cause serious electrical in an accident, so the insulation performance real-time monitoring system for DC bus to avoid electrical accidents have important the significance. The system uses to detect the total combination of the two circuit design approach of the bus voltage and insulation resistance, in particular the principle is shown in Figure 5.

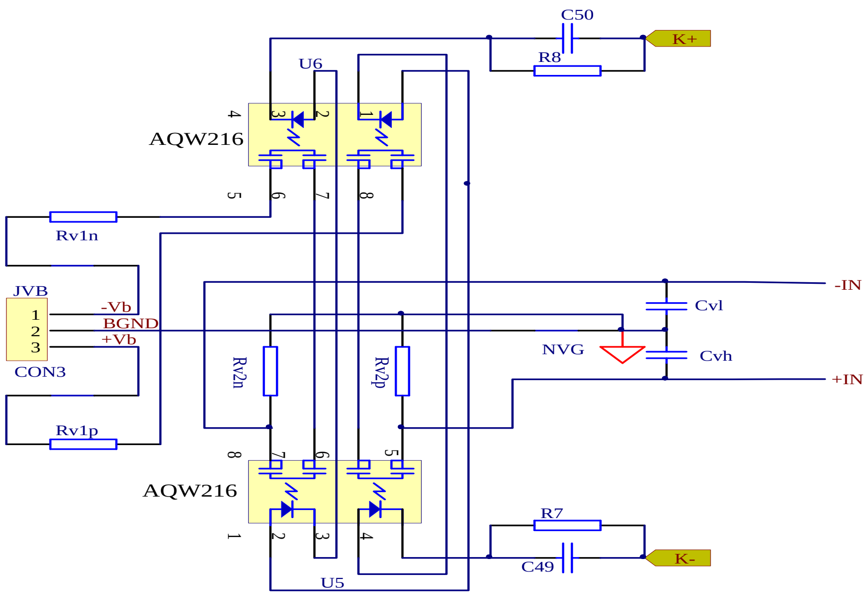

Fig.5. Voltage Insulation resistance measuring circuit

Measuring circuit is provided with four different sizes of dividing resistors, two AQW216 optocoupler relays, opto relay with high sensitivity, fast response, long life and high reliability, be used in high-frequency circuits. Through two / O port of MCU I ,K + and K- control two opto relays off different compositions partial pressure measuring network, when K + = 1, K- = 1 measured the total battery voltage V, when K + = 1, K- = 0 be measured when V +, while K + = 0, K- = 1 measured the voltage V-, then the system can reduce the size of the insulation resistance, We can then derive the system insulation resistance size and total DC bus voltage in accordance with the derived formula.

3.3 Bus Current Acquisition

Conventional current sampling circuit is usually based on the size of the current system, the access precision resistors in the circuit, according to Ohm's law, and then converted to collect resistor voltage, after amplification and isolation into the microcontroller AD port to calculate. This current measuring method is usually used in the case a small current, taking into account the practical application of the system current is large, so the system adopts Hall sensors when the current is real-time acquisition system, the specific model for HCS-LTR-200A, this sensor is a closed loop current sensors, The system uses closed-loop current sensor, relative to the open-loop current sensors for faster response time (<1us), followed by the measurement accuracy of di / dt is high, small temperature drift, and a strong current overload capacity, high resistance interference ability and good linearity, the measurement accuracy in full compliance with the design requirements of the system, which can reach 0.2%. Design of the sensor output ratio of 2000: 1, when 200A current full-scale input, there will be 200mA current output. The system is designed for the current acquisition circuit shown in Figure 6.

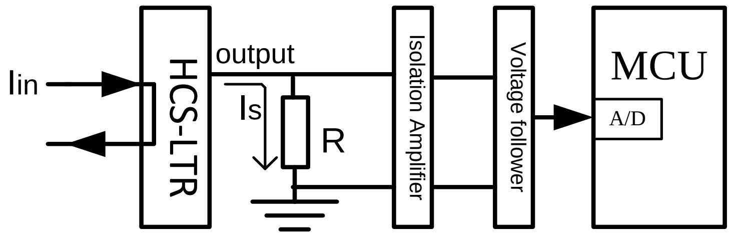

Fig.6. current acquisition circuit

Current sensor supply needs + 12V, the sensor output port external resistor R is as small current sampling resistor, the current is converted into a voltage. The specific model for the ACPL-C790, accuracy up to + 0.5%, 0.05% linearity, and 1.6uS fast response times, suitable for high frequency sampling circuit. Voltage follower as a signal buffering and isolation level ensures that the input to the microcontroller A / D port voltage signal quality. If the system bus current is Iin, obtained by the Hall sensor output current Is is Iin / 2000, the sampled current sampling resistor R completed to converte IV sampling to voltage Vs, the size of R * Iin / 2000, After isolation of the operational amplifier amplifies the signal to the microcontroller inside AD input voltage range, through the voltage follower signal to the microprocessor AD port, the A / D converter to give bus current value.

3.4 Design of the data storage circuit

The system is running in real time monitoring of large amounts of data, such as bus current, bus voltage, single battery voltage, single temperature, alarm status and other information systems in different time periods, these data can accurately reflect the physical state of the system at work for some time, Is there an exception occurs when a certain period of time abnormal operating system, system data for the analysis of abnormal solve system problems have important reference value[6]. In addition, collecting and recording data can predict the performance conditions and evaluation system for assessing battery in photovoltaic and as the advantages of the energy storage device has important significance.

In order to record data in real-time conditions, the module is designed with an external EEPROM (online erasable read-only memory) chips [7], which can frequently be written and read job data. In this paper, FM24C256 as a data recording memory, the high memory read and write speed, be used in more complex high-noise environments. FM24C256[8] storage capacity of 256Kbit, and still well preserved after a power outage data, the device uses an I2C bus bi-directional data transfer, easy to record the real-time data systems, and has a high reliability, SDA is the data line, SCL is the clock line, A1, A2, A3 of the memory address[9]. Circuit design diagram shown in Figure 7.

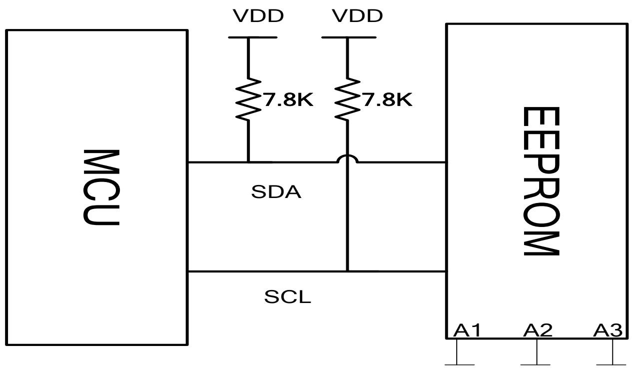

Fig.7. EEPROM hardware connection diagram

3.5 Single battery voltage detection

Inconsistency lithium-ion batteries produced by the working process, the lithium-ion battery after repeated charge-discharge cycles work, the actual capacity will be decreased due to the individual cells themselves have some differences, coupled with the operating temperature, depth of discharge and other differences in external conditions, the rate of decline will inevitably lead to different capacity. It describes the 10 lithium-ion battery, 20Ah of lithium-ion batteries 30 times, the difference between before and after the distribution cycle capacity of 50, 80 times a constant current charge and discharge, be seen by the initial battery capacity balance is better, the presence of small single cells the difference, after repeated charge-discharge cycles, and this difference was a certain increase trend to single battery voltage detection [10].

Battery pack is composed of single cells in series, in order to ensure that the entire system is safe and reliable work in the micro network, you must design the appropriate cell voltage detection network for real-time detection of cell voltage during charge and discharge principle of collecting cell voltage is shown in Figure 8.

Single detection principle of the system as shown in Figure 8. During to capture multi-section single battery voltage, analog multiplexer switches adopted, the device has four address lines, it can produce 16 kinds of signal status at a time all the way through and only choose to send the signal path to a common signal output. KF for the front control signal, KB for the backhaul control signal, KF, KB end connected to the CPU I / O port through the isolation device, CH1, CH2 ... CH16 respectively, each cell voltage input port. First, open the KF to a low level signal, the coupler relay open ,circuit composed by battery charge for the sampling capacitor CS, after a delay, the KF electrical signal is set high, then the voltage on the capacitance CS 16 namely group of 16 single battery voltage, then the KB signal to a low level, and the brightest battery voltage signal to an analog multiplexer, then CPU 16 sequentially given channel multiplexer address strobe, elected through a channel, the channel voltage signal to the common output port, a voltage signal to the CPU through the isolation amplifier element of A/ D port to complete the cell voltage acquisition.

In the acquisition process, in order to avoid the A / D start, to the I / O port sampling voltage instability lead to measurement error, sampling procedures used in the design of the pre-sampling process, voltage and signal averaging multiple acquisitions, greatly improving the accuracy of the cell voltage measurement.

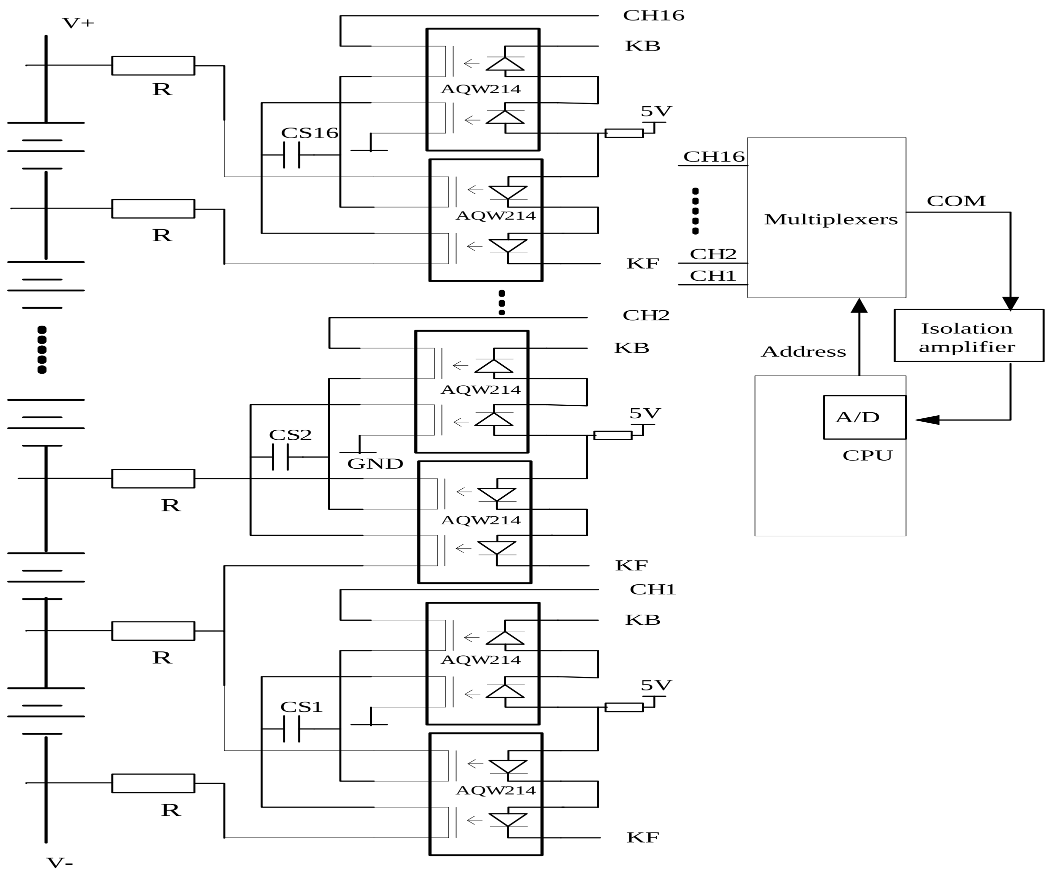

Fig.8. cell voltage acquisition

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3.6 Detecting the temperature of the cells

DS18B20 temperature acquisition using 16 connected to the one bus, the cells can be collected Section 16 temperature， sensor supply using an external power, which can improve measurement speed. Circuit design of TTL NAND gate driver chip, model specific use for the 74HC04, which contain the same internal inverter 6 groups, can transform from high to low and increase signal drive capability. Mining chip digital isolation technology is adopted Couple quad-channel digital isolators ADUM1401, electrically isolated optocoupler isolation compared with ordinary chip, ADUM1401 can achieves low power two-way communication, transfer high data transfer rate and supports a variety of channel configurations [11], low power consumption and common mode transient anti-interference ability.

Multi-point temperature acquisition process: compliance with Timing and internal working practices the single bus of DS18B20, to complete a temperature conversion is performed three actions in MCU: First, the temperature sensor initialization, immediately followed by instruction ROM, and finally to read and write digital signals. Detecting a flow chart shown in Figure 9.

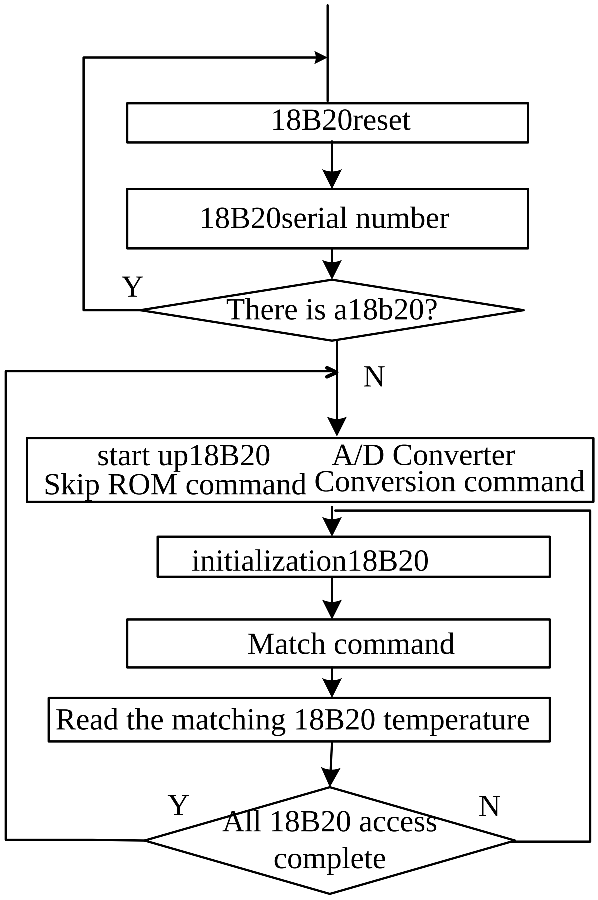

Fig.9.Temperature detection flowchart

4. Bidirectional DCDC control system design

Bi-directional control system includes a bidirectional DCDC controller (HMUI2), high voltage measuring unit and bidirectional DCDC converter three-part, two-way DCDC controller hardware design consistent with the Human Interface Module (HMUI1), the main difference lies in the use of communication interfaces and programming, mainly to complete the function is to control and monitor the DCDC working condition ,then system can be controlled DCDC battery management system to collect data and external battery pack grid operation status of the battery charge and discharge. High-pressure measurement unit mainly completes the high-pressure side of measurement of the DC bus current, voltage and bus insulation resistance.

In the photovoltaic system, when the power grid is in peak condition, battery pack provides power to the outside power grid via an inverter, to meet the power electricity needs. When the solar power and better conditions to fully meet user needs, excess power to the power converter can be stored by the battery pack to charge the battery pack. In the actual environment, the outside power grid to charge the battery pack and the battery pack outside the network supply situation is more complex, which requires bidirectional DCDC converter can smoothly switch between charging and discharging state, and power-down does not occur during the switching process. When the battery pack, also called DCDC converter which can achieve constant current, constant voltage output, choose a reasonable way of charging management system based on real-time monitoring data.

This topic designed lithium batteries power of 12KW, the battery voltage is 150V, capacity 200AH, the use of 43section in series monomer lithium battery, lithium battery monomer charge-cutoff voltage 3.8V, discharge cut-off voltage of 2.6V. The battery power supply systems and process actual working conditions, selection of bidirectional DCDC need to have the following parameters:

(a) Power: 12kw

(b) The battery terminal

Operating voltage: 100V-200V

Current job: ± 60A

When operating in the battery charging, the voltage and current continuously adjustable and has a preset function, current, voltage adjustment signal and the preset signal before the start of the RS485 serial ports and adjust given.

(c) DC bus terminal

Operating voltage: 500V-600V

Current job: ± 20A

When working in the bus on the power supply, the output current continuously adjustable and has a preset function before the start of the current adjustment signal and the preset signal from the RS485 serial port and a given adjustment.

(d) DCDC converter start and direction control

Using RS485 serial communication control (using the MODBUS protocol).

(e) The protection function: overheating, overcurrent, overvoltage protection sound and light alarm function, with overheating, over-current, over-voltage alarm switch status output function, and can be read via RS485 serial port alarm status.

(f) With preset function, soft start, no overshoot, double switch.

(g) Other technical requirements

Voltage Regulation: <1%

Current regulation: ⩽ 1%

Ripple factor: ⩽ 1%

Efficiency: > 90%

Load factor: 0-100%

The DCDC with digital processing capabilities, with constant current, constant voltage and maximum power output, operating modes and online fast and smooth transition, with RS485 serial port, follow the MODBUS communication protocol, you can easily communicate with the DCDC controller, and through the serial port PC connection for remote control, that is DCDC internal register read and write operation, control DCDC's boot, the parameter setting. The system's automatic current sharing feature allows multiple DCDC used in parallel, through the internal balance of power agreement, power sharing, so that all bear the same power station DCDC. Because this system is designed for the power of 12KW and each DCDC power of 5KW, so the use of three DCDC and machine specific connections shown in Figure 10.

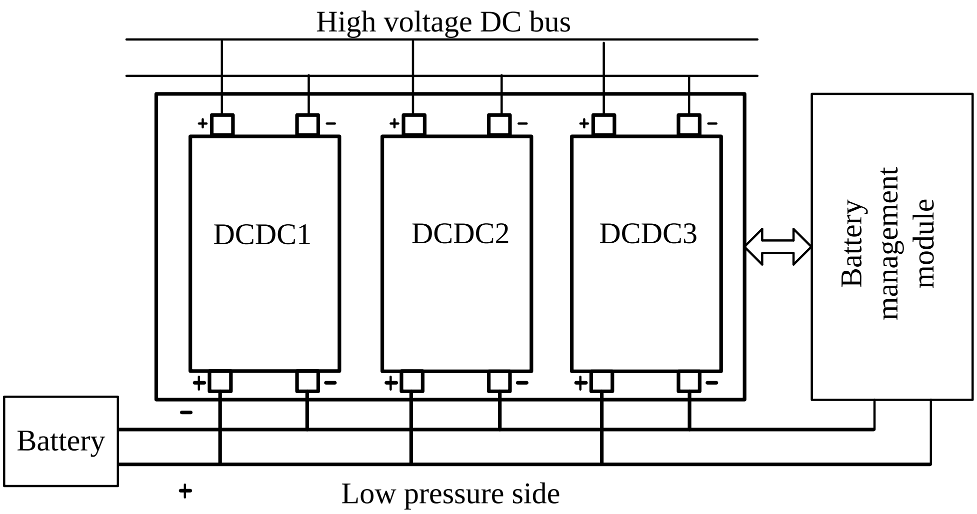

Fig.10. Bidirectional DCDC connection

When DCDC provides power to the external load through the bus 485, battery management system to obtain battery voltage and the SOC state is within the allowable range of values of discharge, with the present system, when the SOC of the battery pack is less than 15%, or when the voltage is lower than 110V, The default battery pack is in the discharge cut-off state, at this time DCDC barriers discharge instructions, and provides an alarm condition. When the external grid charging by DCDC powered battery which is also necessary to detect the status of the battery pack, when the battery SOC is greater than 90%, or higher than 150V voltage battery pack is already known as in full charge state. When the state of charge is appropriate, DCDC need to adjust the output based on the battery voltage range to avoid the process of charging the battery damage and shorten the life of the battery pack.

In accordance with the standard battery charge and the most appropriate electrical process probably can be divided into three stages, pre-charge, constant current charging, constant voltage charging. In order to extend battery life, the system chosen DCDC modules on functional requirements that can achieve constant voltage, constant current output. Battery charging process is shown in Figure 11.

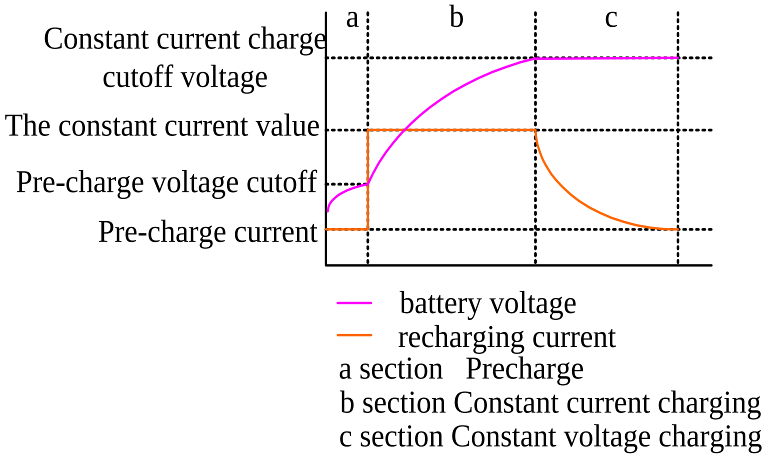

Fig.11. Battery charging process

Precharge: pre-charge, also known as trickle charge, because the lithium battery in the over-discharge voltage is low, there will be an internal problem of the active substance recovery is difficult at this time if a large current charging, then to some extent, will reduce the charging time, However, prolonged high current charging will result in reduced capacity lithium battery, reducing the pot life of the battery. Therefore, when the battery voltage is low when the first small current recovery charge, activating the active material, the battery voltage to rise slowly, after the battery voltage rises to a certain value and then the large current charging, the precharge current is generally 1 / 10C.

Constant current charging: When the pre-charge the battery pack voltage rises to a certain value, the battery pack instead constant high-current charge, which is generally 0.2C-1C, typically 0.7C charge, the system choses DCDC the low pressure side of the maximum supply current to 25A, three parallel flow mode, so the total can provide maximum charge current is 75A, the conditions for security and practical reasons, the charge current is set to 60A. In this process, the battery voltage is gradually increased, but the heat will increase the battery, the cells should be real-time monitoring of temperature alarm status.

Constant voltage charging: When the constant current charging, the battery voltage rises quickly, when the voltage rises to constant current charging cut-off value, the system enters the constant voltage charging stage, a constant voltage to charge the battery, the charging current is gradually reduced stage, when the current is reduced to 1 / 10C when the battery is fully charged, the SOC = 100%, charging is completed, the system shuts off the charge power.

In the actual process of charging, the battery charge is not strictly in accordance with the pre-charge, constant current, constant process of three. Bidirectional battery DCDC battery according to the state of the data management system provides dynamic adjustment of output voltage and output current, to charge current to the size. Specific principles for the battery management system for a total voltage of the battery, temperature, cell voltage and other data integrated current calculated maximum allowable power battery charging voltage and current, and charging and data control via communication interface 485 to transmit bidirectional DCDC, bidirectional DCDC converter adjusts the output data according to the control mode, when the battery pack voltage is lower than 110V, battery management system is in the constant current control to issue commands, command a special format DCDC internal register and sends constant output current size, set to 20A, constant current charging process at this time, the DCDC work status data to the controller in real-time man-machine interface. When the battery temperature in charging is too high or the cells appear abnormal, continue charging may cause an accident, DCDC management system to send a command to stop charging, ensure safety charging.

5. Discussion

Estimates of the battery state of charge (SOC) of the battery have become an important part of management. To estimate the lithium-ion battery state of charge (SOC), on the basis of factors that affect the SOC and SOC estimation method of traditional analysis, based on the actual situation, the use of a new idea, the work status of the battery is divided into static, recovery, charge and discharge three states, respectively, the three states estimate SOC. Get better the estimated value.

6. Conclusion

Research and development of battery management technology are far-reaching, on the one hand, battery management technology can stabilize the system instantaneous power imbalance;

on the other hand, battery management technology to control electrical energy stored in the battery easily and reliably incorporated into conventional power grids, to overcome intermittent and volatile energy issues. Application of battery management technologies will bring major changes in the design of power system planning, operation and control, etc., play a key role in build smart grids. Therefore, the battery management research and design of photovoltaic power generation system are a very worthy of study.

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