THREE-PHASE DRIVE UPS COMPONENT TEST, SYSTEM COMPOSITION AND REALIZATION

Diploma Thesis

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Abstract

Electricity is used widely all over the world in modern industry activities. Accordingly, people's consideration for the quality of the electricity is stricter and stricter. In this case, people can use uninterrupted supplying, which can supply continually alternating-current main for electrical loading equipments while the electric network is abnormal (e.g. power cut, under voltage, perturbance or surging) and maintain the electrical equipment in normal operation.

Supplying power uninterruptedly can be accomplished by two ways: Flywheel-type power and battery uninterrupted power. Owing to its power from gas engine, bringing out a lot of noise and immense size, flywheel-type uninterrupted power is only used in emergency and some special natural conditions. Uninterrupted power is provided by storage battery under normal conditions.

In metallurgy industry, the production process for obtaining high quality special steel includes melting and remelting procedures with certain cooling activities. Cooling is achieved by pumping water taken from a reservoir. Usually, the power required for these pumps comes from the grid. Cooling is essential at any time and for the very few line interruptions encountered-e.g once a year- a simple emergency supply based on a Diesel engine a three-phase generator was found unreliable at starting because of the very long times of standstill (12 months or more) between operation events.

This paper comprises a basic scheme of the establishment of uninterrupted supplying power in general industrial system, among them some key segments, e.g. test for storage batteries, establishment of electrification system of storage battery and uninterrupted supply system for induction machine load.

The test of storage battery mainly consists of discharge detection of storage batteries at constant power and constant current and safeguard of discharge circuits and so on. Beginning with the design of electrical circuits, we run a computer software simulation and finally realize circuits on circuits boards.

The section of establishment of storage battery electrification system mainly consists of storage battery voltage balance segments and storage battery interconnection segments.

The section of establishing the uninterrupted supplying power system, we discuss electricity grid, storage battery, connection of frequency converters and safeguard.

Compiling this paper, we use the listed literature cites at the end of this book as a source of reference. Here let's show our heartfelt gratitude to the writers of these literature cites, units and individual authors concerned.

Kurzfassung

Elektrizität ist in der industriellen Anwendung eine weit verbreitete Energieform in der ganzen Welt. Dementsprechend zielen viele der Bestrebungen zur Erhöhung der Qualität der elektrischen Versorgung auf das Thema Versorgungssicherheit. Zu Verbesserung derselben kann auf unterbrechungsfreie Versorgungen zurückgegriffen werden, welche die Versorgung der elektrischen Verbraucher der Anlagen im Falle von Störungen des elektrischen Netzes (z.Bsp. Netzausfall, Unterspannung und ähnlichem) ermöglichen können und somit einen ordnungsgemäßen Weiterbetrieb gewährleisten.

Unterbrechungsfreie Versorgung kann durch zwei Lösungswege erreicht werden: Durch mechanische Speicher auf Basis von Schwungrädern und unterbrechungsfreie Stromversorgungen durch Akkumulatoren. Aufgrund des Antrieb der Schwungräder durch gasversorgte Verbrennungskraftmaschinen, die eine Menge Lärm und immensen Platzbedarf verursachen, werden Schwungrad-Speicher nur im Falle von Notversorgungen und einigen speziellen Sonderlösungen verwendet. Unter normalen Bedingungen wird die unterbrechungsfreie Stromversorgung durch Notstromakkumulatoren bereitgestellt.

In der metallurgischen Industrie enthalten die Produktionsverfahren für die Erzeugung von Edelstählen hohen Qualität die Prozesse Schmelzen und Umschmelzen mit entsprechenden Kühlprozeduren. Die Kühlung wird erreicht durch das Pumpen von Kühlwasser aus einem Speicher. In der Regel wird die Leistung für diese Pumpen aus dem Netz entnommen. Die Aufrechterhaltung der Kühlung zu jeder Zeit ist wichtig. Aufgrund der nur sehr selten auftretenden Unterbrechungen der Versorgung, z.Bsp. einmal pro Jahr, wird ein konventionelles, dieselbetriebenen Notstromaggregats als zu unzuverlässig beim Anlauf betrachtet, begründet durch die sehr langen Stillstandszeiten (12 Monate oder mehr) zwischen den Einsätzen.

Diese Arbeit präsentiert ein grundlegendes Schema für den Aufbau einer unterbrechungsfreien Stromversorgung für die Verwendung in industriellen Systemen. Im speziellen werden wichtige Bereiche, wie z.Bsp. Test der einzelnen Speicherzellen, Aufbau des kompletten Speichersystems und der unterbrechungsfreien Stromversorgung für die Speisung von umrichtergespeisten Asynchronantriebsmaschinen, behandelt.

Die Prüfung der Akkumulatoren des Speichersystems bestand im Wesentlichen aus der Aufnahme der Entladekennlinien der Zellen bei konstanter Belastung und konstantem Strom, sowie der Schutzmaßnahmen der nötigen Endladeschaltungen. Beginnend mit der Entwicklung der elektronischen Schaltungen, welche im weitern durch Computer Simulation der Funktionen unterstützt wurde, wurden diese Schaltungen schließlich als Prototypenplatinen realisiert.

Der Abschnitt über den Aufbau des Akkumulatoren basierenden Speichersystems behandelt hauptsächlich die Problematik der Balancierung der in Serie geschalteten Speicherzellen und der Verbindungssegmente.

Im Abschnitt über den Aufbau des unterbrechungsfreien Stromversorgungsystems, werden die Themen elektrisches Netz, Speicherakkumulatoren, Einbindung von Frequenzumrichtern und

Schutzmas̈snahmen diskutiert.

Bei der Erstellung dieser Arbeit, wurde auf die, im Anhang aufgeführte, Literatur als Quelle zurückgegriffen. An dieser Stelle soll den Autoren dieser Arbeiten ein herzlicher Dank ausgesprochen werden.

Keywords

Uninterrupted power supply, Battery, Charging, Discharging, Amplifier, Simulation, Load overheating protection, Timing system, Low pass filter, Differential amplifier, Converter, Rectifier, Inverter, 6SE70, Emergency switch.

Acknowledgements

The master thesis is developed under the background of an investigation about realization of an UPS system for a cooling system in metallurgy industry.

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I especially want to thank my parents, my friends, my girlfriend, and all the people who helped me.

Tang Xin
Leoben, 1. Feb. 2008

Declaration

I declare in equivalence to an oath that I, myself, composed this thesis and that the work contained therein is my own, except where stated.

Tang Xin
Leoben, Feb. 1, 2009

Erklärung

Ich erkläre hiermit an Eides Statt, dass die vorliegende Diplomarbeit von mir selbst und nur unter Verwendung der angeführten Literatur verfasst wurde.

Tang Xin
Leoben, Feb. 1, 2009

Contents

Chapter 1

Structure of Uninterrupted Power System

1.1 Uninterrupted Power Supply (UPS) Details

1.1.1 Introduction to UPS

UPS, the abbreviation for Uninterrupted Power System, is an important external equipment which can supply continuous, stable and uninterruptible power.

- Basically, UPS is a device integrating digital and analog circuits, automatically-controlled inverter and maintenance-free energy-storage element.
- Functionally, UPS is capable of effectively purifying the power grid when it goes into abnormality. UPS also can feed the load device for certain period of time when the power grid breaks off suddenly, thus ensuring the industrial system has sufficient time to handle such fault.
- Referring to its purposes, with the coming of the information society, UPS has extensively used in all links from information acquisition, transmission, processing and storage to application. Its importance has been highlighted following the increasing importance of information application.

1.1.2 Components of UPS

Referring to the basic application principles, UPS is a power supply protecting device with an energy-storing device and stabilized voltage and frequency output, and mainly comprises a rectifier, a storage battery, an inverter and a static switch.

1. **Rectifier**: Simply speaking, it is a device used for converting alternating current (AC) to direct current (DC). The rectifier has mainly two functions: Firstly, it converts alternating current (AC) to direct current (DC), and then supplies the direct current to a load or an inverter after going through a filter; secondly, it provides the storage battery with charging voltage. Therefore, it also serves as a charger. [1]

2. **Storage battery**: A storage battery is a device adopted for the UPS to store electric energy. The storage battery consists of a large number of batteries connected in series. Its capacity determines the duration of discharge (power supply). The storage battery has the following functions mainly:

   (a) When the grid power is in normal status, the storage battery converts the electric energy to chemical energy and stores the latter inside the batteries.

   (b) When the grid power breaks down, the storage battery converts the chemical energy to electric energy and provides the latter to the inverter and further to the load.

3. **Inverter**: Generally, an inverter is a device for converting direct current (DC) to alternating current (AC). The converter which consists of an inverter bridge, control logic and a filter circuit.

4. **Static switch**: Static switch is a contactless switch. It is an AC switch made up by two silicon-controlled rectifiers (SCR) reversely connected in parallel. The closing and opening of the static switch is controlled by a logic controller. Moreover, static switches can be divided into conversion and combined type. A conversion type switch is mainly used for the system powered by two power supplies to realize the automatic switching from one circuit to the other circuit; a combined type switch is mainly used for parallel inverters and grid power or large number inverters. [2]

1.1.3 Types of UPS

UPS may be divided into backup and online types according to the operating principles:

- **Standby UPS** is a most common UPS, which possesses the most basic and most important functions such as automatic stabilizing and power-off protection. Although with the change over time about 10ms generally, and the AC output by the inverter is not sine wave but square wave in most cases, backup UPS is extensively used for various fields due to such advantages as simple structure, low price and high reliability.

- **Online UPS** has complex structure, but improved performance, thus being capable of solving all problems concerning the power supply. The online UPS is characterized in that it is capable of offering pure sine wave alternating current in a continuous manner also during the transitions between grid power and battery power, and back again, solving all power supply-related problems such as peak, surging and frequency variation, etc. Online UPSs are generally used in such environment with harsh requirements on electrical power and cause larger investment. [3]

1.1.4 Necessity of UPS

In China, the average frequency of power cut in large cities is 0.5 time/month, 2 times/month in medium-size cities, 4 times/month in small cities and small towns. At least, the following nine problems exist in the power grid: power cut, peak caused by lightning, surging, frequency vibration, voltage leap, voltage hunting, frequency variation, voltage drop, pulse interference, so it is necessary for industrial systems or the systems requiring high-quality power supply to be equipped with UPS.

1.1.5 Selection of UPS types for medium power industrial

Suitable UPS shall be chosen according to the equipment conditions, electricity consuming environment and the purpose of protecting the power. For example, backup UPS are generally applicable for small-power equipments with built-in switch power supplies. Besides, only online UPS is allowable for equipment that does not allow interruption time and require sine wave AC.

1.1.6 Required power of this UPS system

The power for the UPS demanded for this system is supplied by a three-phase asynchronous motor with the power at 10kW. It is used for cooling purposes in metallurgy industry. Generally, the power factor of either backup type or online interactive type UPS is between 0.5 and 0.7, whereas the power factor of an online type UPS is 0.8. It is preferred load the UPS not higher than 60%, thereby achieving the highest reliability. In order to ensure safety, the power rating of the UPS power supply system shall be 2 times higher than that of the motor, namely 20kW.

1.1.7 Cautions during using UPS

1. The environment for using the UPS shall be well ventilated, good at heat radiation and clean.
2. The output load of the UPS shall be limited at about 60% preferentially to achieve the highest reliability.
3. Extremely small load on the UPS may cause deep discharge of the batteries, and reduce the service life of the batteries. The situation above mentioned shall be prevented by battery under-voltage detection and turn off of battery at the limit.
4. Appropriate discharge is helpful to activate the batteries. If the commercial power cut doesn’t happen in a long term, it’s necessary to cut off the commercial power deliberately

and let the UPS with load to discharge once every three months, so as to extend the service life of the batteries. This also ensures operation.

5. After discharge, UPS shall be charged promptly to avoid the damage of the battery caused by extended exposure time at low charge state causing irreversible chemical degradiation.

1.1.8 Common electrical problems and different solutions

It is a common misunderstanding to consider the commercial power as continuous and stable except for occasional power cuts. However, it is not the fact. The commercial power system, serving as public power grid, is connected with thousands of various loads, among which such loads as large inductive and capacitive loads as well as loads of switch power supplies, etc. Load not only obtains electrical energy from the power grid, but also causes adverse effect to the power grid itself by deteriorating the power supply quality of the power grid. Besides, unexpected natural accidents and accidents caused by human beings, such as fire, lightning strike, short circuit of the power transmission and transformation system, also can damage the normal supply of electricity, and affect the normal operation of the load. According to the test conducted by certain electrical experts, the problems regularly occurred in the power grid to cause damage and interfere against the computers and precise instruments are mainly as follows:

1. **Power surges**: That effective value of the output voltage is 110% higher than the rated value, and the duration thereof is one or several cycles. The power surge mainly refers to the high voltage generated in the power grid due to accident unloading when the large electrical facilities connected to the power grid are powered off.

2. **High voltage spikes**: The voltage with peak values up to 6000V in standard 400V grid and the duration from 0.1 millisecond to 1/2 cycle (10ms). High voltage spikes are mainly generated during lightning strike, arc discharge, static discharge or on/off operation of large electrical facilities.

3. **Switching transients**: The pulse voltage with the voltage peak value at 20000V in standard 400V grid and the duration from 1 micro- to 100 micro-second. The main reasons for the generation of switching transients and the adverse effects thereof are similar with that of high voltage spikes, whereas their solutions may be different.

4. **Power sags**: The low voltage status that the effective value of commercial power voltage is between 80% and 85% of the rated value, and the duration is from one or several cycles. Such problems may be caused by the startup of large equipments, large motors and connection in of large electrical transformers.

5. **Electrical line noise**: Radio frequency interference (RFI), EFI and other high frequency interference, which can be caused by motor running, relay operation, operation of motor controls, broadcast transmission, microwave radiation, and electricity storm etc.

6. **Frequency variation**: The variation of the grid power frequency usually stays within 0.05 Hz but can be higher than 3Hz, which is mainly caused by the unstable running of the emergency motor or power supply with unstable frequency.

7. **Brownout**: The effective value of the grid power voltage is lower than the rated value and the duration is very long. The main reasons include start and application of large equipments, switching of main power line, startup of large motors and overload of the lines, etc.

8. **Power fail**: Grid power failure and the duration at least from two cycles to several hours. The main reasons for power fail included tripping of breaker in the line, interruption of the grid power supply, power grid failure, etc. [4]

1.1.9 Proper use and maintenance of UPS storage battery

- Keep appropriate ambient temperature: The main reason affecting the service life of the storage battery is ambient temperature. Generally, the best ambient temperature requested by the manufacturer is between 20°C and 25°C. Although the increased temperature can improve the discharge ability of the battery, the cost is that the service life of the battery is greatly shortened. According to the test result, if the ambient temperature is higher than 25°C, every 10°C increase on such basis may cause the service life of the battery to be shortened by half. The current storage battery used by the UPS mostly is sealed lead acid storage battery free of maintenance, with 5 years designed service life, which can be achieved under the environment required by the manufacturer. If the regulated environment request is not achieved, the service life of the battery can be greatly different. Besides, increased temperature can strengthen the chemical activity inside the battery to generate a lot of heat energy, which can increase the ambient temperature in turn. This kind of faulty cycle may accelerate shortening the service life of the battery.

- Regular charge and discharge: Float charge voltage and discharge voltage in the UPS power supply have been adjusted to the rated values when the UPS power supply leaves the factory, but the discharge current will increase following the load, so the load shall be adjusted reasonably in the application. Generally, the load shall not exceed 60% of UPS' rated load within this range, the discharge current of the battery will not over discharge. Because UPS is connected to the commercial power in a long term and it is in an environment with high quality of power supply and seldom power system failure, so the storage battery is in float charge condition in a long term, which will decrease the mutually transformation activity of battery chemical energy and electrical energy and will shorten its lifetime due to speed up aging after a long term. So generally every 2-3 months, it shall be totally discharged once and the discharge time can be decided according to the capacity and load of the storage battery. After the full load discharge is finished, the storage battery shall be charged again for more than 8 hours according to the regulation. [5]

- Charging with gas-generating voltage: For a lead-acid battery cell, applying a voltage of more than 2.25V to 2.3V per cell causes electrolysis with generation of $2H_2$ and O_2 out of water (H_2O) which is part of the electrolyte. This gaseous mixture of $2H_2$ and

O_2 can explode if ignited by a spark and might destroy the battery. Heavy electrolysis deteriorates the metal plates in the battery and a lots of water.

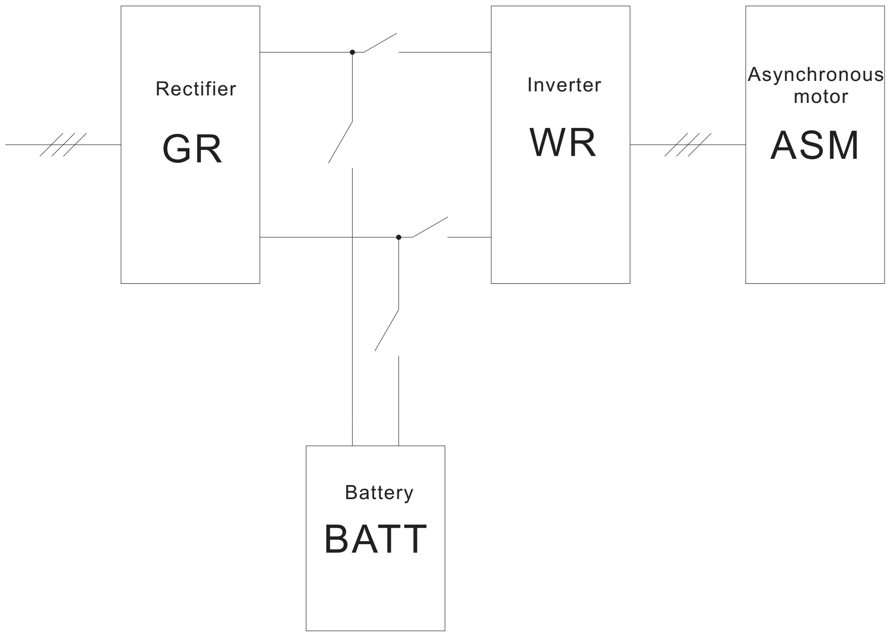


Figure 1.1: Components of UPS

1.2 Application of UPS in the Industry Cooling System

1.2.1 Task introduction

The UPS power in this system which is used to drive a 10kW asynchronous motor is used as the backup power for the cooling system for a metallurgy process. According to the theory stated before, the power of an excellent UPS system shall be 2 times of that motor, so the power of the storage battery itself shall be 20kW. If the rated operating voltage range of each battery roughly supposed to be 12±1.5 V and its rated discharge current to be 50Ah, then it needs about 35 batteries in series for a transformerless 3-phase solution. If 40 storage batteries with the same model in series are planned to be used in this system as the core of UPS, then it can stand 10kW short-term (about 1 hour) workloads. The way of connecting the storage battery into the electricity network as reserve power is shown in figure 1.1. When the electricity network is in normal operation, the current in the electricity network after being rectified and inverted can drive asynchronous motor with load when the storage battery is in charging condition and will not supply power to the load. If the electricity network can not normally drive the load due to failure, then the electricity network will not supply power to the load, when the storage battery group is connected into the input end of the inverter in order to provide power to the load in a short term until the repair of the electricity network is finished.

Chapter 2

Accumulator and Battery Discharging Circuit

2.1 Introduction of Accumulator

A rechargeable battery, also known as a storage battery, is a group of two or more secondary cells. These batteries can be restored to full charge by the application of electrical energy. In other words, they are electrochemical cells in which the electrochemical reaction that releases energy is readily reversible. Rechargeable electrochemical cells are therefore a type of accumulators. They come in many different designs using different chemicals. Commonly used secondary cell chemistries are lead and sulfuric acid, nickel cadmium (NiCd), nickel metal hydride (NiMH), lithium ion (Li-ion), and lithium ion polymer (Li-ion polymer).

This experiment applies second-hand batteries. Available are in total 54. Parameters are as follows [6]:

- Pb Battery (Oerlikon) 12CP50 12V-50Ah
- Float voltage: 13,5V±1% (20°C)
- 5,0A for 10h to 10,8V (20°C)
- 6,3A for 8h to 10,5V (20°C)
- Connection torque:4Nm-2,91bf ft
- LEM-UNIGOR 355

Figure 2.1: Pb Battery (Oerlikon) 12CP50 12V-50Ah

Figure 2.2: Oerlikon battery

2.2 Introduction of Charge Detection

While in charging test, all the batteries are connected in parallel, they are charged through a constant voltage power supply, the voltage of the power supply is established to slightly higher than 13.5V, the current is established to 0.3A, through long-time observation, the situation of each battery's voltage increase are inspected and written down. Then from the value of voltage variation analysis over a certain discharge test whether the battery is qualified, it can be judged.

2.3 Introduction of Discharge Detection

As described before, the power of the asynchronous motor (cooling electrical machinery for metallurgy process cooling pump) required for this project is 9kW, calculating on the basis that the efficiency of motor is 85%∽95%, an input of about 11kW would be needed. If calculating based on use of 20 batteries, the individual power thereof will be 550W. The operating voltage of the battery is supposed to be within the range of 10V∽14V, the current of each battery required will be 45.83A based on the average voltage of 12V. From the point of view of the current value, a circuit capable of withstanding at least 100A would be necessary for the purpose of safe production. During the detection of discharge, an essential matter is that when in operation, i.e. the voltage is within the range of 10V∽14V, the battery may maintain a discharge at constant rating, which in this project is 550W. Therefore, when designing the circuit, the voltage drop along with the discharge process, the current would increase accordingly, thereby maintaining the consistency of power.

$$P = U \cdot I \tag{2.1}$$

2.3.1 Calculation of battery equivalent discharging resistance

Calculation from the data of the battery,

- Pb Battery (Oerlikon) 12CP50 12V-50Ah
- Float voltage: 13,5V±1% (20°C)
- 5,0A for 10h to 10,8V (20°C)
- 6,3A for 8h to 10,5V (20°C)

If the battery discharges at the current of 5A for duration of 10 hours, the voltage of the battery drops from 13.5V to 10.8V. By means of rough calculation, the 10V, 12V and 14V voltages

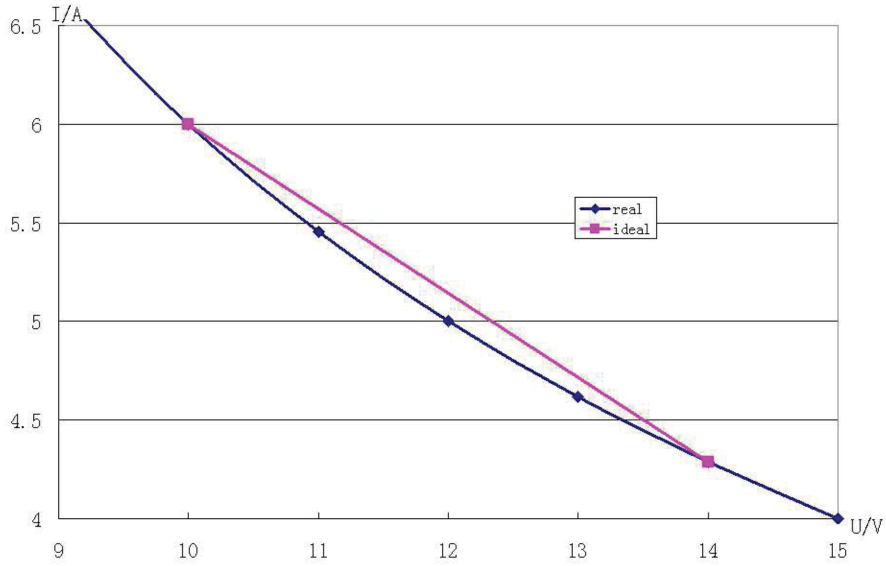


Figure 2.3: Real and approximate U-I curve

are taken as the reference points, consider 60W to be the discharging power of the battery, the current value at the various voltage points are found out:

$$I = \frac{P}{U} \tag{2.2}$$

At the voltage of 12V

$$I = \frac{60W}{12V} = 5A \tag{2.3}$$

At the voltage of 10V

$$I = \frac{60W}{10V} = 6A \tag{2.4}$$

At the voltage of 14V

$$I = \frac{60W}{14V} = 4.29A \tag{2.5}$$

It can be seen from the figure 2.3 that, in operational range of the battery (10V-14V), a section of arc can be deemed as a line. This means that within a small variation range of voltage, the change of current is linear, when the voltage drops from 14V to 10V, the current increases linearly, the current at a voltage of 12V may be considered to be the average between 14V and 10V. That is to say, when discharging, before the voltage of battery drops to 10V, the discharge may be considered to be constant at 12V, and the current value is constant as that at the voltage of 12V. The advantage of a linear is the assumption of load current versus battery voltage is the simple calculation of the corresponding reference current between 14V and 10V, the circuit design will be simplified.

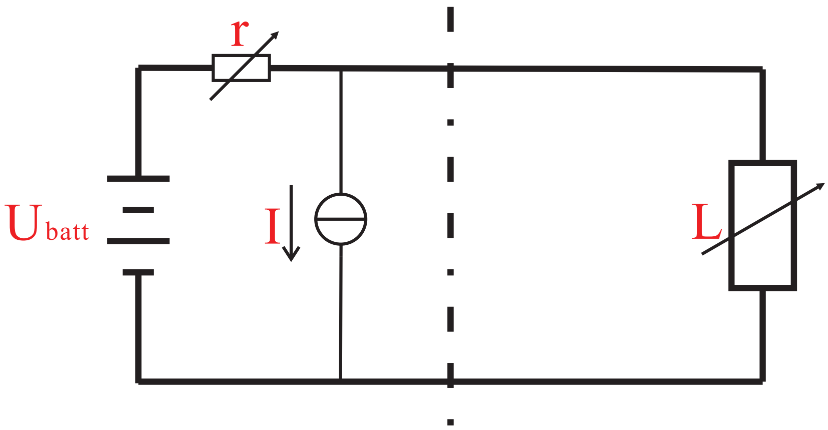


Figure 2.4: Battery equivalent circuit

The aim was to keep the power of the battery circuit constant as shown in figure 2.4. When the battery is discharged, due to the variable loads, the current is also variable, therefore the internal resistor is variable and the discharging power is kept constant with decreasing the battery voltage and increasing the battery current. When the battery is discharged, the current can be calculated as follow:

$$I = I_{12v} - \Delta I(U_{batt}) \tag{2.6}$$

$$I = \frac{60W}{12V} - \frac{U_{batt} - 12}{\mid \frac{\Delta U}{\Delta I} \mid} \tag{2.7}$$

$$\mid \frac{\Delta U}{\Delta I} \mid = \mid \frac{10 - 14}{4.29 - 6} \mid = 2.34\Omega \tag{2.8}$$

Then the formula 2.8 is taken into the 2.7,

$$I = \frac{60W}{12V} - \frac{U_{batt} - 12}{\mid \frac{\Delta U}{\Delta I} \mid} = 10.13 - 0.427 \cdot U_{batt} = constantA - constantB \cdot unknownC \tag{2.9}$$

From the formula 2.9 it can be seen, if $U_{batt} = 12$V, I_{out} is 5A; if $U_{batt} > 12$V, $I_{out} < 5$A; whereas if $U_{batt} < 12V$, $I_{out} > 5$A. Based on the formula the established model can be used to realize power constant discharging circuit.

2.4 Electronic Elements

2.4.1 78L05 Voltage Stabilizer

2.4.1.1 Introduction

78L05 is one type of the LM78LMXX series of 3 terminal positive regulators. 78L05 has important application in this experiment.

The LM78LXX series of three terminal positive regulators are available with several fixed output voltages making them useful in a wide range of applications. When used as a zener diode/resistor combination replacement, the LM78LXX usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM78LXX to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. The LM78LXX is available in the plastic TO-92 (Z) package, the plastic SO-8 (M) package and a chip sized package (8-Bump micro SMD) using National's micro SMD package technology. With adequate heat sinking the regulator can deliver 100 mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistors is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

- LM78L05 in micro SMD package
- Output voltage tolerances of 5% over the temperature range
- Output current of 100 mA
- Internal thermal overload protection
- Output transistor safe area protection.
- Internal short circuit current limit
- Available in plastic TO-92 and plastic SO-8 low profile packages
- No external components
- Output voltages of 5.0V, 6.2V, 8.2V, 9.0V, 12V, 15V

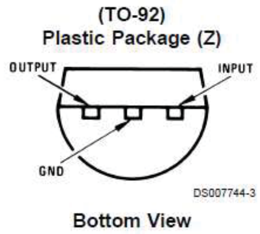


Figure 2.5: Connection diagram of 78L05

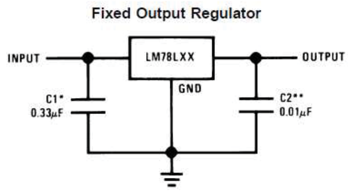


Figure 2.6: Typical application of 78L05

2.4.2 TL084 Operational Amplifier

2.4.2.1 Introduction

The TL084 is high speed J-FET input quad operational amplifier incorporating well matched, high voltage J-FET and bipolar transistors in a monolithic integrated circuit.

- Wide common-mode (up to Vcc) and differential voltage range
- Low input bias and offset current
- Output short-circuit protection
- High input impedance J-FET input stage
- Internal frequency compensation
- Latch up free operation
- High slew rate:16V/us

2.4.2.2 Typical application

1. Voltage follower amplifier (see figure 2.8) [7][8]

$$U_o = U_i \tag{2.10}$$

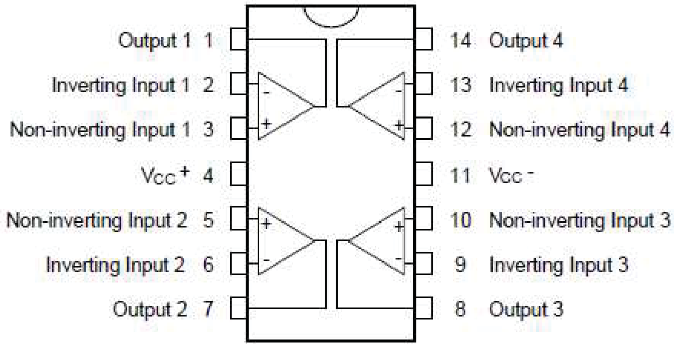


Figure 2.7: Top view of TL084

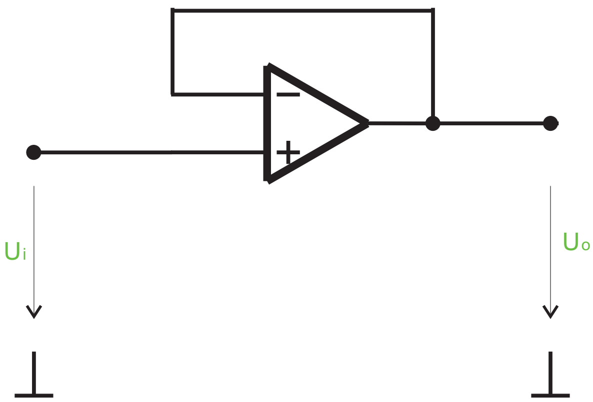


Figure 2.8: Voltage follower amplifier

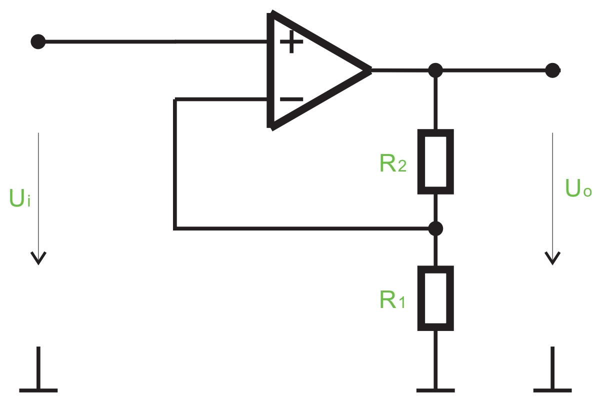


Figure 2.9: Non inverting amplifier

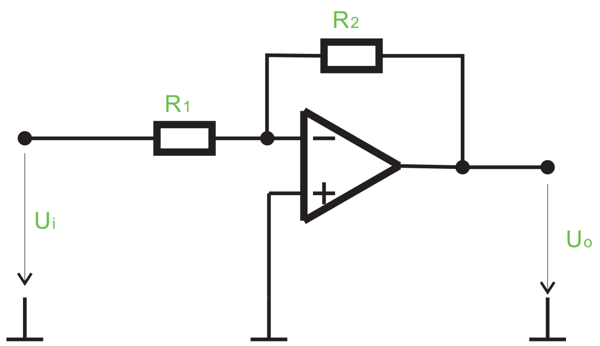


Figure 2.10: Inverting amplifier

2. Non inverting amplifier (see figure 2.9)

$$U_o = (1+\frac{R_2}{R_1}) \cdot U_i \tag{2.11}$$

3. Inverting amplifier (see figure 2.10)

$$U_o = -\frac{R_2}{R_1} \cdot U_i \tag{2.12}$$

4. Summing amplifier (see figure 2.11)

$$U_o = -(\frac{R_2}{R_{11}}U_{i11} + \frac{R_2}{R_{12}}U_{i12} + \frac{R_2}{R_{13}}U_{i13}) \tag{2.13}$$

if R_{11}=R_{12}=R_{13}=R_1

$$U_o = -\frac{R_2}{R_1}(U_{i11} + U_{i12} + U_{i13}) \tag{2.14}$$

5. Differential amplifier (see figure 2.12)

$$U_o = \frac{(R_1+R_2)R_4}{(R_3+R_4)R_1}U_{i2} - \frac{R_2}{R_1}U_{i1} \tag{2.15}$$

if R_1=R_3;R_2=R_4

$$U_o = \frac{R_2}{R_1}(U_{i2} - U_{i1}) \tag{2.16}$$

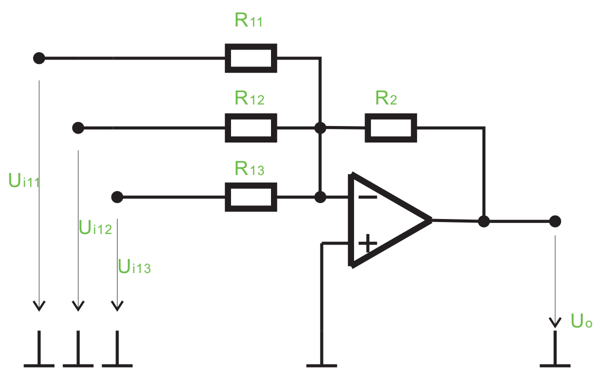


Figure 2.11: Summing amplifier

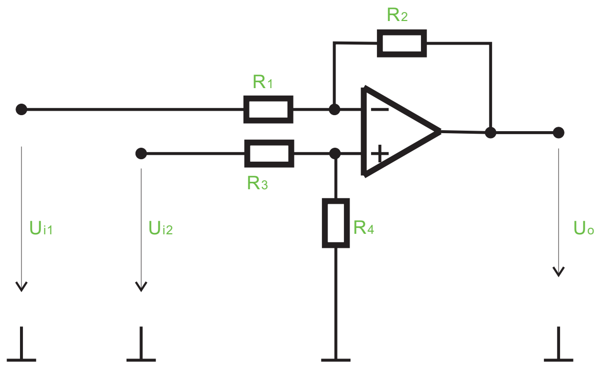


Figure 2.12: Differential amplifier

2.4.3 BC237/238 Bipolar Transistor

2.4.3.1 Introduction

BC237/238 is a sort of amplifier transistor triode which can be used as a power amplifier, and it can enlarge the current to the MA-class. Using this emitter current as base current of the power amplifier, it can be realized the safe on-off of the power amplifier. Besides, combining with LED, BC237/238 can make up of a signal light, so it can well perform its function as a switch by controlling the base current.

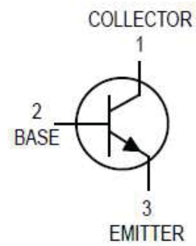


Figure 2.13: Connection diagram

Figure 2.14: Real figure of BC237/238

2.4.4 CD4093 CMOS Logic Circuit

2.4.4.1 Introduction

CD4093 is CMOS Quad 2-input NAND schmitt triggers, it consists of 4 schmitt-trigger circuits. Each circuit functions as a 2-input NAND gate with schmitt-trigger action on both inputs. The gate switches at different points for positive- (U_P) and negative-going (U_N) signals. Through controlling the 2-input voltage (digital signal: high=1; low=0), different output voltage can be got.

Features

- Schmitt-trigger action on each input with no external components
- Hysteresis voltage typically 0.9V at V_{DD}=5V and 2.3V at V_{DD}=10V
- Noise immunity greater than 50%
- No limit on input rise and fall times
- Standardized, symmetrical output characteristics
- Maximum input current of 1μA at 18V, overfull package temperature range, 100 nA at 18V and 25°C
- 5V,10V AND 15V parametric ratings

Applications

- Wave and pulse shapers
- High-noise-environment systems
- NAND logic

Figure 2.15: Positive Temperature Coefficient

U_{in1}	U_{in2}	U_{out}
0	0	1
0	1	1
1	0	1
1	1	0

Table 2.1: The logic between input and output [9]

2.4.5 Thermistor (PTC)

2.4.5.1 Introduction

Positive Temperature Coefficient (PTC) refers to materials that experience an increase in electrical resistance when their temperature is raised. Materials which have useful engineering applications usually show a relatively rapid increase with temperature, i.e. a higher coefficient. The higher the coefficient, the greater an increase in electrical resistance for a given temperature increase. This effect can be used to create resettable fuses, often as part of a semiconductor. As the temperature rises, nearing danger levels, the resistance increases, so less current flows, thereby protecting the vulnerable equipment that receives the current flow. These products often use electron beam processing in their manufacture. Commonly used PTC materials include:

- High density polyethylene filled with a carefully controlled amount of graphite, so that the volume increase at the glass transition temperature causes the conducting particles to break contact (also known as Poly-switch fuses)
- Titanate ceramic materials, which work by gain boundary effects

PTC materials are sometimes used as heating elements, because such elements act as their own thermostats, switching off the current when reaching their maximum temperature.

2.4.5.2 Application of thermistor (PTC) in this item

PTC used in this experiment has the following characteristics: When the temperature is higher than 60°C, it will present as the high-impedance state. When the temperature is lower than 60°C, it will present as the low-impedance state. Based on characters like these, they can be used to watch the power load employed in the battery detection. During the detection of the battery discharge, there will be a heavy current flowing through the load, resulting in a high temperature on the surface of the load. As a result of the excessive varying of the termination temperature, the load resistance will be varied and the safety will be reduced. The combination of thermal fin and air cooling system can effectively control the temperature of the load, but the experiment must be terminated immediately if some damage of the cooling system had taken place or the load temperature is higher than some specific value. That means some element, which can precisely measure the temperature, would be required to stop that discharging of the battery. PTC thermistor has just this character. Because of its different resistance with different temperature, PTC can be employed together with CD4093 to output the high level or low level. Using this power level as the base signal of BC238, we can control the on-off of the circuit connected to its terminals.

2.4.6 CD4049 CMOS Logic Circuit

2.4.6.1 Introduction

The CD4049 and CD4050 devices are inverting and non-inverting hex buffers feature logic-level conversion using only one supply voltage (V_{CC}). The input signal high level (V_{IH}) can exceed the V_{CC} supply voltage when there devices are used for logic-level conversions.

Features

- CD4049 Inverting
- CD4050 Non-Inverting
- Wide supply voltage range 3.0V to 15V
- Direct drive to 2 TTL loads at 5.0V over full temperature range
- High source and sink current capability
- Special input protection permits input voltages greater than V_{DD}
- 5V, 10V and 15V parametric ratings

Applications

Figure 2.16: Connection diagram of CD4049 & CD4050

- CMOS hex inverter/buffer
- CMOS to DTL/TTL hex converter
- CMOS current "sink" or "source" driver
- CMOS high-to-low logic level converter

2.4.7 HEF4521 (24-stage frequency divider and oscillator)

2.4.7.1 Introduction

The HEF4521B consists of a chain of 24 toggle flip-flops with an overriding asynchronous master reset input (MR), and an input circuit that allows three modes of operation. The single inverting stage (I_2/O_2) will function as a crystal oscillator, or in combination with I_1 as an RC oscillator, or as an input buffer for an external oscillator. Low-power operation as a crystal oscillator is enabled by connecting external resistors to pins 3 ($V_{SS'}$) and 5 ($V_{DD'}$). Each flip-flop divides the frequency of the previous flip-flop by two, consequently the HEF4521B will count up to 2^{24}=16777216. The counting advances on the HIGH to LOW transition of the clock (I_2). The outputs of the last seven stages are available for additional flexibility.

	500kHz Circuit	50kHz Circuit	unit
Crystal characteristics			
resonance frequency	500	50	kHz
crystal cut	S	N	-
equivalent resistance:R_s	1	6.2	$k\Omega$
External resistor/capacitor values			
R_O	47	750	$k\Omega$
C_T	82	82	pF
C_S	20	20	pF

Table 2.2: External circuit parameters

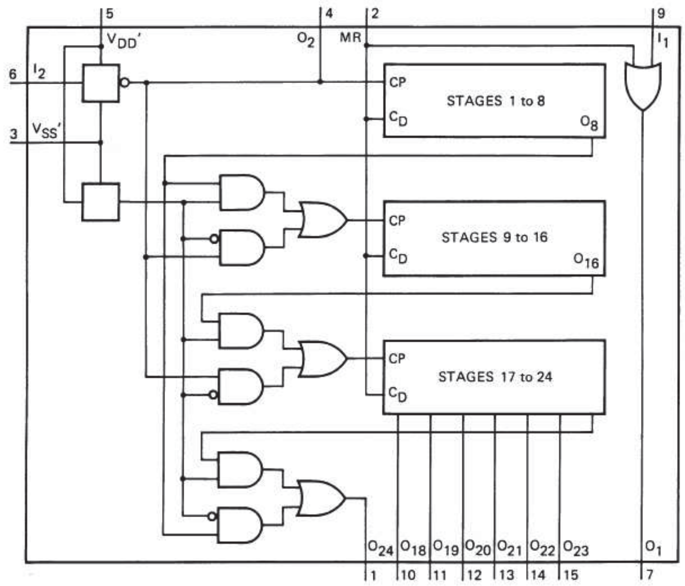


Figure 2.17: Functional diagram of HEF4521B

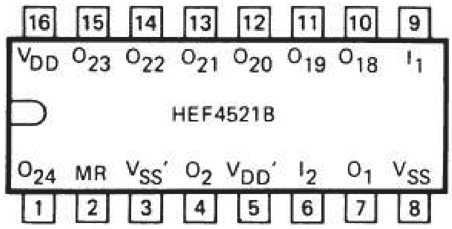


Figure 2.18: Connection diagram of HEF4521B

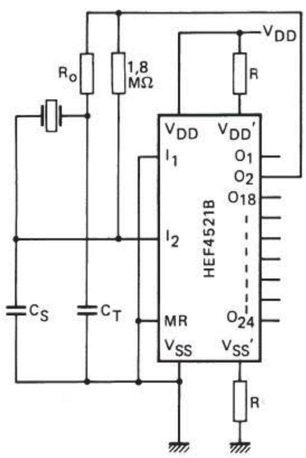


Figure 2.19: Crystal oscillator circuit

2.4.7.2 Application of HEF4521 in this item

HEF4521 is a sort of frequency divider with 24 classes, in which an oscillator circuit is integrated which allows using a quartz crystal for high temperature stability. While in use, different frequencies will be generated at different outputs only by combining the HEF4521 and a frequency generator, which in general is quartz oscillator. From the table 2.3, if 16.777MHz quartz is applied, output O_{24} will generate a 1Hz frequency, and similarly at output O_{23} will generate a 2Hz frequency, by parity of reasoning. The quartz used in this experiment is the 4.19MHz one. From the table, pin 14 will generate a 1Hz frequency at O_{22}. The cycle of a 1Hz frequency is one second, which means the signal generated at O_{22} can be a stopwatch to be used as a calculation of battery discharge experiment. Connecting a frequency counter with the stopwatch, we can know the time span of battery discharge by reading the number indicated on the frequency counter.

OUTPUT	COUNT CAPACITY
O_{18}	2^{18}= 262 144
O_{19}	2^{19}= 524 288
O_{20}	2^{20}= 1 048 576
O_{21}	2^{21}= 2 097 152
O_{22}	2^{22}= 4 194 304
O_{23}	2^{23}= 8 388 608
O_{24}	2^{24}=16 777 216

Table 2.3: Count capacity

In the battery discharge experiment, it is not nearly enough to synchronize the frequency counter with discharging. When the experiment is interrupted because of some particular factors, for example, the exorbitant temperature of the load feed backed to the protective circuit by PTC, or voltage of battery being lower than some specific value, will both cut off the discharge circuit, the frequency counter will be required to simultaneously stopped. The counter won't go on counting until some manual operation gets the battery back to be the discharging state. In this experiment the counter must have this function, otherwise we can't get the accurate time span of the discharge. And if we can't get precise data from the experiment, the characteristic of the battery couldn't be determined correctly.

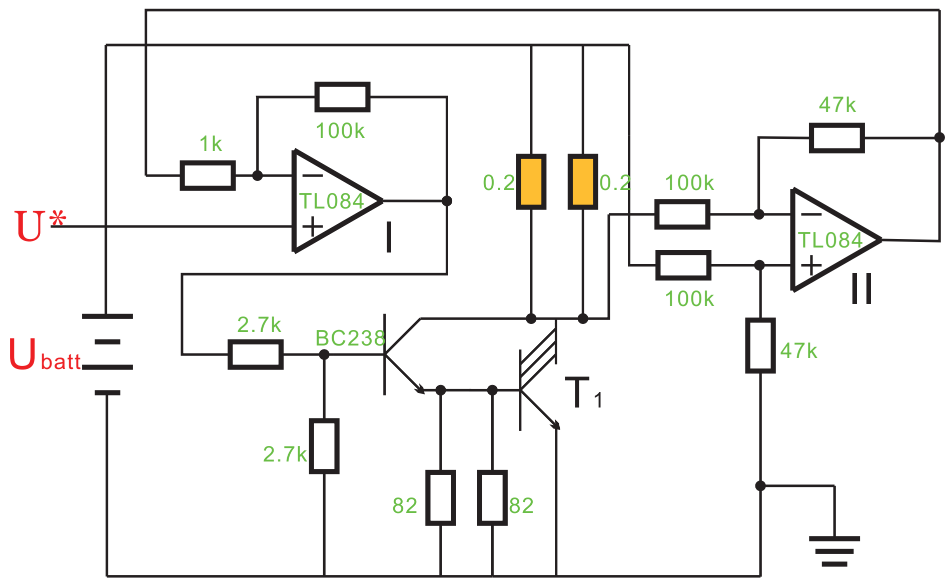


Figure 2.20: Main battery discharge circuit

2.5 Main Battery Discharge Circuit with Constant Power or Constant Current

2.5.1 Main battery discharge circuit

By the foregoing analysis and introduction of electronic components, the battery discharge circuit can be designed as follows based on the demand of its characteristics. The specific planning has been shown in the figure 2.20. This circuit is made up of a battery, TL084, BC238, a power amplifier, a heavy current load resistor, some heat dissipation device, some lab resistor, some capacitor, 78L05, a switch and a sliding rheostat. The introduction of specific component has been mentioned above, so here is some detailed about this circuit. Supply of power and controlling component discharge in this discharge circuit is both the battery itself without any external power supply. So the battery must be assured working in rated voltage, which means the discharge experiment would be terminated if the battery voltage is lower than the certain value. The design of the protective circuit will be elaborated on in future.

In the figure 2.20 the yellow resistance is loading, using two parallel resistors. Amplifier I is P-controller and amplifier II is differential amplifier circuit. Darlington driver T_1 Dynatron BC238 is proposing circuit of Darlington circuit opening (that is, by controlling BC238 base circuit, to achieve control for Darlington transistor circuit). Amplifier II is responsible for monitoring two ends voltages of load resistor equivalent to a current-proportional voltage drop, which is feed back to comparator and for comparison with another voltage U^*. U^*, as a reference voltage, achieved by the other circuit (described in chapter 1). Controller output end can achieve the control of entire circuit. This circuit in total is a voltage controlled (U^*) current sink for the battery.

It has been stated in chapter 1 that the rated power is 600W and the rated voltage is 12V, which means the battery rated current is 50A with the rated power and the working span of battery voltage is 13.5V∽11V. After some calculation, the discharge current should be between 44.44A and 54.55A with rated power. Considering that the high power load resistor in this discharge circuit is two 0.2Ω, 300W resistors respectively in parallel, so the following is required: the voltage across the two load resistors should be between 4.4V∽5.4V; Discharge current ought to be lower than 50A when the voltage is higher than 12V, whereas discharge current ought to be higher than 50A when the voltage is lower than 12V. Thereby the battery can be assured to discharge with the 600W rated power.

In the lab, at first a feasibility study is done for discharge circuit. It's very dangerous to use 50A current. Therefore in accordance with 5A discharge current design, practical method very simple, just replacing the 0.2Ω resistor with 2Ω one. When circuit is feasible, we rechanged the load resistor in the circuit to 0.2Ω for the battery monitoring.

Battery discharge process should be carried out in accordance with certain conditions; discharge circuit requires two functions:

- constant power discharge
- constant current discharge

2.5.2 Discharge with constant power

The above introduced main circuit for battery discharge, through auxiliary circuit feedback, provides the following function: battery between 13.5V∽11V can be discharged at constant power to achieve capacity measurement of the battery. The external circuit discharge current is equal to:

$$I = 10.13 - \frac{U_{batt}}{2.34} = 10.13 - 0.427 \cdot U_{batt} = constantA - constantB \cdot U_{batt} \tag{2.17}$$

This formula is obtained by proximate calculate when battery voltage between14V∽10V, using 12V average voltage in lieu of all voltages within this interval. Then we can get a current formula depending on voltage. For a battery voltage between 14V∽10V, the formula can be used for linearity discharge.

From the formula we can see when battery voltage is higher than 12V, current lower than 5A; conversely when battery voltage is lower than 12V, current higher than 5A. There is only one variable U_{batt} in this formula. If 1V represents 1A, U^* in direct proportion to:

$$U^* \propto I = constantA - constantB \cdot U_{batt} \tag{2.18}$$

U^* can be signal of feedback to controller and used to control BC238 and further the current magnitude of discharge circuit. The specific circuits are shown in figure 2.21.

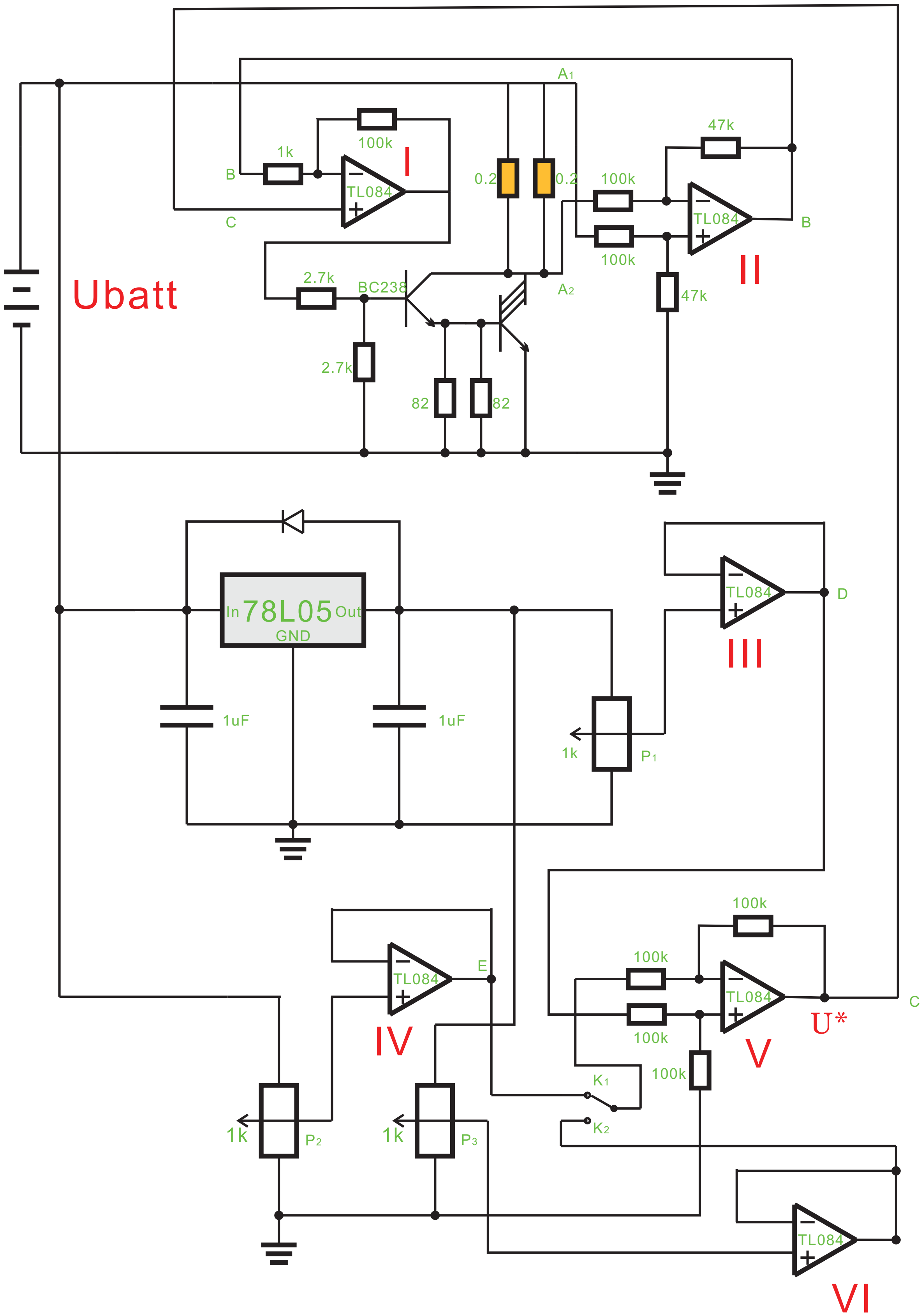


Figure 2.21: Complete discharge circuit

2.5.3 Discharge with constant current

The definition discharge at constant current is also involved in battery circuit. That's to say, keep the voltage between 11V and 13.5V, make the battery discharge with constant current, for example, 50A, record the time span of discharge, and then determine the quality (remaining capacity) of the battery. To get the discharge circuit diagram with constant current, it is only needed to make some small adaptation on the discharge circuit with constant power. In the discharge circuit with constant power, U^* is altered linearly as a feedback voltage, and the current is altered together with this voltage, so it is realized to keep the product of voltage and current namely power to be constant. As introduced above, the current is proportional to U^*, so it will not vary and discharge with a constant value if U^* was kept constant. If the switch in the figure 2.21 is closed to K_2, the current will be kept constant by control. Since what the K_2 is connected to is the voltage signal that comes from 78L05 through the sliding rheostat. We can get a current of any value by adjusting the sliding rheostat and U^* will be constant when we stop adjusting it, with the current constant correspondingly.

As stated above, the design of circuit has realized two forms of storage battery discharge. Switching K_1 and K_2 can perform both the discharge experiments with constant power and current. We can get the optimal discharge circuit by fine tuning the sliding rheostat.

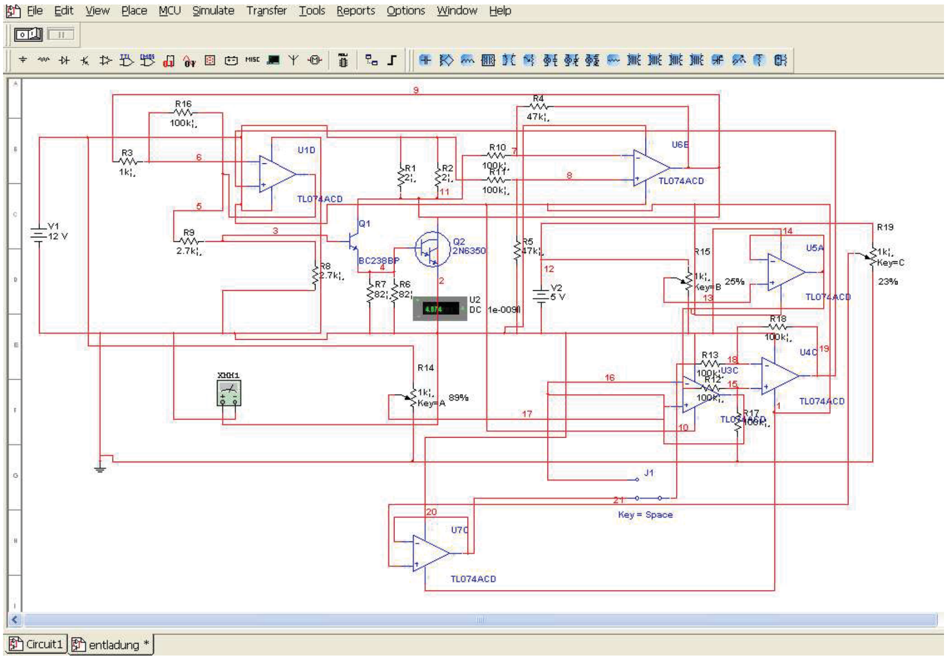


Figure 2.22: Discharge simulation in Multisim 10

2.6 Simulation

The computer simulation can be first applied as soon as the theory has formed. The simulation software in this experiment is Multisim 10. As the latest vision of Multisim published by NI (National Instruments), NI Multisim 10 is the upgraded vision of EWB (Electronics Workbench). NI Multisim 10 has adapted the means of software to simulate the electronics and electrical components, the instruments and meters. It is virtualization and simulation software of arranging the schematic circuit and testing the circuit function. The application of NI Multisim 10 can perform the computer simulation design and virtualization experiment, realize the synchronization of design with testing, be convenient to modify and debug, be easy to test and analyze the circuit parameters, directly print the experiment data, testing parameters, curves and the schematic circuit diagram. And it is low costing, quick, effective, and the circuit that has been designed and passed through the testing can be immediately put into service in the product. [10]

When the software is used to simulate the circuit, most common components can be found in Multisim 10. Some similar ones could also be useful if there was some that have not been designed in advance in the software. Considering that the computer simulation is an experiment in perfect state, so it is mostly used to check if the circuit is working like the theoretical assumption. But the experiment performed in the reality could not be possible sublimate, so some artificial modifying and supplement will be necessary to make the circuit optimal.

What has been shown in the figure 2.22 is the discharge circuit diagram with constant power simulated in computer, it can be seen from the diagram that this circuit can be run in accordance with the theoretical thought, and it could be moved to the next step of the experiment in the lab.

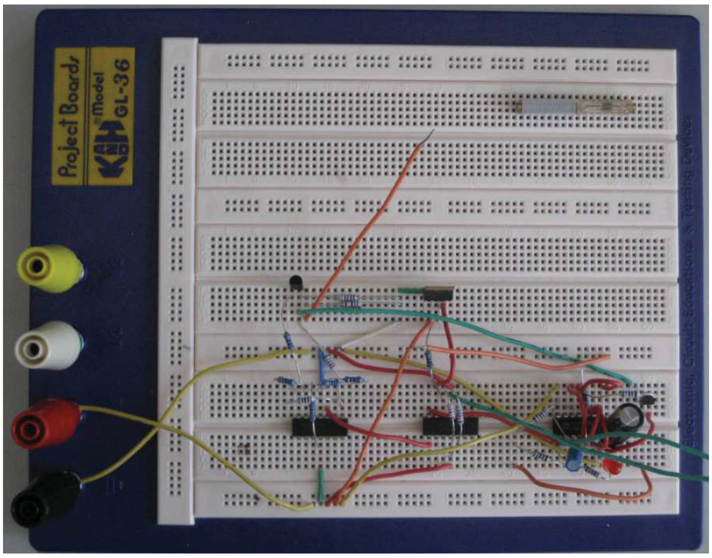


Figure 2.23: Experiment with project board

2.7 Application of Project Board in this Experiment

After the simulation of the circuit in computer, it could be done to start to actually operate to accomplish the assembly of the circuit. It would avoid a lot of needlessly wasted time to test on project board before soldering the circuit board. As shown in the figure 2.23, project board is a sort of circuit board applied in lab for the field of electronic circuits. On that board we can connect the electronic components in the form of plug and play, instead of soldering those on the board such as resistors, capacitors, inductors, diodes, triodes, switches. While in use, this assembled circuit can work as the soldering one, and the strongpoint is simple to operate without soldering. Further more, we can optimize by continual exchange of components until reaching a perfect state. It will increase the difficulty of modifying (need to remelt the soldering spot and take out the components for re-soldering) to solder the circuit on the board.

Some tests before soldering could be carried out after plugging the circuit on project board. The circuit has no difference with the soldered one in properties except that the components are not joint firmly. While testing the circuit, we could first use a relatively lower current.

In this experiment, we first adapt a 5A current as the test current. By this, improvement of the load part has to be done and the two 0.2Ω resistors will be replaced by the 2Ω ones. Now the resistance of them in parallel is 1Ω , 10 times of the resistance in the plan before. Obviously, the current will decrease by tenth of the initial value, which is 5A, with the constant voltage. At first the power supply of the lab is adapted to replace the battery. Manually adjust the power supply and make the voltage decrease slowly from 14V, simulate the effect of the storage battery discharge from 13.5V to 10.5V. Before recording the experimental data, we set the power voltage at 12V, and then measure the current. The discharge current can be increased or decreased by adjusting the sliding rheostat P_1 and P_2 in the circuit. So we can set the current at 5A, and record the voltage of point D and point E, output of amplifier III and IV respectively,

Figure 2.24: 0.2Ω resistor

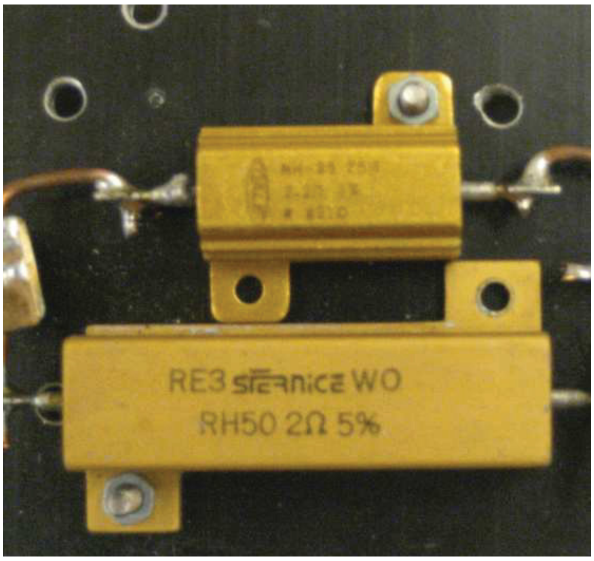


Figure 2.25: 2Ω resistor

and then we can carry out some tests on the circuit and an analysis of the data (see figure 2.21).

First of all, adjust the power voltage to about 13.6V, record the current value every time when the voltage decreases by 0.3V-0.5V until it comes to around 11V. Because of the heat, the load resistance will vary irregularly. So we must repeat the measurement for several times to obtain relatively precise experimental data. In this experiment, every time we get four groups of data (from 13.5V→11V→13.5V→11V). With the voltage interval of 0.5V, select the point and write down the current value. After that, carry out some analysis of data and draw them into tables. The following is the experimental result and the diagrams (see figure 2.26).

2.7.1 Testing in discharge experiment with constant power

From the experimental result, we can see the curve of voltage has almost come to a invariableness, but there is some relatively bigger bending on the edge, being a little far away from the

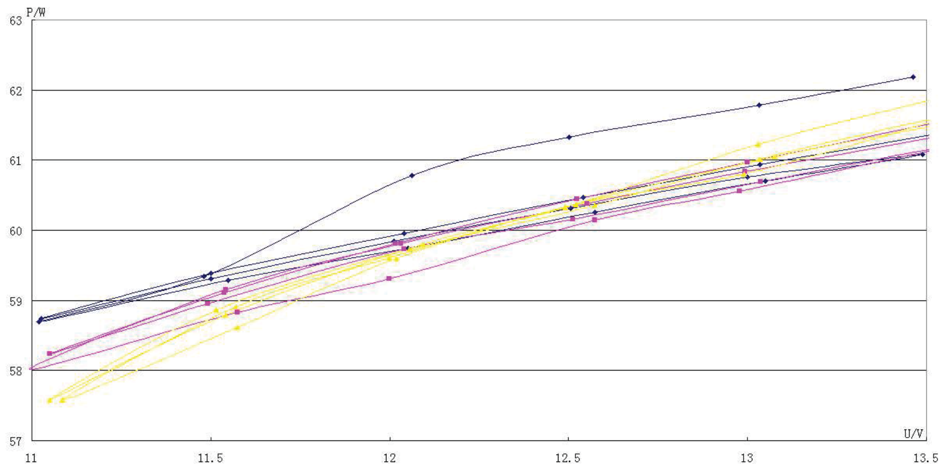


Figure 2.26: Before trimming

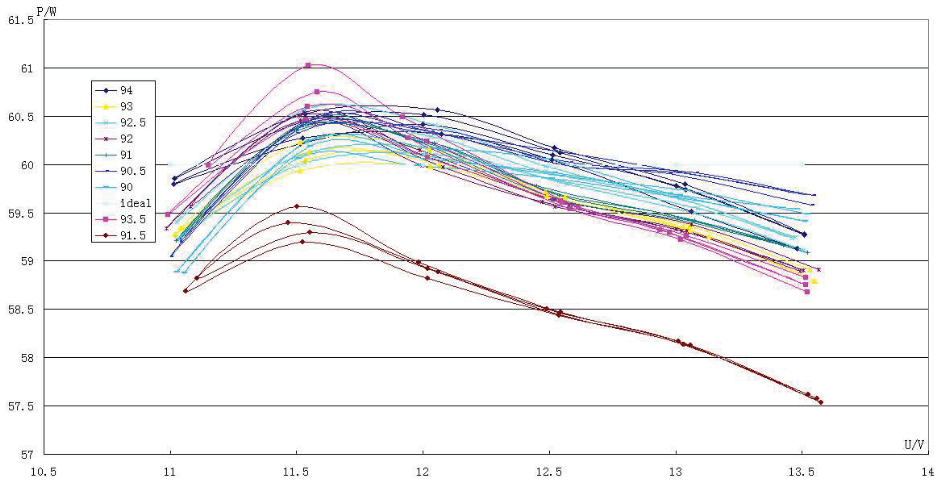


Figure 2.27: After trimming

perfect state. In such situation, what ought to be done is to reset the power voltage at 12V, adjust the sliding rheostat P_1 and P_2. Usually P_1 is first adjusted upwards or downwards from the 95% of 5V in turn. And then lock P_1 and adjust P_2 to make the ammeter invariable at 5A when the power voltage is 12V. After that let the battery discharge again and measure and write down the data (see Figure 2.27). Do that for several times, what is got is all in the table below. Find the optimal curve of constant power by some contrasting. The circuit arrangement corresponding to this curve is just the optimal arrangement, and then the circuit can be soldered and assembled according to that. By contrast, it can be seen green curve is close to ideal value, it can be installed according to green curve. Measuring the circuit again with this point, test results are shown in figure 2.28.

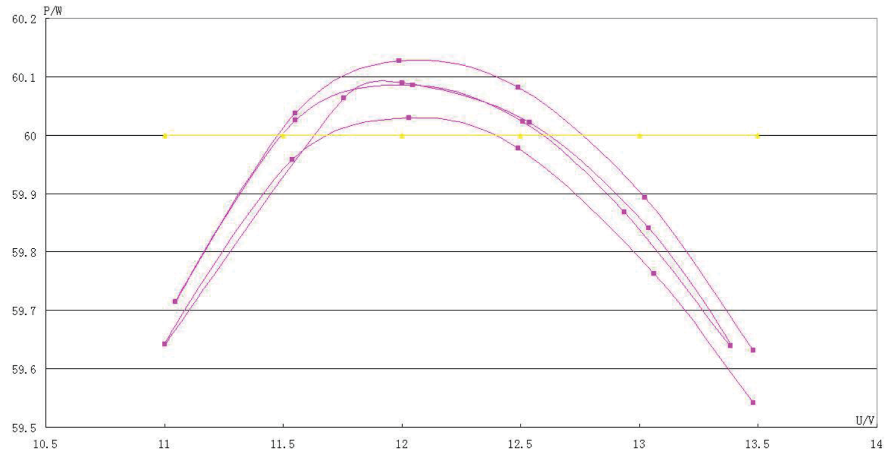


Figure 2.28: The optimal power constant discharge circuit

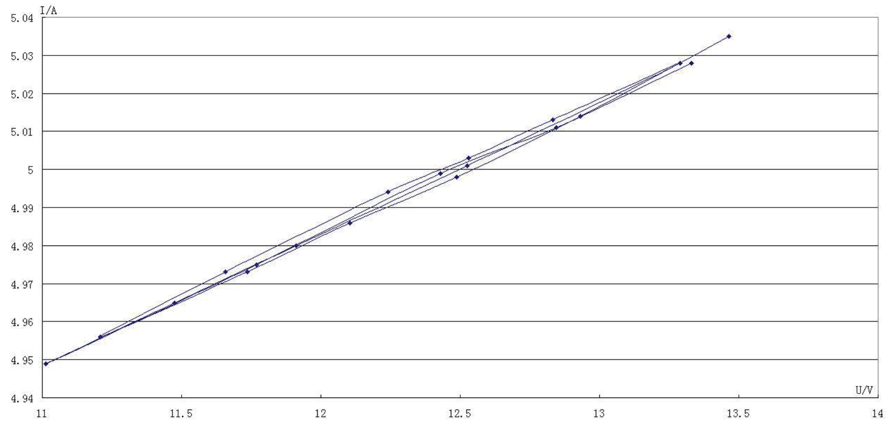


Figure 2.29: The optimal current constant discharge circuit

2.7.2 Testing in discharge experiment with constant current

Testing of discharge with constant current shown in figure 2.21 is also necessary besides that with constant power. First of all, get the switch set at K_2 from K_1, put through the power, adjust its voltage to 12V, keep the current invariable at 5A by adjusting sliding rheostat at P_3, then do the measurement after regulating the power voltage to around 13.5V with the way similar to the constant power experiment. It has been repeated that for several times and get the data down in the table below and fund the optimal curve of constant current after some contrasting. The circuit arrangement responding to this curve is just the optimal one. It can be soldered and assembled according to this arrangement. The test results are shown in figure 2.29.

According to the P-type control(proportional control) we get a certain influence of battery voltage on the current. P-control is very stable, rather fast but not totally precise. We preferred a robust P-control over a critical I-control.

2.8 Soldering the Circuit Board

After continuous modification and debugging the circuit diagram plugged on project board above, the circuit has been optimized and can be solder on the circuit board. We should do some planning before soldering. The circuit board used in lab has 37 lines and 59 columns, with the cover picture covered by insulated material, the back lengthwise connected by copper wire, been laterally cut out by insulated material. So all these components are laterally bridge connected and the soldering ports are soldered directly on copper wire to form a loop, that makes it is convenient to use. After designing the circuit diagram, the components on project board has to be pulled out to solder on the circuit board. What is shown in the figure is the soldering diagram, in which X means the column is cut off at this point and the above part is disconnected with the below. The soldered circuit board is as shown in the figure 2.30.

After the accomplishment of soldering circuit board, we need to correct the circuit board over again. Except some special situation, the circuit should accord with the one tested in project board above. In this experiment the soldered circuit board can work regularly and it could be used in coming battery measurement.

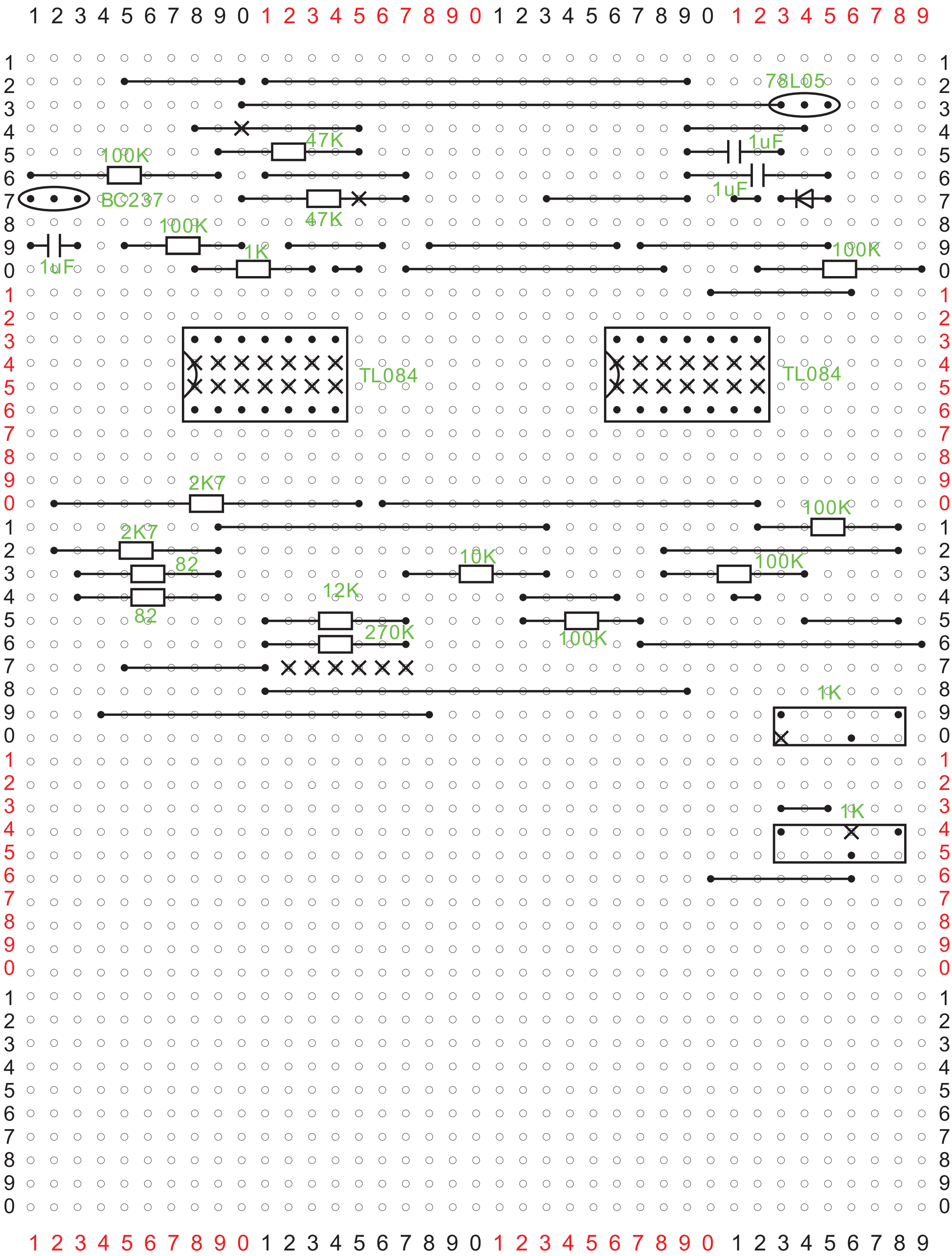


Figure 2.30: Soldering the circuit board

2.9 Protective Circuit of the Discharge Circuit

In the battery testing experiment, it is not sufficient to have the main discharge circuit. Since the experiment is carried out in heavy current environment, there is many potential dangerous factors. For example, the load will emit plenty of heat for the heavy current. Some critical consequences would take place if the load keep emitting heat without any limitation. So some accessorily protective circuit has to be built to protect the discharge circuit when necessary. In this experiment, the following are the several respects which we have considered to accessorily protect and design the circuit:

1. Load overheating
2. Under-voltage of storage battery
3. Over current of main circuit

2.9.1 Load overheating protection circuit

The current used in the experiment is 50A. After a continuous interval of discharge experiment, the load will create plenty of heat since the long time flowing of heavy current, so some special heat dissipation device (cooling device) has to be applied on the load. In this experiment, thermal fin has been employed as accessorial heat dissipation device (shown in figure 2.31) on the load and power amplifier which could create a big amount of heat. Therefore resistor and power amplifier are fixed onto the thermal fin, at the same time a fan supplied by external power supply has been employed to dissipate heat. While this discharge experiment is running, the thermal fin will receive the heat brought by the load or power amplifier for a long time. If the thermal fin doesn't work regularly because of being overheating or some other factors, the main discharge circuit ought to be cut off immediately to move the experiment into a safe condition.

It has been introduced in advance that a thermistor (PTC or NTC) has a capability like this. The resistance of thermistor will be greatly changed when the temperature varies, so PTC used in experiment can monitor the temperature of the thermal fin. With PTC on the surface of thermal fin, when the temperature is higher than 60°C, PTC will be at high-impedance state (MΩ level); whereas, when the temperature is lower than 60°C, PTC will be at low-impedance state (about 60Ω).

According to the property of PTC, the temperature monitoring protective circuit can be designed as in the diagram 2.32 (Pink area).

In the figure 2.32, point *G* is directly connected to the base of primer triode of power amplifier in main discharge circuit. When the temperature of thermal fin is lower than 60°C, PTC is

Figure 2.31: PTC and cooling device

at low-impedance state, input of CD4093 will be set to a high level. Because of existence of electrolytic capacitor, input of D_2 will be set to a high level, too. Point C will output low level; main discharge circuit discharges regularly. When the temperature of PTC is higher than 60°C since the thermal fin become overheating, it will be at high-impedance state. Now C_1 indicates a low level because PTC has taken up most of the battery voltage. As preceding introduction, in the NAND gate of CD4093, the output will be a high level if only one of the inputs is set to a low level, so point C will output a high level, transistor T_1 and T_2 are both open, alarm light L_1 is on. Meanwhile, the largest amount of the base current flows through T_1, because T_1 is connected with the base circuit of prime triode in the power amplifier of the discharge circuit. As a result the power amplifier is closed, discharging is stopped, and the circuit is protected. When the temperature of thermal fin is lower than 60°C again, output C_1 will get back to high level. But because of CD4093's memory function, C will output low level again only if the input state is changed. So we need to instantaneously press switch T_3, and when the voltage stored by electrolytic capacitor becomes low level, which means D_2 is instantaneously input a low level, D will output a high level. So C_1 and C_2 are input a high level at the same time, resulting in that C outputs a low level. T_1 will not take current from the base of discharge circuit, so discharge circuit will get back to work normally. [11]

After some analysis, just like the discharge circuit, the theoretical circuit is simulated in the computer and the simulation diagram is shown in figure 2.33.

In simulation, the circuit is found to work normally. So the circuit can be assembled on project board and tested, and after that it can be soldered on circuit board.

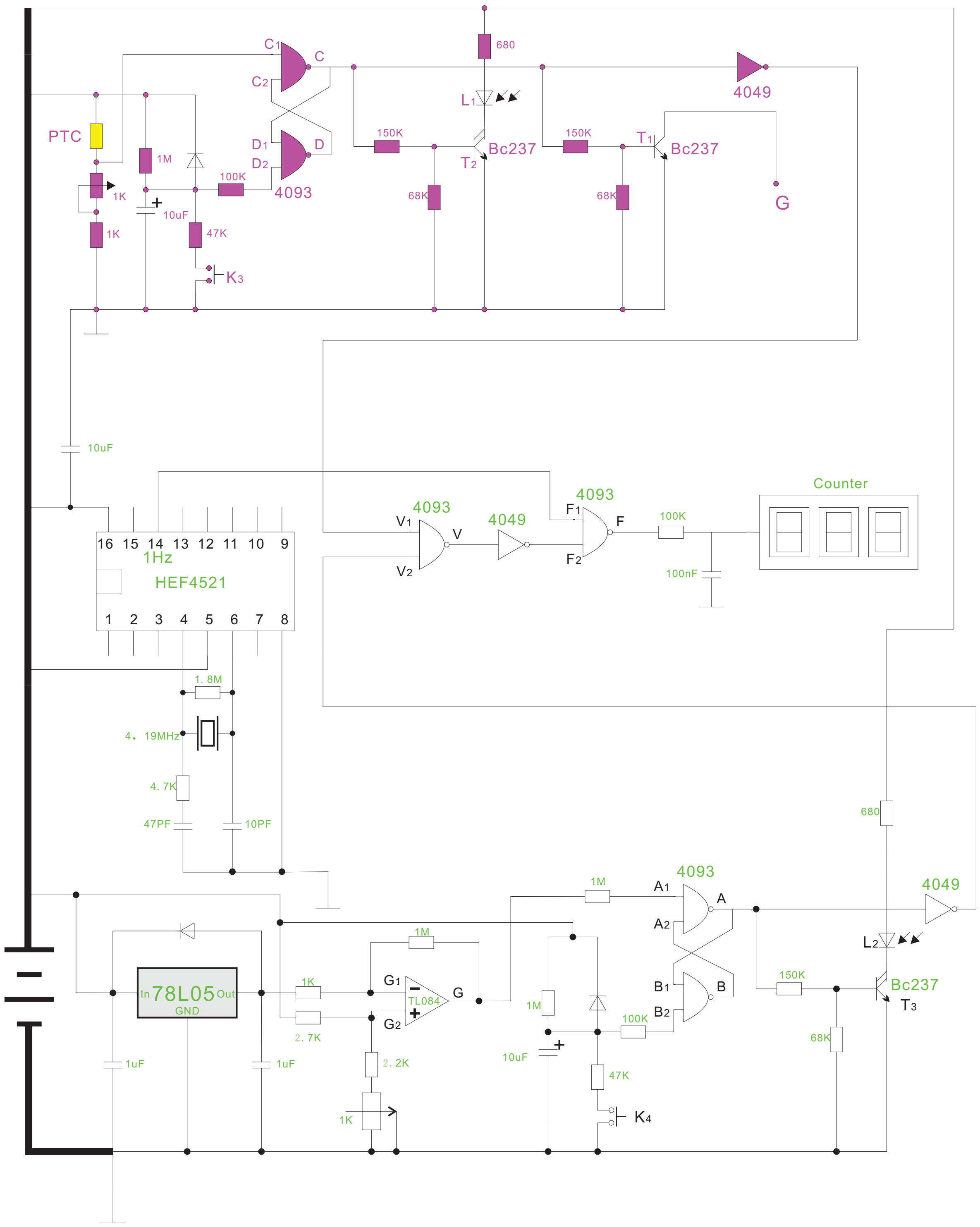


Figure 2.32: Load overheating protection circuit

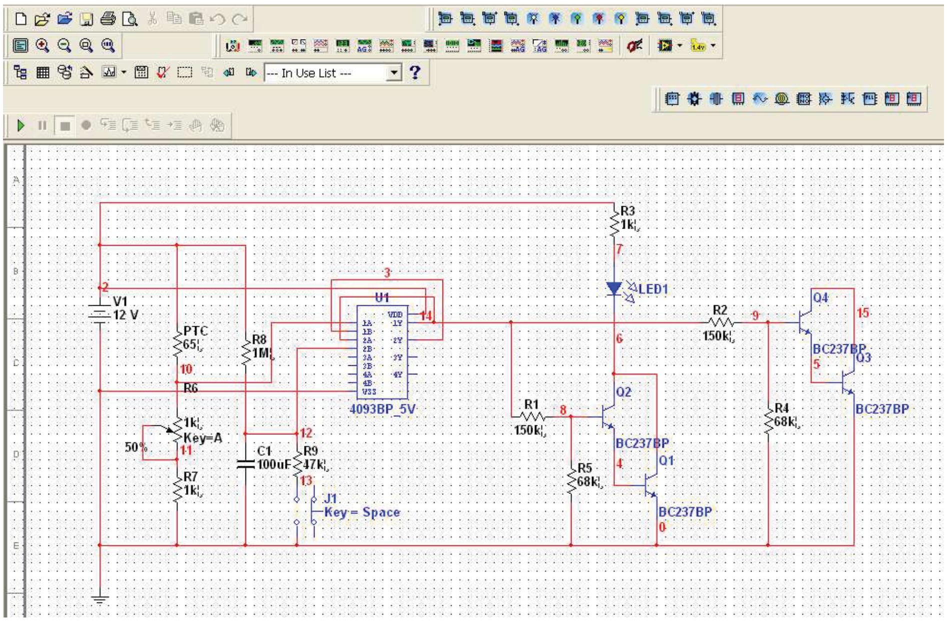


Figure 2.33: Simulation of the load overheating protection circuit

2.9.2 Protection circuit for low voltage of storage battery

After a moment of battery discharge the voltage will fall to a great extent. When the battery voltage becomes lower than a specified value, the continuation discharge will be meaningless but the battery may be damaged. Because the battery voltage now can not achieve the effect of heavy current discharge, we need to change battery or charge it. Thus the auxiliary circuit ought to be considered in circuit design, which can automatically cut off the discharge circuit if the battery voltage is too low.

In this experiment, it is set that discharge will be automatically stopped when the voltage is lower than 10.8V. About the method of circuit design, it can be similar to the temperature protective circuit. We need a fixed voltage to contrast with battery voltage or the zoomed one, as well as a proportional amplifier to compare the voltages. The fixed voltage can be steadily output at 5V by use of 78L05; battery voltage should be limited around 10.8V. Comparator could be designed as in the figure 2.32, in which the loop is composed by battery, $2.7k\Omega$ and $2.2k\Omega$ resistors, and a $1k\Omega$ sliding rheostat. The voltage across point G_2 is:

$$U_{G_2} = \frac{2.2 + (0 \sim 1)}{2.7 + [2.2 + (0 \sim 1)]} \cdot U_{batt} = 4.85V \sim 5.86V \qquad (2.19)$$

That means, by adjusting the resistance of sliding rheostat, when battery voltage is 10.8V, the voltage across point G_2 could be lower than 5V. This circuit can be applied to avoid the battery voltage being too low.

If the battery voltage is higher than 10.8V, the battery can be discharged normally, leading to a large current flowing through the load and power amplifier. So the potential of point G_2 is higher than that of point G_1 (the potential of G_1 is about 5V, the same as the voltage across 78L05) and point G of comparator output a high level. As a result, when a high level is applied at input A_1 of CD4093, the initial state of low level output by CD4093 will be changed. Point B_2 will output a high level because of electrolytic capacitor; when the discharge has been going on for a while, the battery voltage will decrease to 10.8V. Now the potential at point G_2 will be lower than that of G_1, and A_1 will be input a low level, leading to a high level output by A. Alarm light L_2 will be turned on. Discharge experiment is stopped by now, we need to change the battery for a new one or charge it.

The battery voltage will be higher than 10.8V again after changing or charging the battery. By instantaneously close the switch K_4, B_2 can get a low level. So output A again obtains a low level. The discharge experiment starts over again with the indicator light off.

2.9.3 Battery discharge timing system

The quality of battery is determined by the time span of discharge. So there is always a timing system synchronous with the battery discharge whether discharge is going on with constant power or current. That means some system that can record the time span of battery discharge is required. It ought to record time while the battery is discharging normally, stop recording at the same time as discharge stops, and go on recording or start over again.

To build such a system, we can first make an outline of the general planning, and then improve the circuit based on this planning. If the frequency created by a frequency generator is 1Hz and a frequency counter has received it, then the frequency can be regarded as a cycle and the T is 1s.

$$f = \frac{1}{T} \tag{2.20}$$

That means the frequency counter indicating the time can be regarded as a stopwatch, so the tool of recording time has been determined. Input a 1-Hz frequency, is kept as a carrier, together with the signal representing the on-off of discharge circuit into CD4093 as a NAND gate, and a frequency counter will receive the frequency from the output of CD4093 to realize the assembly of time. About the frequency generator, the 4.19MHz quartz is applied as a oscillation source in this experiment. HEF4521 is used as a frequency divider, in which a oscillator is integrated. It has been introduced above that HEF4521 is 24-level frequency divider, which can demultiply the 2^{24}Hz oscillation source into 1Hz. For the 4.19MHz oscillation source, which is 2^{22}Hz, a piece of HEF4521 is just enough. Design the oscillating frequency dividing circuit as the figure 2.32, the output of pin 14 is just 1Hz signal. In the voltage limiting and temperature protection circuit, it has been introduced above that, with the discharge circuit is going on normally, the circuit will discharge regularly if the output of C, in charge of the temperature limiting, and A, in charge of the voltage limiting, and the circuit will be suspended, leading to termination of discharge, if the output is a high level. If only one of the two conditions can not be achieved, the discharge must be terminated. If we infer backward with logic, 1Hz carrier signal and a signal from the protection circuit has been input into input F_1 and F_2 of

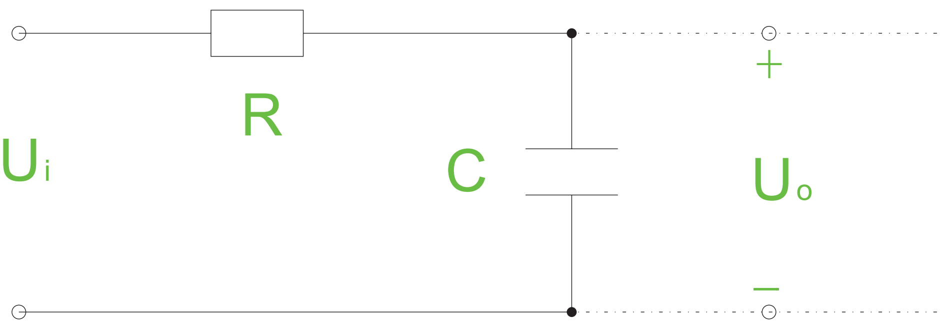


Figure 2.34: Low pass filter

CD4093 and a frequency counter is placed at output F of CD4093, so we can know that the counter begins to count when the F_1 is a high level, and it stops counting when F_1 is a low level. Considering the protection circuit, as the preceding introduction, A and C output a low level when discharge circuit goes on normally, and output a high level respectively because the voltage is lower than the fixed value and the temperature is too high when there is an accident. If only one of the two situations has happened, the counter ought to stop counting immediately. A CD4093 can be employed here, and it does not agree completely with the design if only these devices above are involved. Now a NEGATOR-circuit CD4093 has to be involved to make the circuit in accordance with the design (as in figure 2.32). Through CD4093, the signal from point A and C realizes the level switch to output signal V_1 and V_2. V_1 and V_2 enter CD4093 together. If only U and V are both high levels, V will output a low level. A high level point F_1 can be got if the signal passes through another CD4093, which can drive the counter to count. If any one of points A and C goes wrong, the signal arriving at F_1 can only be a low level and the voltage output from F can only be a high voltage. The counter can no longer read any change of voltage, so the counting is stopped, which means the discharge is terminated.

2.9.4 Application of low pass filter

2.9.4.1 The basic definition

A low-pass filter [12] is a filter that passes low-frequency signals but attenuates (reduces the amplitude of) signals with frequencies higher than the cutoff frequency. Figure 2.34 shows a low-pass RC filter for voltage signals, it consists of a resistor in series with a load, and a capacitor in parallel with the load.

The capacitor exhibits reactance, and blocks low-frequency signals, causing them to go through the load instead. At higher frequencies the reactance drops, and the capacitor effectively functions as a short circuit. The combination of resistance and capacitance gives you the time constant of the filter τ= RC. The corner frequency f_c(in Hz) is determined by the time constant:

$$f_c = \frac{1}{2\pi \cdot R \cdot C} \tag{2.21}$$

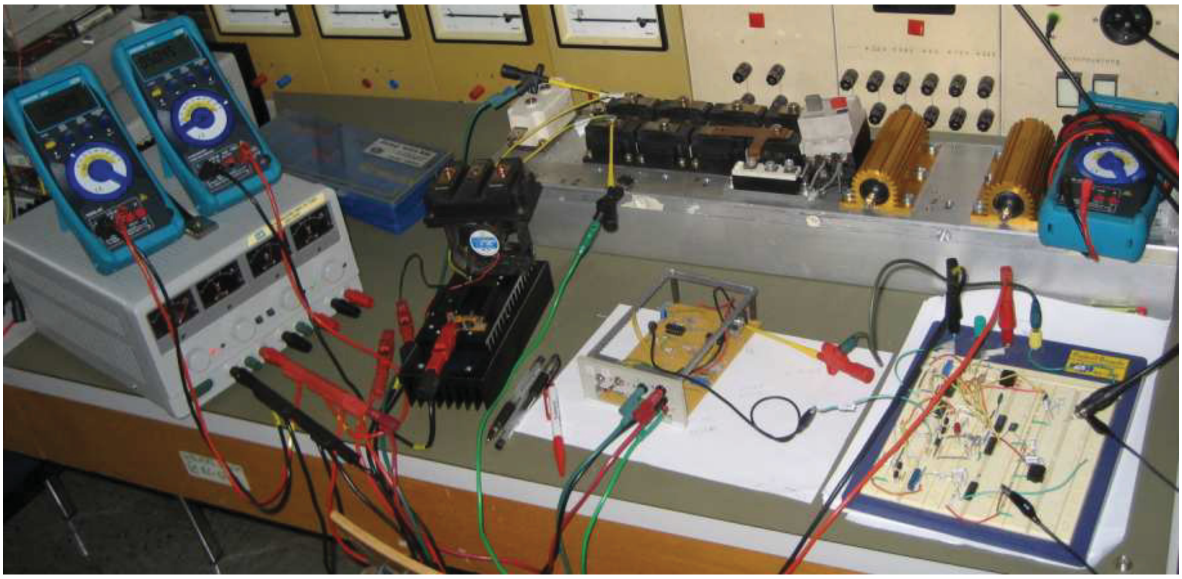


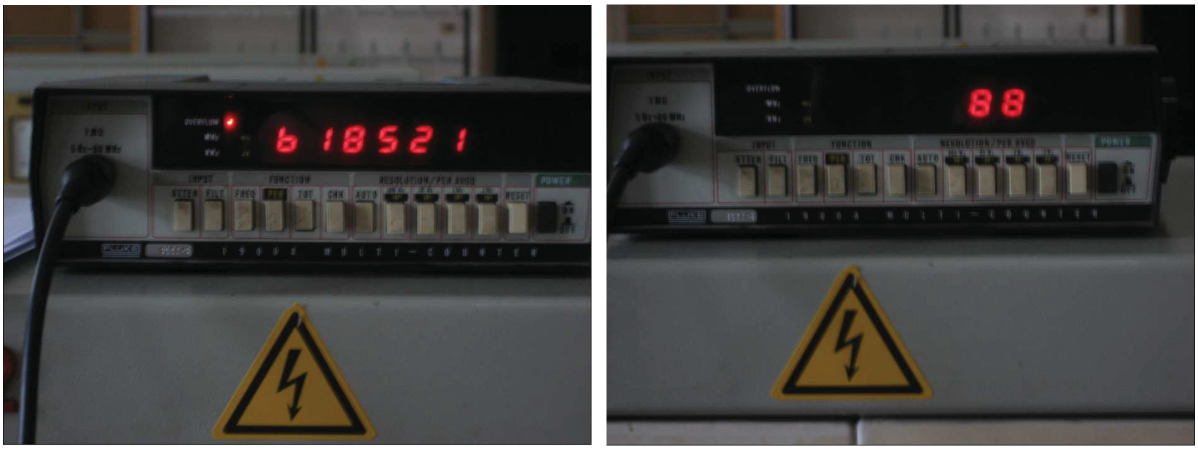
Figure 2.35: Battery discharge with timing system

One method to understand this circuit is to focus on the time the capacitor takes to charge. It takes time to charge or discharge the capacitor through that resistor:

- At low frequencies, there is plenty of time for the capacitor to charge up to practically the same voltage as the input voltage.
- At high frequencies, the capacitor only has time to charge up a small amount before the input switches direction. The output goes up and down only a small fraction of the amount the input goes up and down. At double the frequency, there's only time for it to charge up half the amount.

2.9.4.2 Application of low pass filter in battery discharge timing system

By the theoretical study above, the specific execution scheme can be determined. It can be tested on project board after the simulation in the computer. With circuit board inserted, its output V is used as input of frequency counter and the counting begins. After the circuit is closed, the counter can not count steadily. The key to this problem is that some high frequency harmonic waves, besides the 1Hz fundamental wave, are output from point V, leading to some jamming to the frequency counter. One way to solve the problem is to arrange a low pass filter before the frequency counter receiving the frequency. This filter can effectively prevent high frequency getting involved into the counting so that experimental result can be stabilized. It can be seen from the figure 2.36, before using the filter, the timing system is unstable; after using the filter, it can work normally.



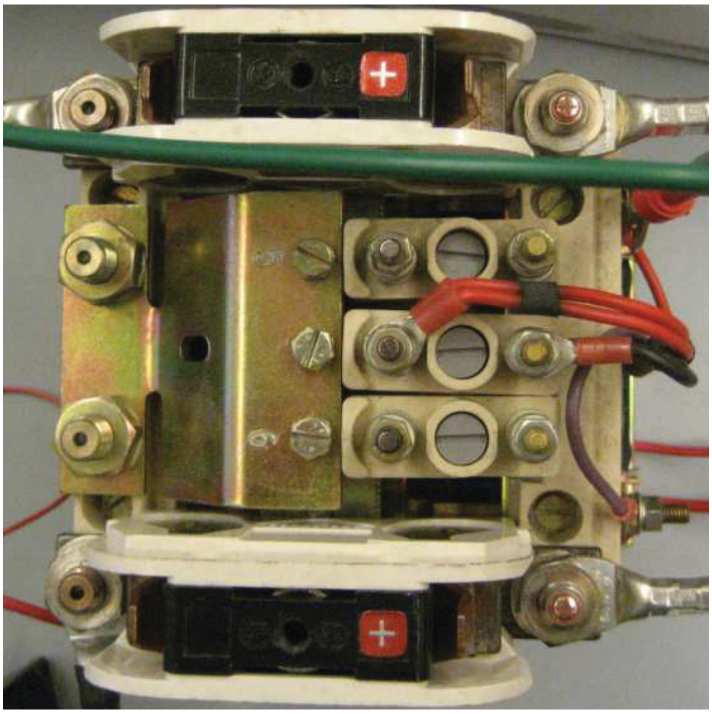
(a) Before filtering (b) After filtering

Figure 2.36: Comparison before using filter and after using filter

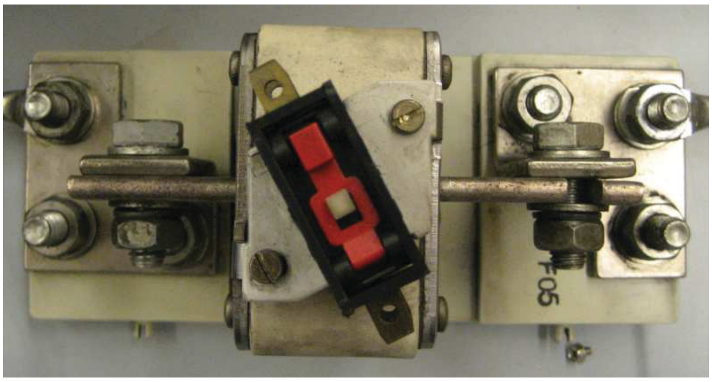
2.9.5 Protection circuit for over current of main circuit

In order to ensure the safe and reliable discharging of a circuit, and to prevent the accidents due to excessive current caused by short circuit or other factors, the main circuit must be equipped with a fuse and a relay. The model of the fuse used in this test is PROTISTOR BP3025, and the relay is Schaltbau S700 which is a normally open mechanical switch with the operating principle as follows: The switch is in off state under the condition of no current; the switch is provided with a joint with the main circuit and a joint with excitation circuit as well. The main switched can be closed by means of connecting an external auxiliary circuit with the excitation end of the switch to make the winding thereof electrified to form magnetic field; when no current runs through the excitation circuit, the switch will be off again. Voltage of the Schaltbau excitation circuit is 24V. The main switch has the opening current of 3.7A which will drop to 0.9A quickly after opening. The breaking current of the main switch is 0.5A after opening. By placing a Power MOSFET (RFH30N15) into the auxiliary excitation circuit, the on-off control of this circuit can be realized so as to realize the on-off control of the main circuit.

The current in the main circuit needs to be monitored. When the current exceeds a defined level, the information will be fed back to a gate of Power MOSFET, and the excitation circuit will be disconnected through the control of the gate to the MOSFET, thus realizing the purpose of disconnecting the Schaltbau power switch, namely when the main switch is disconnected, the discharge will stop immediately to ensure the safety of the test. A preferred way to monitor current is to use a shunt resistor in figure 2.38. In electronics, a shunt is a device which allows electric current to pass around another point in the circuit. When a circuit must be protected from over-voltage and there are failure modes in the power supply that can produce such over-voltage, the circuit may be protected by a device commonly called a crowbar circuit. When this device detects an over-voltage it causes a short circuit between the power supply and its return. This will cause both an immediate drop in voltage (protecting the device) and an instantaneous high current which is expected to open a current sensitive device (such as a fuse or circuit breaker). This device is called a crowbar as it is likened to dropping a metal tool called a



(a) Schaltbau S700



(b) PROTISTOR BP3025

Figure 2.37: Switch and fuse

crowbar across a set of bus bars (exposed electrical conductors). An Ampere-meter shunt allows the measurement of current values too large to be directly measured by a particular Ampere-meter. In this case a manganin resistor of accurately-known resistance, the shunt, is placed in series with the load so that nearly all of the current to be measured will flow through it. The voltage drop across the shunt is proportional to the current flowing through it and since its resistance is known, a millivolt meter connected across the shunt can be scaled to directly read the current value. In order not to disrupt the circuit, the resistance of the shunt is normally very small. Shunts are rated by maximum current and voltage drop at that current, for example, a 500 A/75 mV shunt would have a resistance of 0.15 $m\Omega$, a maximum allowable current of 500 amps and at that current the voltage drop would be 75 mV. By convention, most shunts are designed to drop 75 mV when operating at their full rated current and most ”Ampere-meter” are actually designed as voltmeters that reach full-scale deflection at 75 mV. The shunt resistance used in

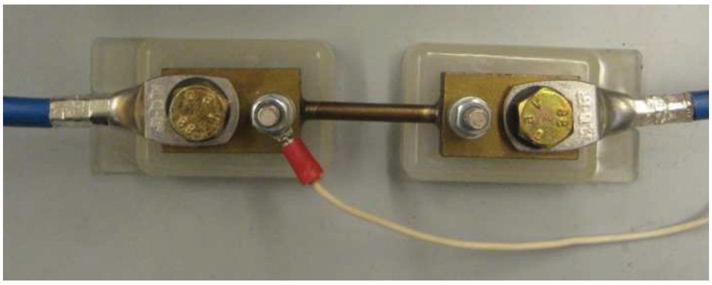


Figure 2.38: 60A/60mV shunt resistor

this test is of 60A/60mV, namely that voltage drop on the shunt resistance is 60mV when the current in the circuit reaches 60A, in other words, 1A/mV. By monitoring the voltage of the resistance, the status that whether the circuit current is excessive or not can be determined, and by comparing the signal with a given signal through a comparator, the opening or closing of circuit may be determined. The actual implementing method includes the following processes:

- Selection of amplifier
- Actual consideration of the circuit
- Problems arising in the test and solutions

2.9.5.1 Selection of amplifier

Because of the extremely small resistance value of the shunt resistance itself, even large current exists, the voltage at two ends of the shunt resistance will only reach mV Class. Since voltage of mV Class is adverse of application in the test, thus it is necessary to use an amplifier to increase the voltage. The amplifiers have similar functions, while amplifiers in different types have their own characteristics. Not all amplifiers are capable of amplifying mV-class signals. In the test, TL084, LM324 and LM2904 amplifiers are selected and compared by means of connecting these amplifiers according to the connection method of non-inverting proportional amplifier (see figure 2.9), enlarge upon 100 times, inputing mV-class voltage signal from the input end of anode, and comparing these amplifiers can be compared from 0 to 100mV.

As indicated in the figure 2.39, under the condition that the input signals of LM324 and LM2904 are lower than 100mV, the input signals can be amplified in a linear and undistorted manner, while with such characteristic as fast response, etc., TL084 amplifier is unable to work under amplification state when the input signals are lower than 100mV. Therefore, amplifiers in LM series must be selected for the amplification towards the voltage of shunt resistance in the test. Eventually, LM324 amplifier is adopted to amplify the voltage of the shunt resistance in this test.

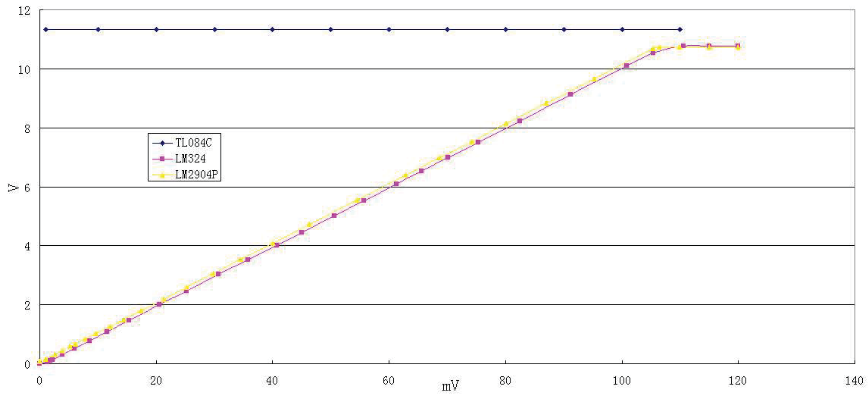


Figure 2.39: Gain characteristic contrast from several kinds of amplifiers

2.9.5.2 Actual consideration of the circuit

As the voltage of the shunt resistance may change with current in the circuit, it is necessary to determine a particular limiting voltage. When the voltage of the shunt is higher than such limiting voltage, the circuit current is deemed to be excessive, then the discharge current must be cut off; when the voltage of the shunt is lower than such limiting voltage, the circuit is deemed to work in normal status, thus battery discharge can keep going. Hereby, a comparator may be used for the comparison between two voltages above-mentioned. The limiting voltage inputted set to in the anode of the comparator is a constant value which can be achieved by using a zener diode, while the amplified voltage of the shunt resistance is inputted in the cathode of the comparator. When the voltage of the shunt resistance is lower than the limiting voltage, the comparator will output high level; on the contrary, when the voltage of the shunt resistance is higher than the limiting voltage, the comparator will output low level. The output end of the comparator may be connected with a Schmitt trigger which has the same operating principle with the preceding Schmitt trigger used for temperature monitoring. The output end of the Schmitt trigger is connected with a signal lamp. When high level is at output side, the signal lamp brightens, indicating that discharge test is over, and the excitation circuit of the Schaltbau is disconnected and the Schaltbau is also disconnected simultaneously. In other words, the gate voltage of MOSFET (RFH30N15) is required to be zero. The logical relationship is as follows: When the signal lamp brightens, the gate voltage of MOSFET (RFH30N15) is zero, requiring to apply a not gate herein. Such circuit may be realized by connecting the voltage of the signal lamp to two input ends of another CD4093 simultaneously, making the output end of the latter in low level, thus realizing the control to MOSFET. As for the formation of the excitation circuit, an external power supply with a rated voltage of 24V is required. In this test, a power supply of 24V3A/5A is used as the power supply for the excitation circuit, with a constant output voltage of 24V, a current up to 5A during short-time electrification. During long-time power supply, it can work normally below 3A. As indicated through measurement in the test, the Schaltbau has a momentary current of 3.7A before conduction, and a stable conducted current about 1.5A. Such power supply is allowable for use.

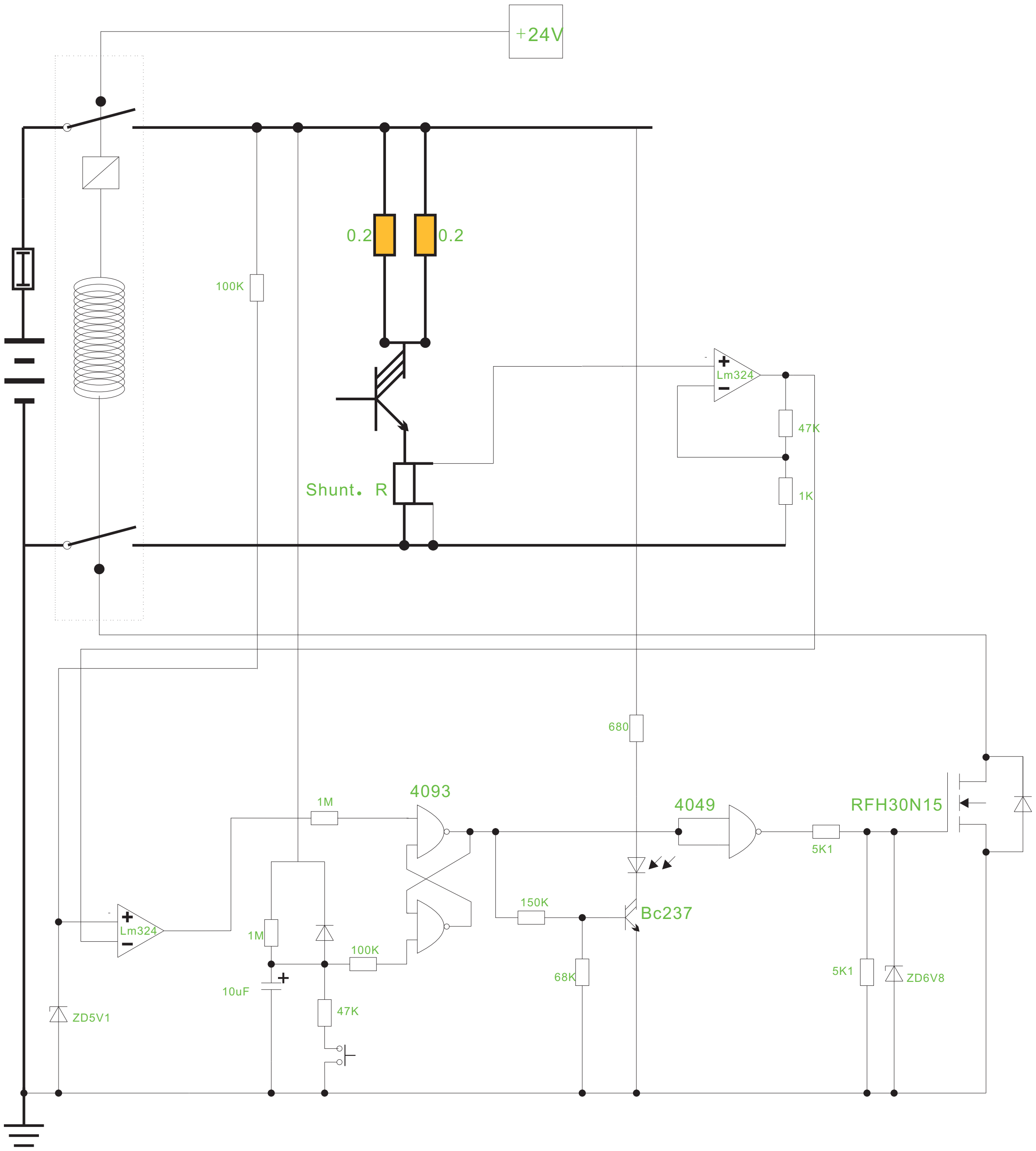


Figure 2.40: Over current protective circuit

2.9.5.3 Problems arising in the test and solutions

During the test on Schaltbau excitation circuit, the situation that Schaltbau can not be conducted happens when the voltage of the shunt resistance is lower than 100mV. Through examination, it is founded that the problem is due to the positions of MOSFET and Schaltbau are exchanged, namely the field power supply, Schaltbau and MOSFET are in serial connection, but certain order is required. The correct order is the field power supply$\longrightarrow$ Schaltbau$\longrightarrow$ MOSFET. If the positions of MOSFET and Schaltbau are exchanged incorrectly, although the gate of MOSFET bears opening voltage, the U_{DS} is insufficient to make MOSFET conducted as the source of the MOSFET is unearthed, which causes the U_{DS} insufficient to make MOSFET conducted, excitation current not large enough, and the Schaltbau not being conducted. Therefore, circuits must be connected strictly following the order of excitation source$\longrightarrow$ Schaltbau$\longrightarrow$ MOSFET in the test.

In chapter 2, processes of achieving the battery discharge circuit and its protection circuit was discussed. Upon completion of these circuits, the test of battery discharge can be started.

Chapter 3

Charging System and Battery Discharging Results

The storage battery without any quality problems after tested by the discharge test system shall be used to form the core part of UPS system. 40 storage batteries with the same model in series are used as the power supply source in this system, but in the application, a large difference in voltage can be encountered between these batteries due to different quality of the batteries, which is very dangerous in the industry production because when the battery is charging, over current which can damage the batteries or system or even cause an explosion can be generated with these batteries, so in the actual industry production all the batteries shall be monitored and during the monitoring process, the battery with comparatively high voltage shall be discharged solely, and the discharge degree is based amount by which a specific battery voltage is higher than that of another battery. The storage battery group only can be uniformly charged when the voltage of all batteries is almost the same, which will be used as the power supply source for the load when the next power down of electricity network occurred.

From the above stated conditions, we know that the storage battery must have a monitoring system for the battery voltage, comparing system for the battery voltage (or control system for battery discharge) and battery discharge system for each individual battery inside a battery group.

3.1 Monitoring System for Battery Voltage

3.1.1 Differential amplifier circuit

The differential amplifier [13] circuit is a good choice to conduct synchronized monitoring on the voltage of all storage batteries. The detailed differential amplifier circuit is shown in the figure 3.1. The basic working principle of such circuit is that the signals are applied simulta-

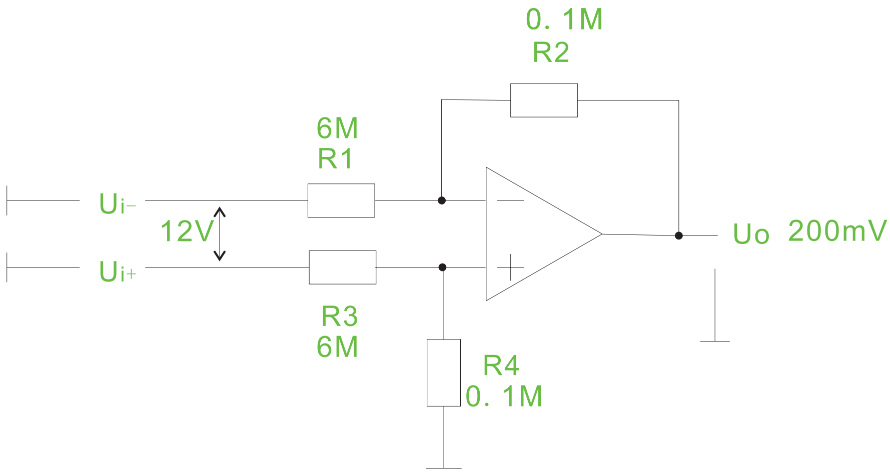


Figure 3.1: Differential amplifier circuit

neously both into the anode input end and the cathode input end of the amplifier, wherein, the relation of the input and output is represented in the formula 3.1.

$$U_o = \frac{(R_1 + R_2) \cdot R_4}{(R_3 + R_4) \cdot R_1} \cdot U_{i+} - \frac{R_2}{R_1} \cdot U_{i-} \tag{3.1}$$

In order to simplify the circuit and make the relation between input voltage and output voltage only relating to R_1 and R_2, it is a general choice to make $R_1 = R_3$ and $R_2 = R_4$ when building the circuit, thus transferring the relation between input and output as stated in the formula 3.2, as a result, the complex formula is transferred to regulating the proportional amplifying relation between input and output by controlling the value of R_1 and R_2. Therefore, the requirements on the accuracy of R_1, R_2, R_3 and R_4 are relatively high in the differential amplifier circuit, and the ideal case is that the values of R_1 and R_3 are completely equal, and so is the values of R_2 and R_4, otherwise big common mode error will arise in the circuit.

$$U_o = \frac{R_2}{R_1} \cdot (U_{i+} - U_{i-}) \tag{3.2}$$

In this system, since the storage battery sets are connected in by 40 batteries with the working voltage of 12V respectively in the way of serial connection, the maximum voltage to earth should be about 450V∼550V. Moreover, as the maximum voltage at the input end of the amplifier should not exceed 10V, while the highest voltage to earth of the storage battery is even more than 500V, the values of R_1 and R_3 must be ensured to largely exceed that of R_2 and R_4, so as to enable R_1 and R_3 to get higher voltage, thus ensuring the voltage at the input end of the amplifier not exceed 10V and ensuring the circuit operate normally. The ratio of the value of R_1/R_2 is 60/1, the values of R_1 and R_3 are respectively $6M\Omega$, and that of R_2 and R_4 are $100k\Omega$, thus ensuring the voltage at the input end of the amplifier not to exceed 10V. We connect the input end of the differential amplifier circuit between the two electrodes of the battery according to the figure; it can be known through calculation that the output voltage of the differential amplifier circuit is 200mV when the battery voltage is 12V.

3.1.2 Detailed implementation and correction of the differential amplifier circuit

The differential amplifier circuit introduced in figure 3.1 is the circuit in the ideal status, while in the actual production process, because of the offset voltage on the amplifier body, inaccurate resistance value, the influence of harmonic wave in the circuit, the temperature and humidity in the air and other factors, the differential amplifier circuit is quite inaccurate. When the differential amplifier circuit is used as monitoring circuit for battery voltage, it is necessary that the differential amplifier circuit shall reach high accuracy. Besides, because the output voltage is mV level, the error of the differential amplifier circuit is required not to exceed 1mV.

Before building the differential amplifier circuit, it is necessary to confirm the model of the amplifier. Through comparison of amplifiers in different models, amplifiers with lower offset voltage include LM324, TL084, LM2902, etc. The amplifier TL084 with the maximum offset voltage of 2mV is adopted in the experiment.

3.1.2.1 The confirmation of the resistance value of differential amplifier circuit

After selecting the amplifier, the resistance value of the resistance should be confirmed first. The resistance error margin for standard laboratory resistors is 1%. The bigger the resistance value, the lower the resistance accuracy will be, and simultaneously the bigger the change of the resistance value generated by the interference of external condition. When the resistance value reaches $M\Omega$ level, the weak air flow can make the resistance value change in the range of $\pm k\Omega \times 10$, and even $\pm k\Omega \times 100$, thus making the differential amplifier very inaccurate. So the resistance of $6M\Omega$ selected as planned needs to be replaced by several resistances with different values. The selection of resistance is carried out according to the principle of high to low, that is select resistance with $M\Omega$ level first and then $k\Omega$ level, and at last Ω level, and to replace one resistance with series of resistance in series, thus making the resistance value after connecting in series reaches the theoretical value more accurately after level-by-level selection of resistance.

Two groups of $4.7M\Omega$,$1.2M\Omega$ and $100k\Omega$ are selected as the initial values of R_1 and R_3 in the test. Since the resistance has a tolerance, the resistance value after connecting in series not equals $6M\Omega$. By measuring the total resistance value after connecting in series with multimeter, and adding proper resistance with lower resistance value, the sum of resistance in series exactly finally equals $6M\Omega$. Such sum of resistances is the resistance value of R_1 and R_3; Additionally, two resistances of $100k\Omega$ are needed to act as R_2 and R_4 in the differential amplifier circuit, and the accurate selection can be conducted in the manner similar to the selection method of R_1 and R_3, thus making the resistance value in the differential amplifier circuit accurate. In order to get a more accurate resistance value and simpler operation, sliding rheostat may be added. The real values of the resistance of differential amplifier circuit are shown in the figure 3.2. The figure indicates that (contrast with 3.1) the R_1,R_2,R_3 and R_4 in the circuit diagram are replaced by several resistances in series in the real tests, thus realizing the value of $R_1 = R_3$ and $R_2 = R_4$.

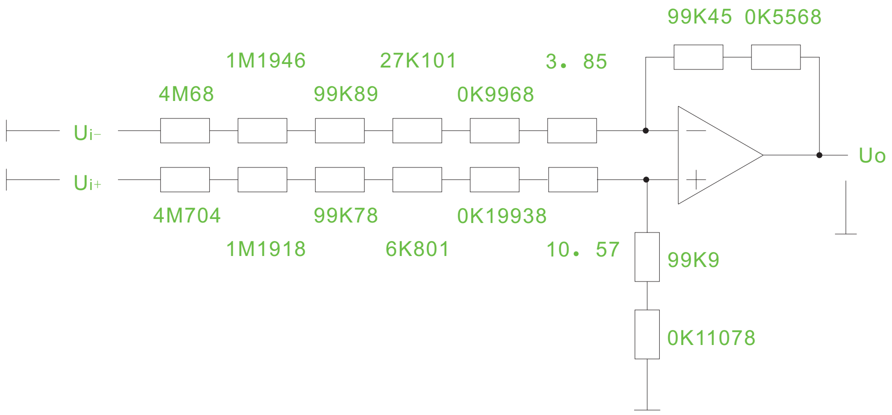


Figure 3.2: Practical differential amplifier circuit

3.1.2.2 Offset voltage compensating circuit

The confirmation of the resistance for the differential amplifier circuit does not mean that the circuit can be used directly. Disregarding the error caused by measurement, the amplifier itself has offset voltage error which is not within in the range of allowable error, so a compensating circuit must be adopted to compensate the offset voltage to make the output of the system constantly at 0V when the input signal is 0V. There are various specific forms for offset voltage compensating circuits, but only one kind of compensating circuit is enumerated in this test, as shown in the figure 3.3 with the shaded part.

3.1.2.3 Auxiliary filter circuit

The input is a same AC voltage of 220V into the anode and cathode input ends of the differential amplifier circuit to check whether the circuit is capable of working normally or not. Under ideal conditions, the output waveform of the circuit should be 0V, and the actual output waveform of the circuit is shown in the figure 3.5. It is indicated in the figure that the output waveform of the circuit is sine wave and the average value is not 0V. Such sine wave represents that because the input voltage frequency is 50Hz, the output voltage may go with harmonics, and it is necessary to add a low pass filter at the input end to limit the harmonics. When the average value of output voltage is not 0V, the offset voltage of the circuit needs further compensation through the specific methods of regulating the sliding rheostat. The circuit of low pass filter is shown in the figure 2.34. The selection of used capacitance shall be settled by calculation first:

$$f_{corner} = \frac{1}{2\pi \cdot R \cdot C} \tag{3.3}$$

wherein, the set frequency f_{corner} is 1Hz. Because the differential amplifier circuit is used for the measurement of the storage battery, its frequency is 0Hz. The capacitance value C obtained by calculation for the resistance with the value of $4.7M\Omega$ is about 30nF, and that for the resistance with the value of $1.2M\Omega$ is about 130nF for a $f_{corner} = 1$Hz. The output waveform after connecting the filter circuit is shown in the figure 3.5 which indicates that the effect of

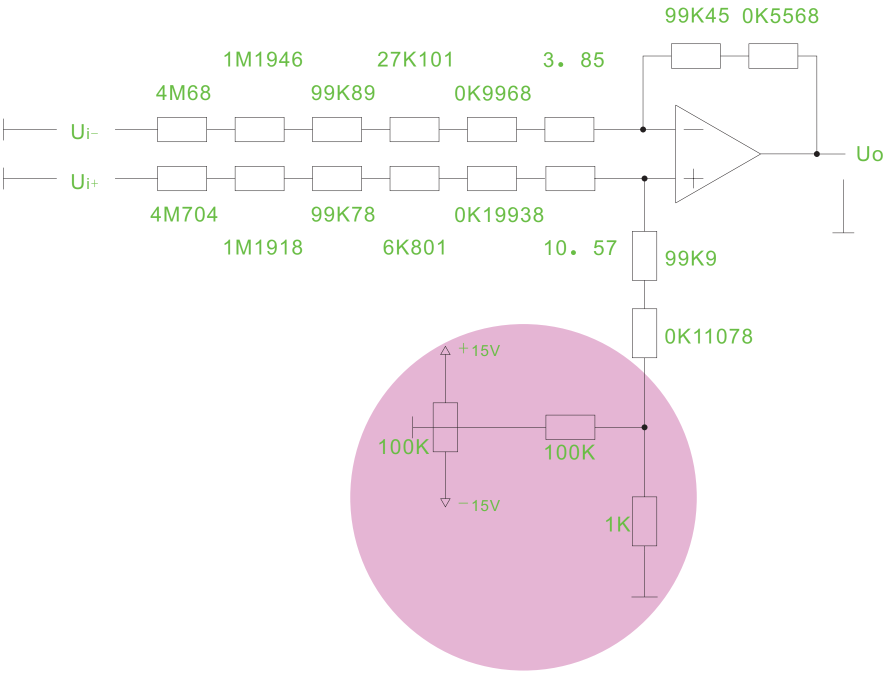


Figure 3.3: Practical differential amplifier circuit

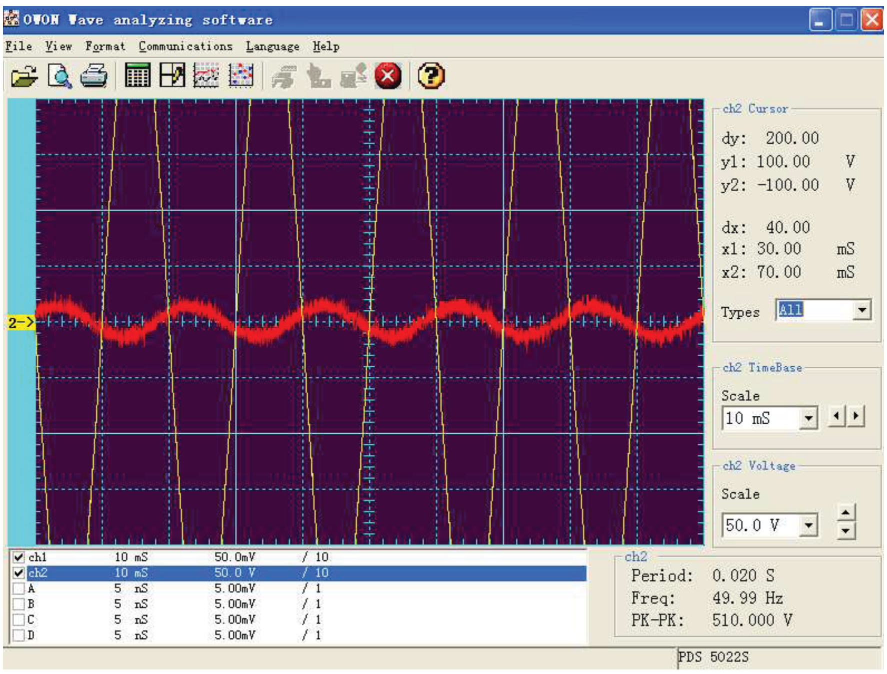


Figure 3.4: Unfiltered practical differential amplifier circuit

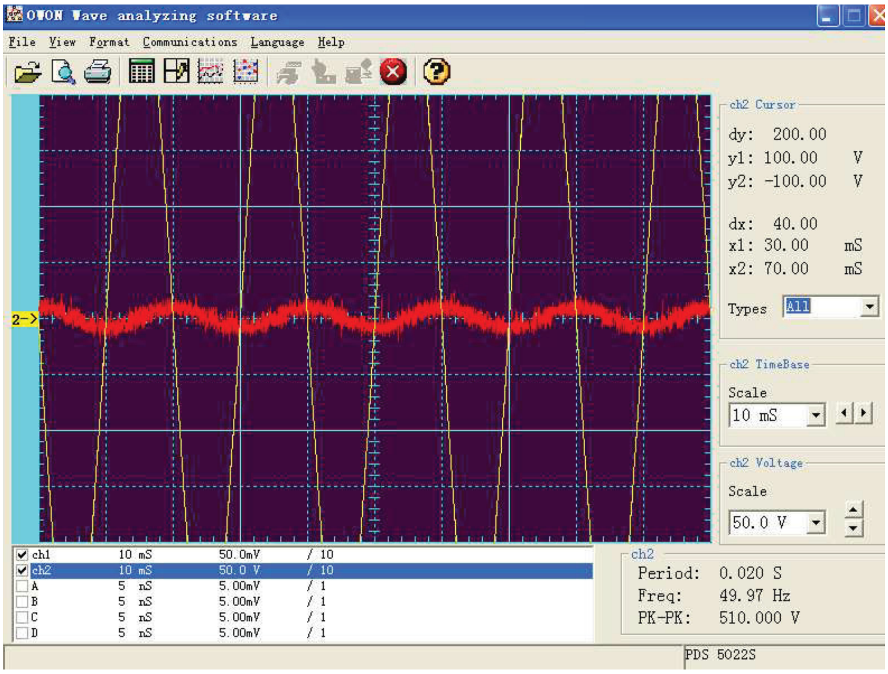


Figure 3.5: Lowpass practical differential amplifier circuit

the differential amplifier circuit has been improved a little but not ideal. Filter capacitance was replaced until the circuit diagram is the same as illustrated in the figure 3.6. After the capacitances of 30nF and 130nF are replaced by capacitances of 470nF, the output waveform of the circuit will be significantly improved. The waveform as displayed on the oscilloscope is shown in the figure 3.7.

3.1.3 Differential amplifier circuit test

Even in strict accordance with the above criteria assembled differential amplifier circuit, we can not immediately use it. Because of various errors in the assembly (for example, inaccurate resistance measurement, limited insulation, etc.), which may result in a lot of errors in differential amplifier circuit assemble, the need to first test the circuit is required. Differential amplifier circuit detection mainly takes two steps:

1. offset voltage test
2. magnification testing

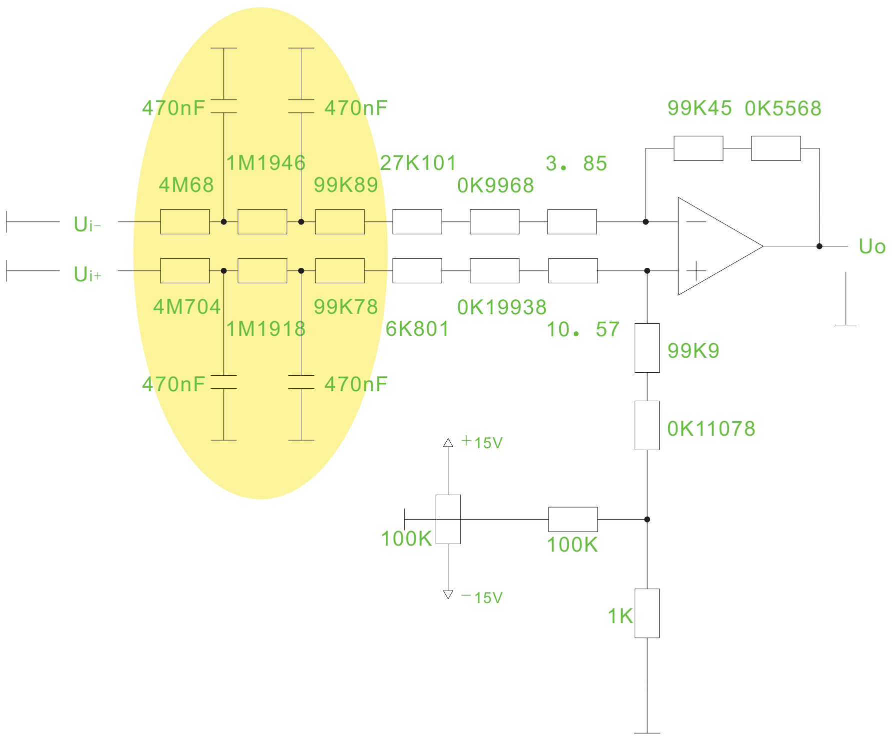


Figure 3.6: Optimal differential amplifier circuit

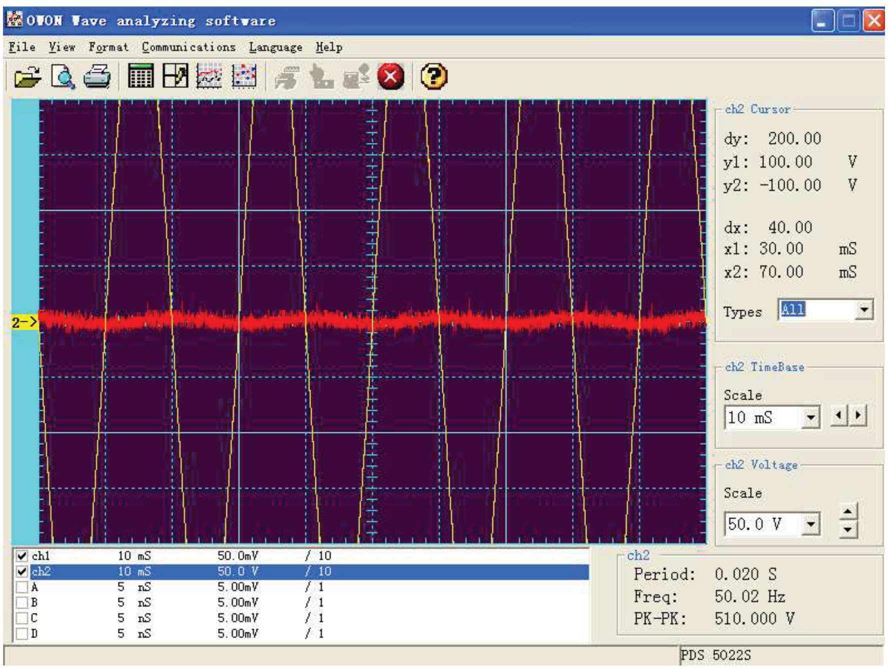


Figure 3.7: Waveform of the oscilloscope

3.1.3.1 Offset voltage test

Offset voltage test is vital. Because of output voltage of differential amplifier circuit is at mV level, which requires offset voltage regulate below 1mV. There are two major aspects in offset voltage test: one is AC regulation. The other is DC regulation.

AC regulation Auxiliary filter circuit has ever introduced in the exchange regulation section, AC regulation refers to two input terminals of differential amplifying circuit first be short-circuit connections, and then access a high-voltage alternating current as input voltage (220V transformer tune in experiment), using the oscilloscope to observe input voltage and output voltage, the ideal state of input voltage waveform should be a sinusoidal signal waveforms, the average output voltage is 0, waveform should be a coincidence with the oscilloscope horizontal lines. If the average output voltage is not 0, then it proves that the differential amplifying circuit requires offset voltage trimming; if the output voltage waveform is sine wave or similar sinusoidal waveform, it refer to the output signal contains high frequency harmonics. Re-select input used to constitute a low-pass filter capacitor works. Through constant change, the output waveform comes close to the ideal waveform. Through the exchange of regulation can effectively filter high harmonics in differential amplifying circuit output.

DC regulation After AC regulation, a DC input regulation in differential amplifying circuit is required whose specific methods are similar to AC regulation. Just like DC regulation, first differential amplifier circuit of the two input connections, and then access a high-voltage direct current, DC voltage can be adjustable by 220V single-phase transformer with diode rectifier, diodes can be used 1N4007, in the rectifier termination of a circuit output capacitance, used to stabilize the output voltage, adjustable by regulating transformer, allows the output voltage in rectifier circuit shift between 0V and 324V. First, adjust voltage level of adjustable voltage transformer to 0V, at this time the rectifier circuit output voltage is 0V as well. That is to say, positive and negative-level input terminals of differential amplifying circuit are short circuit, no input voltage available, this time the output voltage measured at 57mV. With AC regulation, offset voltage still exists. Make adjustment for offset regulator, allowing output voltage come to 0V.

Then adjust transformer to its maximum output, this time after rectification the rectifier DC output voltage come to 324V, resurvey differential amplifying output voltage at this time reach 30mV, while the theoretical value should be 0V. The solutions to this problem is that connect a small resistance grounding sliding rheostat in output feedback or cathode-side input termination of differential amplifying circuit. Firstly, try $1k\Omega$, $2k\Omega$ or 500Ω resistance or sliding rheostat to fine-tune; this is different from the $100k\Omega$ sliding rheostat used in offset sliding rheostat adjustment circuit. The reason is that when circuit input is at a low voltage, due to resistance inaccuracy in differential amplifying circuit, only greater scope of the resistance regulator can made offset voltage to 0V. However, when differential amplifying circuit is in a high-voltage input, since the circuit is very sensitive, small changes in resistance would result in significant changes in voltage offset. At this time, it is not easy to regulate large resistance slide rheostat, but minor adjustment of small resistance slide rheostat. When the amount of resistance change is not too much, offset voltage can be achieved to 0V.

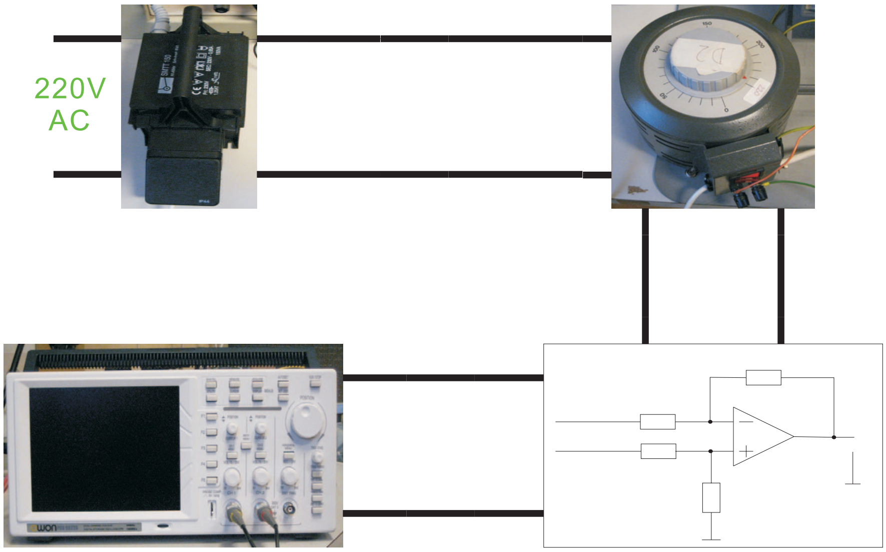


Figure 3.8: AC regulation

3.1.3.2 Magnification test in differential amplifier circuit

With AC detection and DC testing in differential amplifier circuit, the filter performance and offset voltage have got very proper regulation. Then we check differential amplifying circuit for monitoring whether the battery can also work correctly. In the experiment, using two voltage sources, one set to 15V. Through connection and reversal connection, ±15V are available. As the use of amplifier power, the other one set to roughly 12V, in replace of battery voltage, and then connect it between positive input terminal and negative input terminal. High voltage termination is connected to negative input, a low voltage to the cathode input termination. Such a connection will make the output voltage negative. Next, magnification of differential amplifier circuit can be detected. the magnification of the detection voltage in different paragraphs. Since 40 batteries in series, there are relatively low potential at the end of the battery pack, and it has relatively high potential in the battery pack to the top of the battery. In order to guarantee the differential amplifying circuit for each battery, monitoring can be proceeded smoothly. The need for a different electric potential under the inspection is essential. By regulating the rectifier output voltage, the grounding potential of differential amplifying circuit can be raised or lowered.

When output voltage of rectifier circuit is 0V, it is equivalent to the last one of 40 batteries in differential amplifier circuit; when output voltage of rectifier circuit is 324V, it is equal to differential amplifier circuit which is located at 28th battery of 40 battery voltage, that is from the very minimum end (suppose battery voltage is 12V, the formula for calculating the number of batteries is that $324 \div 12 + 1 = 28$). Adjustable regulator allows differential amplifier circuit at different grounding level. In this case, we set a 12V DC voltage in positive and negative input level to observe and record the differential amplifier output voltage. Suppose input voltages of differential amplifier circuit are kept as the same, after front AC regulation and DC regulation, the output voltage read in oscilloscope is roughly constant, at around-200mV± 0.5mV as

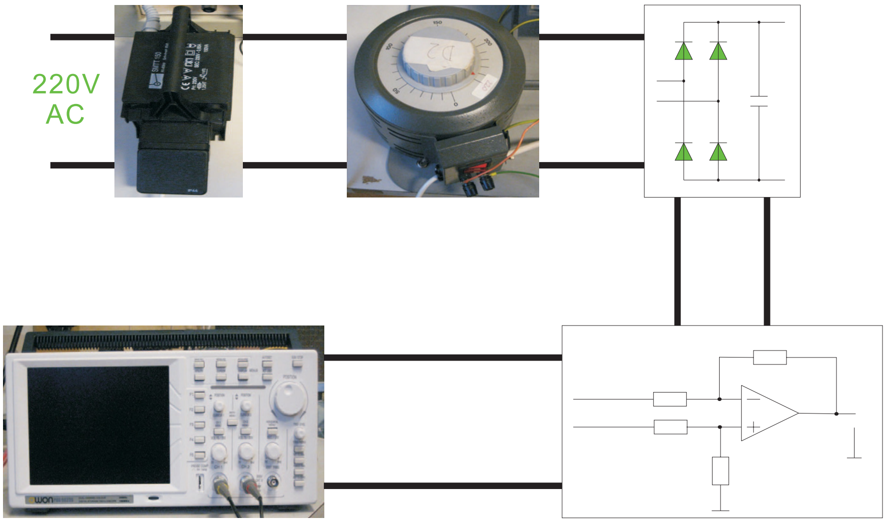
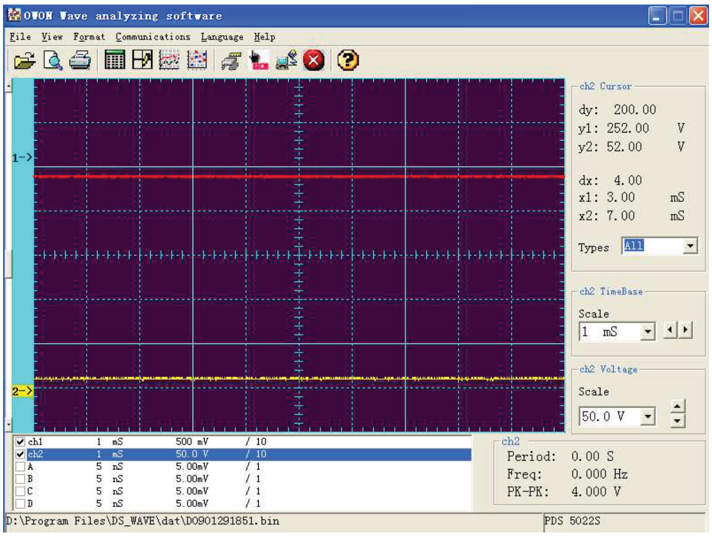
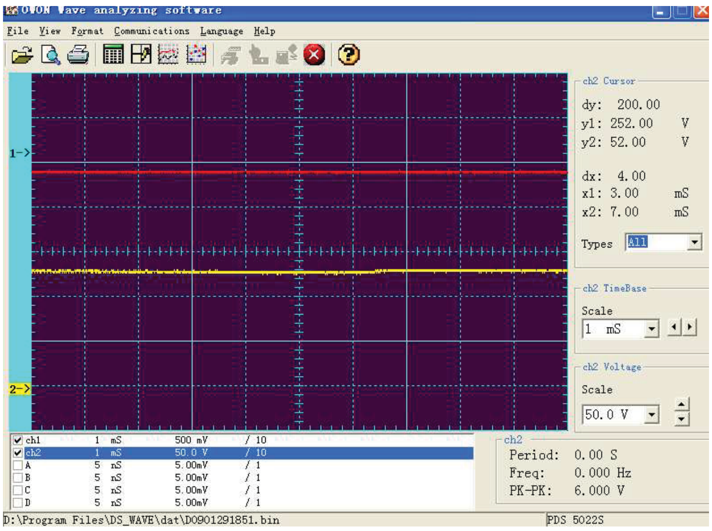


Figure 3.9: DC regulation

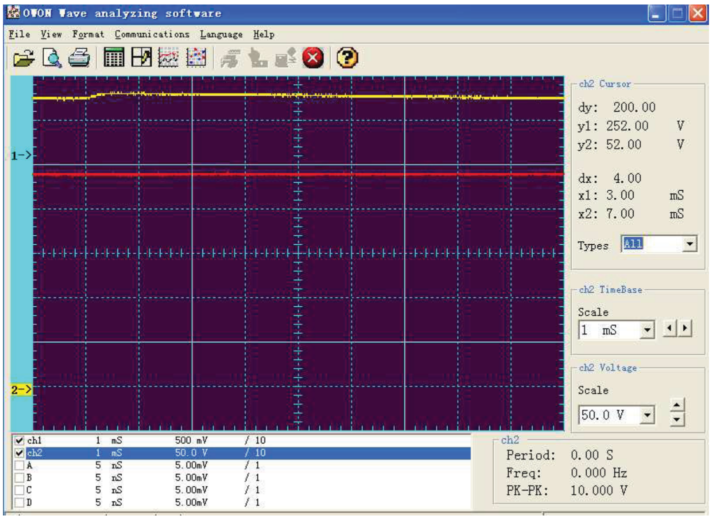
shown in figure 3.10. So shown magnification is constant, in line with the feature of differential amplifier circuit, so further use is available.



(a) Output voltage of rectifier circuit:low



(b) Output voltage of rectifier circuit:mid



(c) Output voltage of rectifier circuit:high

Figure 3.10: Output voltage of differential amplifier circuit in different voltage levels

3.2 Comparative System for Battery Voltage (Battery Micro Discharge Control System)

After the differential amplification circuit meets the standards, 40 such circuits in total shall be assembled according to uniform standard and used for real time monitoring of the current voltage of each battery in the battery set (the voltage symbol is negative), and such battery voltage is used for driving the signals of battery discharge circuit after undergoing judgment. Whether the battery should conduct discharge shall be concluded after the comparison with a limiting voltage. The limiting voltage is the average value of 40 batteries, and when a battery voltage is higher than the average value of the battery voltage, the battery should moderately discharge first until the voltage equals the average voltage, and this method can make all the battery voltage basically equal, and then conduct charge of all the battery. The average value of the battery voltage can be realized by a summing amplifier. The specific circuit is shown in figure 3.11. The figure 3.11 shows that the voltage of the 40 batteries is transformed to 1/60 of the original voltage by the differential amplification circuit, and then all the voltage enter the input end of the summing amplifier, and the point A as the output end of the summing amplifier is the average value of the voltage of the 40 batteries. The implied average value is used as limiting voltage (the voltage polarity is negative). [14]

Taking the B_1 battery in figure 3.11 as an example, the output voltage (negative) of the differential amplifier and the average value of the battery voltage (positive) are taken as the two input voltages of the summing amplifier. When the absolute value of the voltage of B1 storage battery is higher than the average value of the voltage, the output end of the V_1 summing amplifier will output a positive voltage which is used for triggering the discharge circuit of subsequent battery; on the contrary, when the absolute value of the voltage of B_1 storage battery is lower than the average value of the voltage, the voltage at the output end of the V_1 summing amplifier is negative and will not trigger the discharge circuit of the batteries.

3.3 Voltage Balance System of Batteries

The discharge circuit of the batteries is shown in figure 3.11. An opto-coupler is adopted as preamplifier circuit of the circuit. The opto-coupler has the advantage that opto-coupler diode termination can be activated by low current, thus making the discharge control circuit very sensitive. A 4N25 type opto-coupler is used in test. When the output of V_1 summation is a sufficient and positive voltage, the opto-coupler opens and generates an amplifying current which can be used as the base opening current of BD139 triode of the battery discharge circuit. The collector electrode and emitter electrode of BD139 are connected to the anode and cathode respectively of the battery to constitute a discharge loop. The discharge current of the discharge loop can be limited by the resistances installed on its collector electrode and emitter electrode. It is specified in the test that the current of BD139 after conducted is about 100mA, and the resistance which can be obtained by ohm's law is about 100Ω. Because the maximum power of the resistance used in test is $0.6W$, a plurality of resistances with low value respectively are

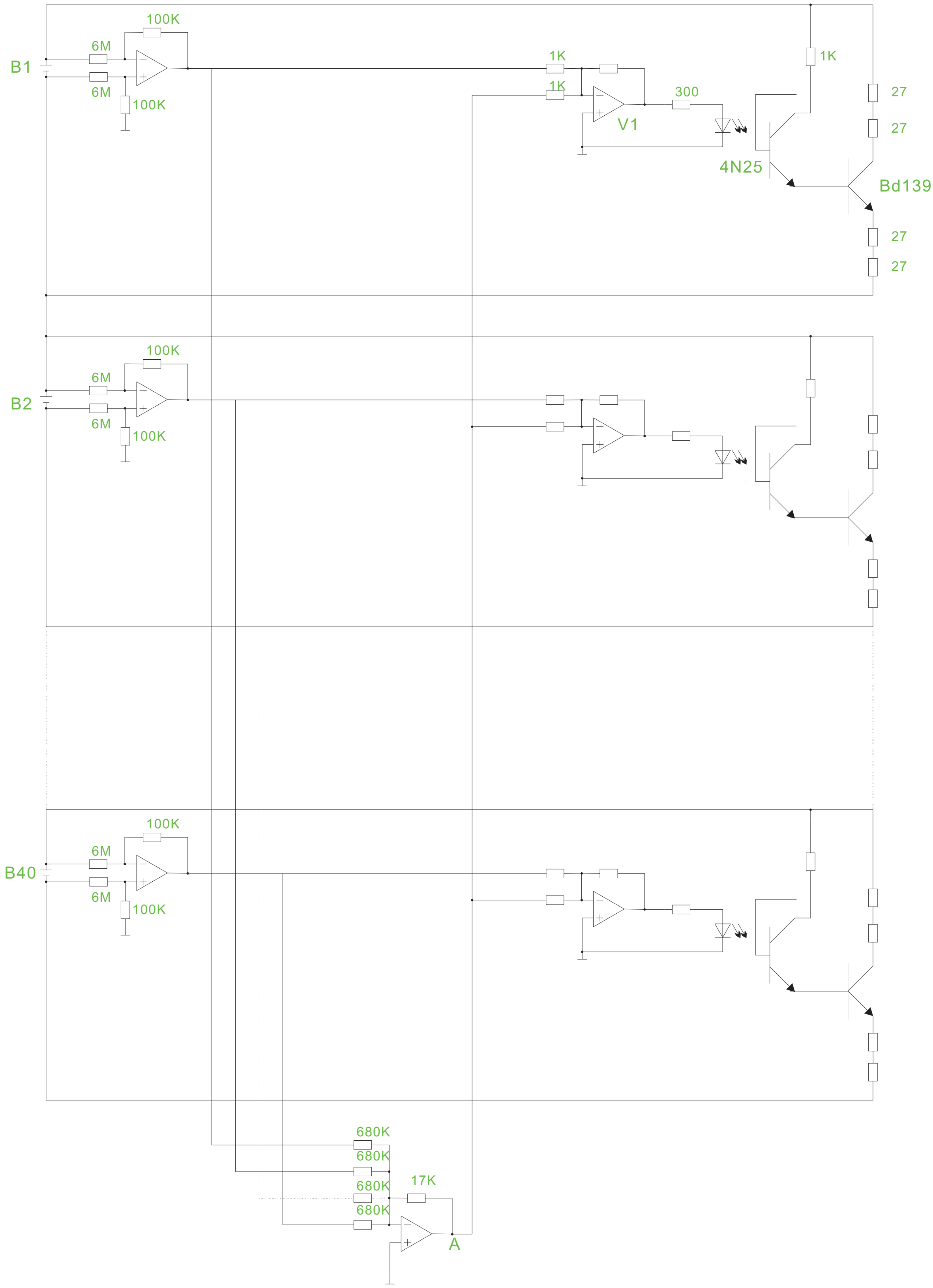


Figure 3.11: Battery discharge control and discharge system

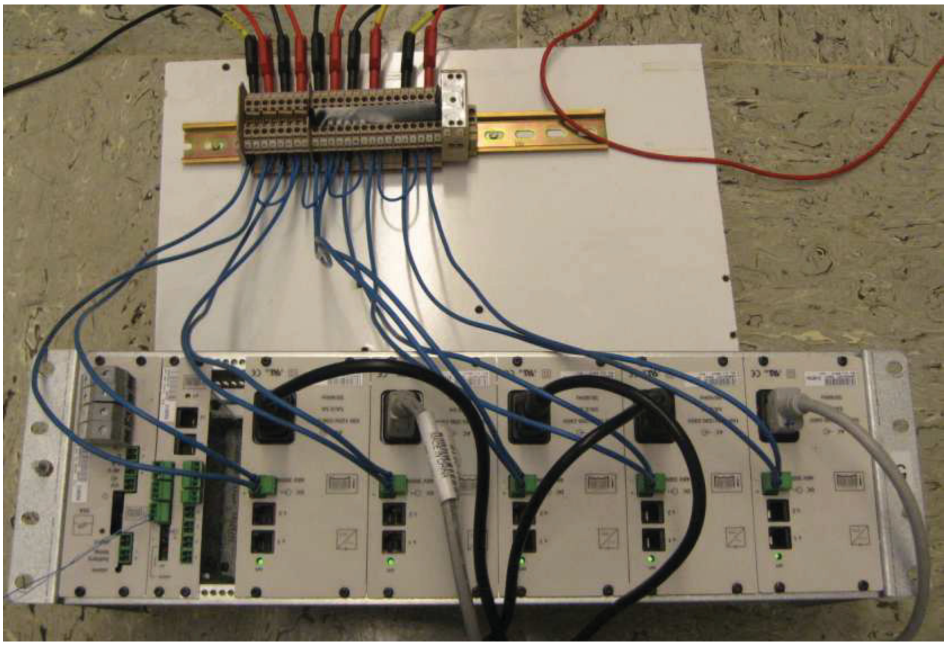


Figure 3.12: Battery chargers

needed to be connected in series to replace one 100Ω resistance. The specific scheme is shown in the figure where a resistance of 27Ω×4 is adopted to replace a 100Ω resistance.The power consumption of each resistance is calculated to be about $0.3W$. It is tested that when the current is 100mA, the resistance is slightly hot, and the discharge effect is good.

The circuit above mentioned is the balancing circuit for battery voltage before the battery is charged. The circuit is capable of making the voltage difference of each battery tend to 0V, thus realizing the safe charge of the storage batteries.

3.4 Battery Charging System

The input voltage of charger is 220V AC and the output is 54V DC, the rated power is 300W, the rated current is 6A. Each charger can charge 4 batteries in series connection, 40 batteries add up to 10 chargers. Due to the battery are connected in series, the charger must be contacted in series too, it can make the charger and battery having the same value of voltage. The total circuit is shown in figure 3.13. The charging devices in figure are named Cha1, Cha2...Cha10. According to the chart, the chargers are connected in series, and then take the negative pole output of the Cha5 to the PE (protective earth) point, after that the -270V∼270V DC voltage can be obtained, this voltage can be used as charging voltage for the 40 batteries, each charger output charges corresponding to 4 in series connected batteries, for preventing the danger of over current from battery short-circuit, between every 4 batteries 80A fuses are installed, in addition the diodes are connected in parallel on each battery shown in figure 3.13, the diodes are used as bypass in case some batteries have problems: the current flows through the diode on the corrupted battery during discharge of battery unit, this failure battery is bypassed and will not be reversely charged (at opposite of natural polarity). Besides that, the battery voltage balance system (see chapter 3.2 and 3.3) also must be installed.

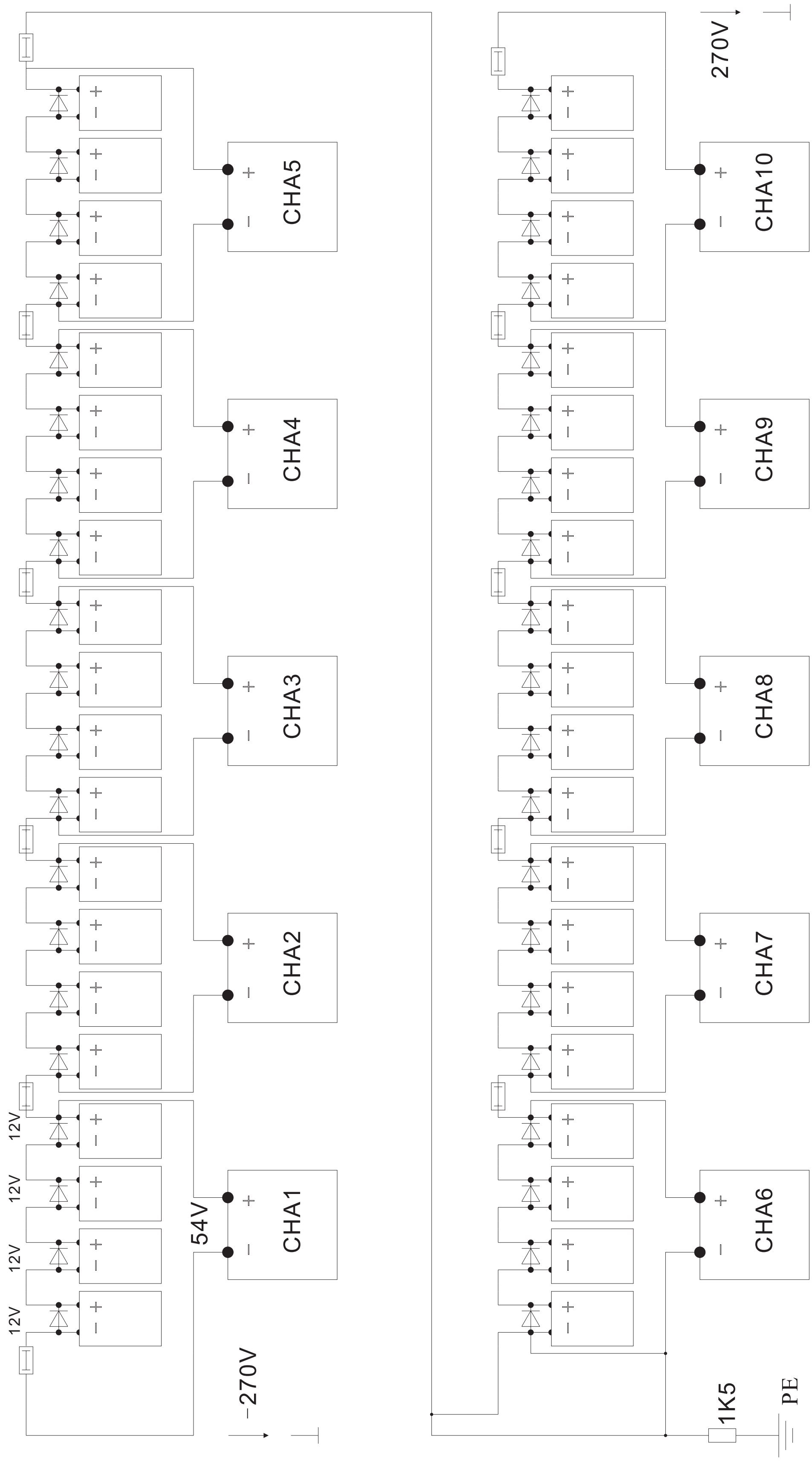


Figure 3.13: Sketch of battery charging

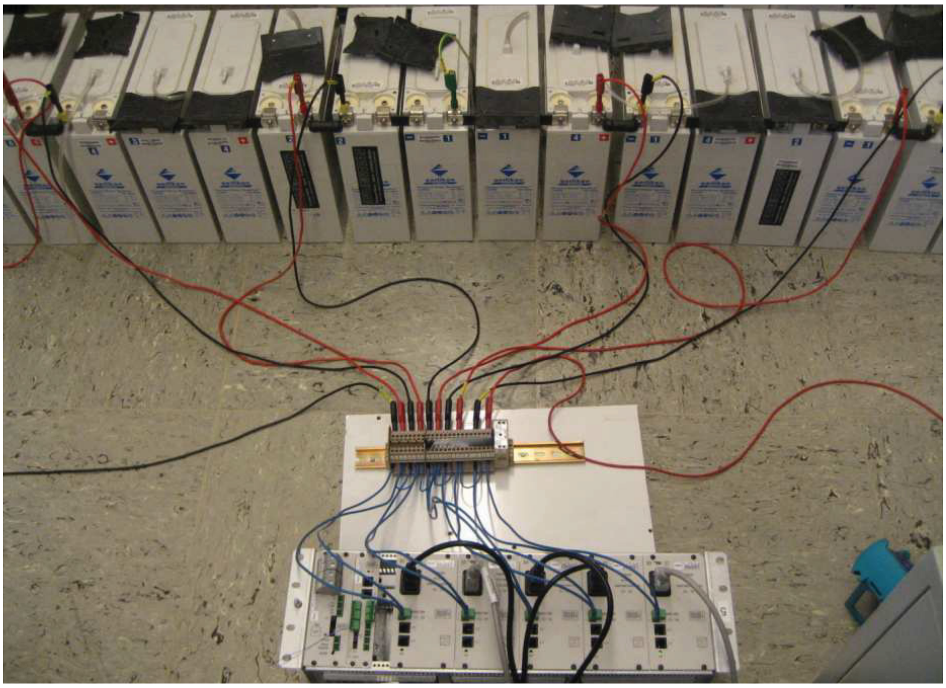


Figure 3.14: Battery charging system

3.5 Results of the Battery Charging Test

In the figure 3.14 20 batteries are in series connected, 5 chargers are used.

The voltages of batteries and serial numbers are as follow:
Before charging:

serial number	voltage[V]	serial number	voltage[V]
6009094	12.213	6165276	12.600
6130956	12.224	6056960	12.200
6043841	12.538	6043831	12.560
6165231	12.221	6056940	12.189
6112024	12.619	5991253	12.607
6112016	12.005	6130959	12.218
6043838	12.336	6117160	12.584
5991258	12.261	6056937	12.087
6164571	12.638	6056941	12.525
6009093	12.179	6130957	12.181

Table 3.1: Battery voltage list before charging

After charging:

serial number	voltage[V]	serial number	voltage[V]
6009094	12.915	6165276	13.188
6130956	12.821	6056960	12.982
6043841	13.112	6043831	13.389
6165231	12.993	6056940	12.875
6112024	13.213	5991253	13.124
6112016	13.012	6130959	13.011
6043838	13.006	6117160	13.175
5991258	12.883	6056937	12.881
6164571	13.238	6056941	12.961
6009093	13.103	6130957	12.863

Table 3.2: Battery voltage list after charging

From table 3.2 can be seen, all the batteries after charging with 54V charger, the voltage can not reach 13.5±1%V, this means: the capacity of the old battery is relative poor than new batter, whether these batteries can be used or not, firstly must go through battery discharging test.

Figure 3.15: Battery discharging system

Figure 3.16: Monitoring of battery discharging by multimeter-PClink

3.6 Results of the Battery Discharging Test

The fully charged batteries are discharged by use of the discharge circuit which was introduced in chapter 1. The test results are as follows:

3.6.1 Test results of battery discharging with constant power

There are 10 batteries discharged with constant power. Because the battery has internal resistance, when the circuit is conducting, a voltage drop will appear across the resistor. Therefore, although a battery at static state has 13V, when it begins discharging, the voltage at the bat-

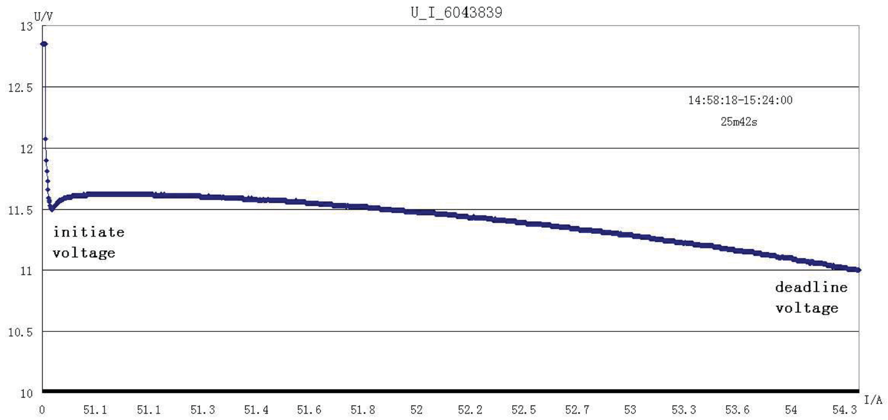


Figure 3.17: Test result of 6043839 discharging with 600W

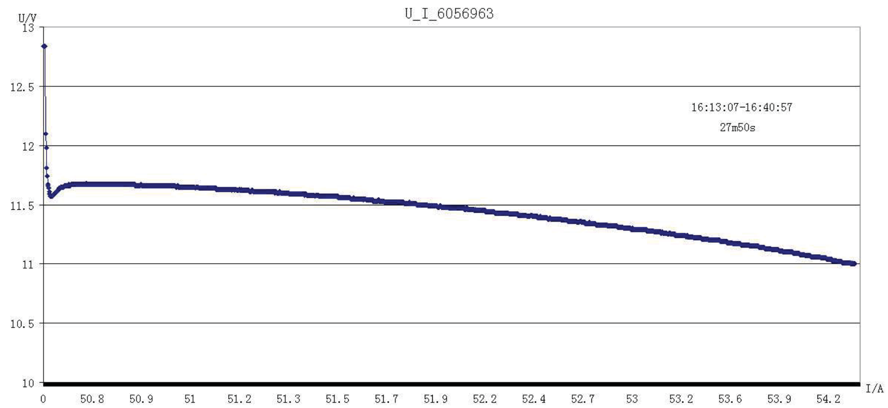


Figure 3.18: Test result of 6056963 discharging with 600W

tery output point falls to about 11.7V quickly, and then we test the battery discharging between 11.7V∽11V, 11V is as deadline voltage of battery discharging test. Voltage, current and discharging time can be monitored by multimeter-PClink, then the graphics are made in EXCEL (figure 3.17∼figure 3.26).

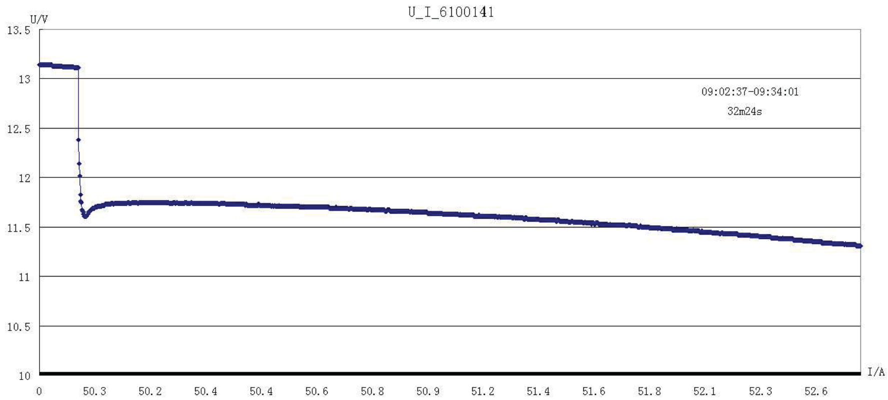


Figure 3.19: Test result of 6100141 discharging with 600W

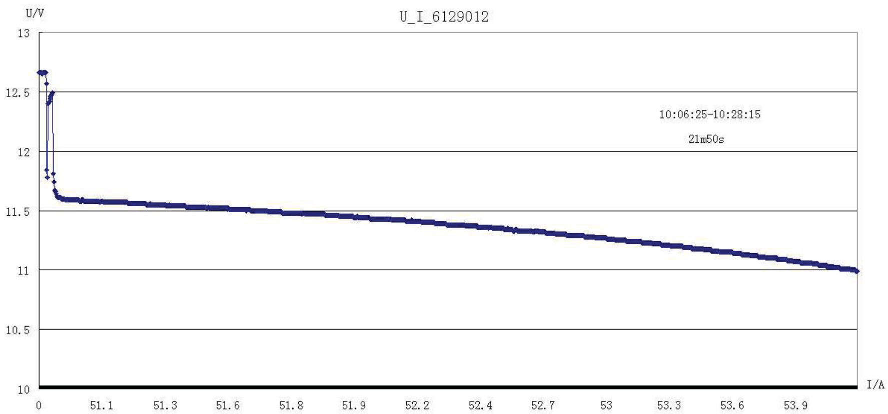


Figure 3.20: Test result of 6129012 discharging with 600W

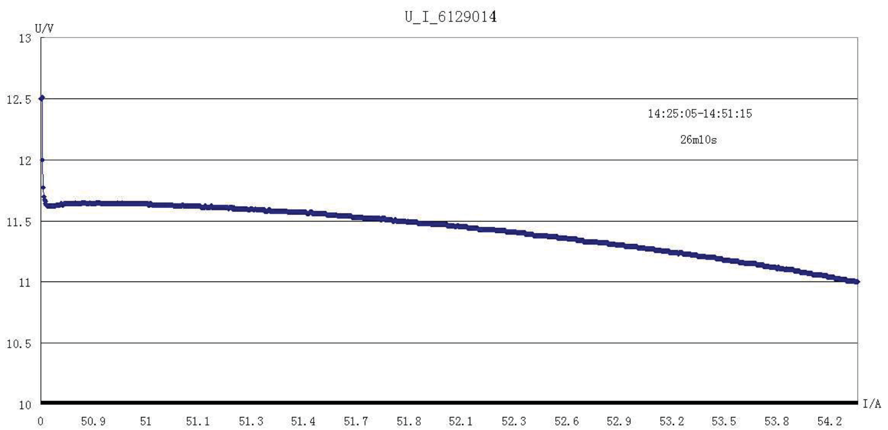


Figure 3.21: Test result of 6129014 discharging with 600W

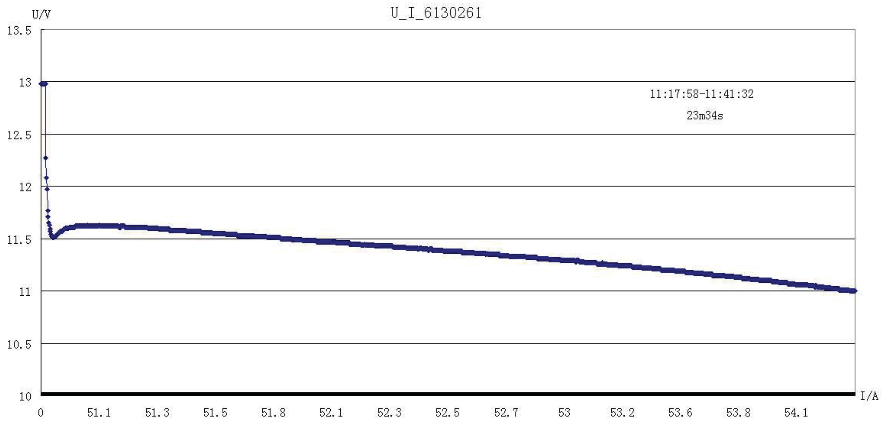


Figure 3.22: Test result of 6130261 discharging with 600W

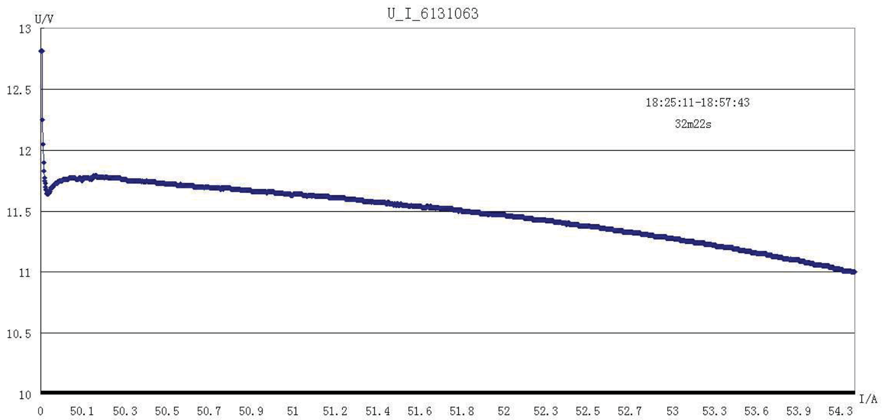


Figure 3.23: Test result of 6131063 discharging with 600W

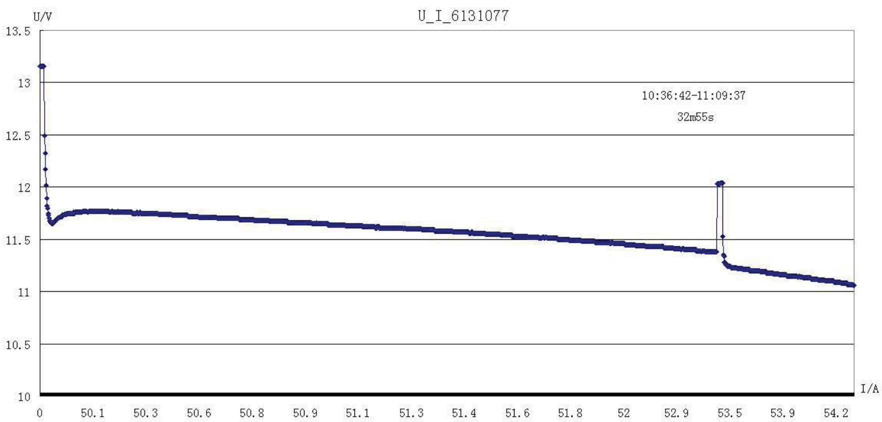


Figure 3.24: Test result of 6131077 discharging with 600W

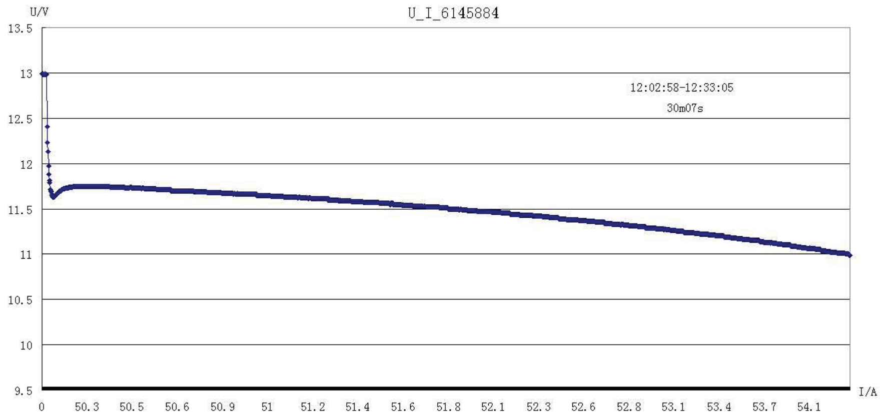


Figure 3.25: Test result of 6145884 discharging with 600W

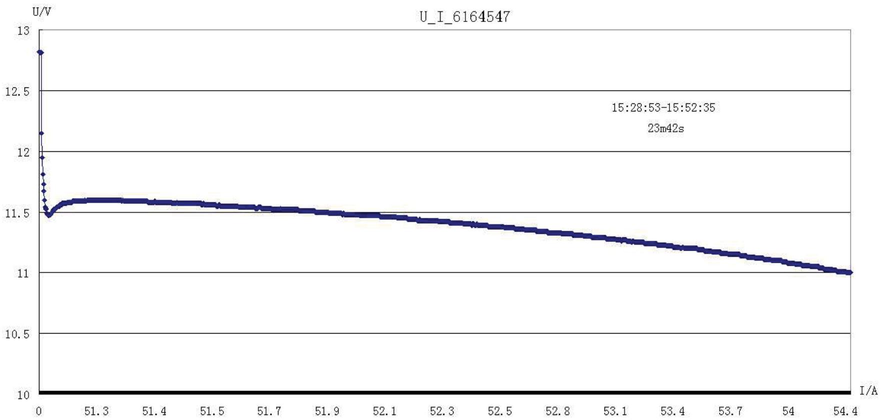


Figure 3.26: Test result of 6164547 discharging with 600W

From the discharge duration and initial voltage we can see that these batteries have rather different capacities. The batteries which has strong capacity can be used to build UPS system.

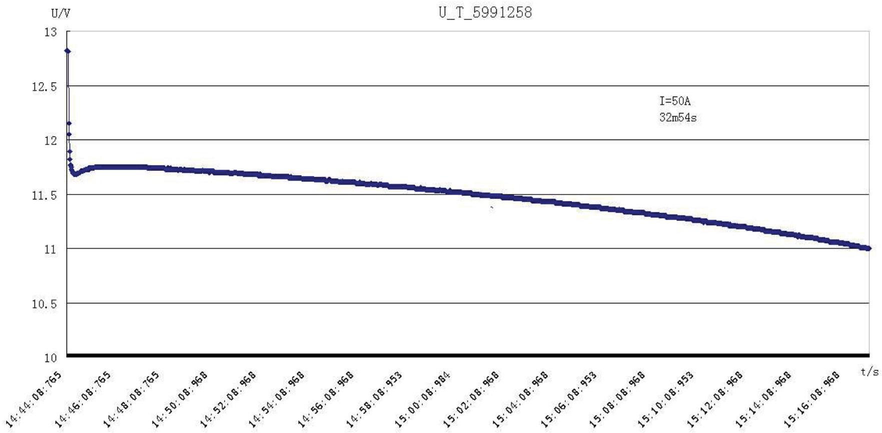


Figure 3.27: Test result of 5991258 discharging with 50A

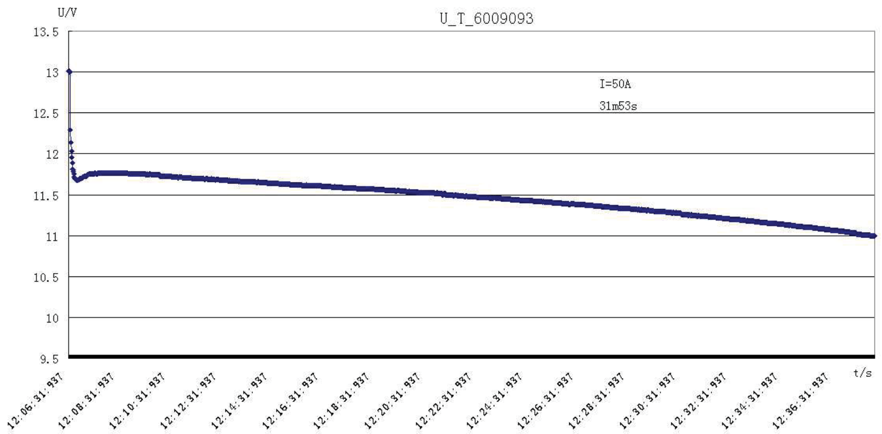


Figure 3.28: Test result of 6009093 discharging with 50A

3.6.2 Test results of battery discharging with constant current

3.6.2.1 Battery discharging with 50A

All 50 batteries must be discharged with 50A constant current, the test results are shown in figures (3.27 - 3.31).

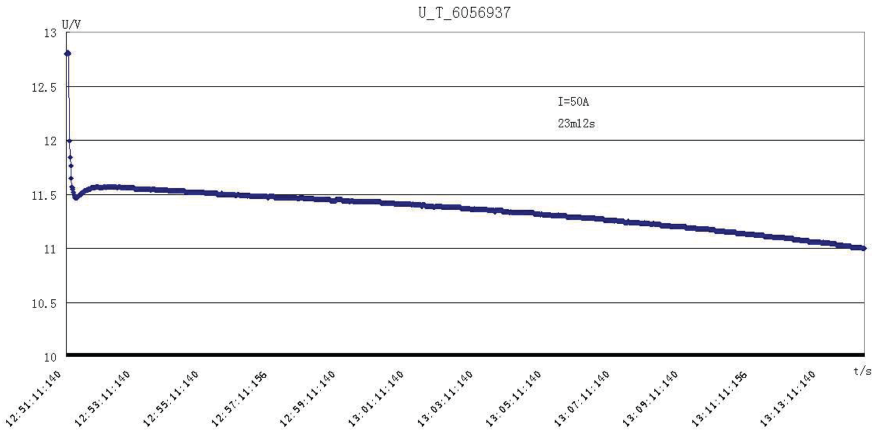


Figure 3.29: Test result of 6056937 discharging with 50A

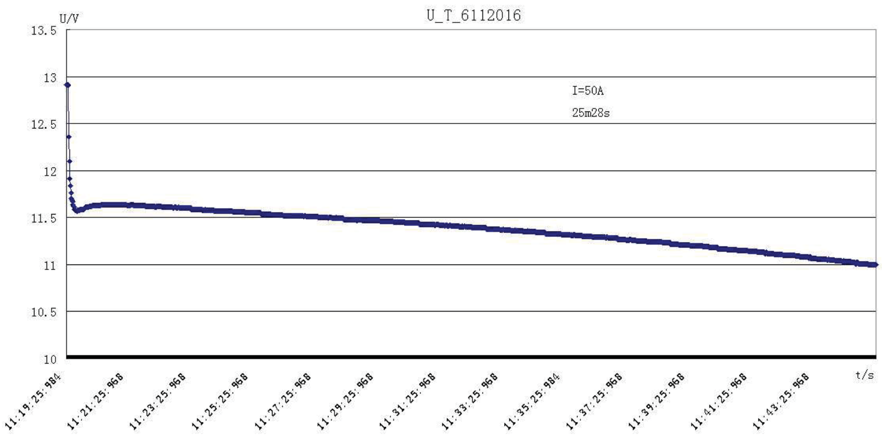


Figure 3.30: Test result of 6112016 discharging with 50A

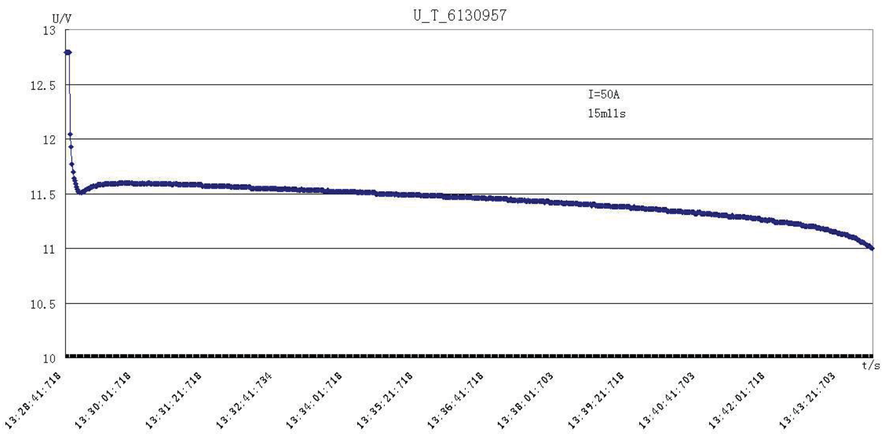


Figure 3.31: Test result of 6130957 discharging with 50A

The other battery discharging data can be seen in appendix. Battery serial number and corresponding duration of discharging with 50A are in the table 3.3. The red color marked batteries are the weakest ones in the experiment, the blue color marking denotes a weaker battery.

serial number	duration[minute/second]	serial number	duration[min/second]
5991258	32m54s	6009093	31m53s
6056937	23m12s	6112016	25m28s
6130957	15m11s	5991263	34m23s
6043831	24m26s	6043838	14m18s
6043841	22m49s	6056941	22m54s
6117160	28m33s	6130956	26m44s
6165231	29m25s	6165276	31m05s
6009094	6m28s	6009095	28m51s
6056940	29m14s	6056960	24m03s
6112024	30m41s	6130959	27m59s
6043830	1m27s	6056956	25m14s
6111796	29m47s	6117554	25m06s
6128999	29m24s	6145886	28m39s
6164458	30m35s	6164459	32m40s
6043839	26m42s	6056957	33m02s
6099573	27m56s	6100141	31m19s
6112193	29m02s	6129012	23m15s
6129014	27m01s	6130261	24m10s
6131077	29m04s	6145884	28m04s
6164547	25m38s	5991262	33m11s
5991265	30m57s	6043933	18m13s
6130265	26m12s	6130266	27m42s
6130958	29m37s	6164460	16m03s

Table 3.3: Duration of battery discharging with 50A

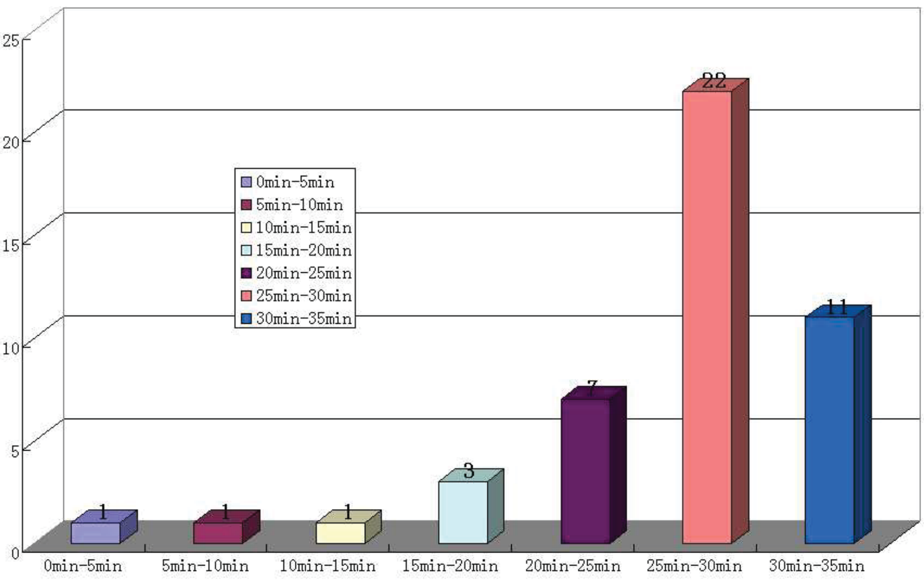


Figure 3.32: Duration distribution of the battery discharging with constant 50A

The battery discharging duration distribution can be seen in figure 3.32. From the statistical figure can be found that most battery discharging with 50A can sustain more than 20 minutes, these batteries can be used as power supply for UPS system.

3.6.2.2 Battery discharging with other currents

After discharging with 50A, in order to further understand the battery characteristic, the battery has to be discharged with different currents. In this experiment we choose 30A, 20A, 10A and 4A as test current and for each current level we select 3 batteries as samples, see table 3.4.

serial number	duration[hour/minute/second]	current[A]	capacity[Ah]
5991263	1h8m10s	30A	34.1
6043841	55m9s	30A	28.6
6056941	47m21s	30A	23.7
5991258	1h54m30s	20A	38.2
6130956	1h40m22s	20A	33.5
6165231	1h45m11s	20A	35.1
6112024	4h39m14s	10A	46.54
6165276	4h39m14s	10A	46.54
6009093	12h45m	4A	46.77
6056937	11h18m	4A	46.62
6117160	11h50m	4A	46.56

Table 3.4: Duration distribution of the battery discharging with different constant currents

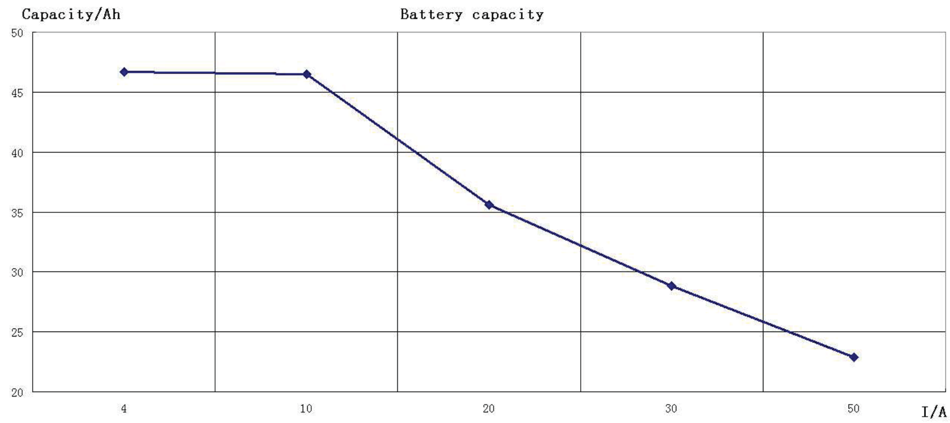


Figure 3.33: Battery capacity distribution

In theory, if a battery can be measured repeatedly, test results will be more precise, but battery charging and discharging takes a long time. Therefore, we used multiple batteries for the measurement, and then take the average for battery capacity researching, the result is shown in figure 3.33. We observe that a discharge current higher than (rated capacity/5h)—in our case: 50Ah/5h=10A —results in a diminution of total discharge capacity. E.g. at about 50A=50Ah/1h we do not obtain rated capacity any more but only about one half of it. This is a common point for any lead-acid batteries.

Chapter 4

Structure of UPS System

4.1 Basic Knowledge of Converter

Rectifier and inverter are power electronics units that are used widely in the industrial production. In combination with direct current intermediate links (DC-links), it is named converter. The power is loaded from the grid, and the alternating current is transposed to fix stable or adjustable direct current, named ”rectification”, that is AC/DC converter. Contrarily, to translate the direct current to be frequency, or alterable of the alternating current, and supply to the load directly, we call it ”inverter”, this is DC/AC converter.

4.1.1 Rectifier

The line commutation circuit can be classified to be uncontrollable commutation circuit, semi-controllable commutation circuit, and controllable commutation circuit. Depending on number of phases of current network, it can be classified to be single phase commutation circuit and three phases commutation circuit.

In the industrial production, three phase current network is used widely in the field of high power. Three phases commutation circuit is the commutation circuit to be used in this experiment. The discussing target on this experiment is mainly projected to use three phases uncontrollable commutation circuit, or controllable commutation circuit.

4.1.1.1 3-phases uncontrollable commutation circuit

Three phases uncontrollable commutation circuit is shown in figure 4.1. The transformed current apparatus in the circuit has high power diodes, and it can not be controlled for a defined

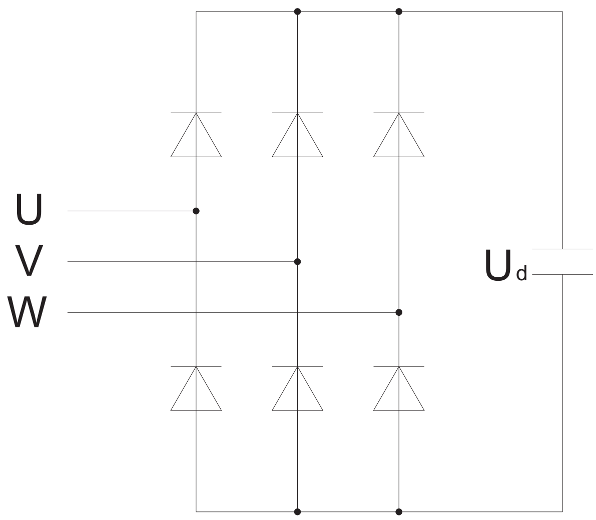


Figure 4.1: Three phases uncontrollable commutation circuit

current or turned off. The commutation of the circuit is carried out by going through the phase voltage to control to make and break of the diode, and the current is transferred from one diode to another diode. The advantage of this kind of circuit is that the producing cost is cheap, and the disadvantage is that the output of the direct current voltage can only be adjusted through terminal voltage of current network (transformer). The average value of outlet voltage actual is three phases controllable commutation circuit, when thyristor controls angle $\alpha = 0$. The output voltage U_d is:

$$U_d = \frac{1}{\frac{\pi}{3}} \cdot \int \sqrt{2} \cdot U_{UV} \cdot sin\omega t \cdot d\omega t = 1.35U_{UV} = 2.34U_V \tag{4.1}$$

Ripple amplitude:

$$U_{ripple} = U_p \cdot (1 - sin60^\circ) \tag{4.2}$$

In the formula 4.1 and 4.2, U_d is average output voltage, U_p is peak voltage, U_{UV} is line voltage RMS, U_V is phase voltage RMS.

4.1.1.2 3-phases controllable commutation circuit

There are many kinds of commutation circuit, and one which is used widely is three phases controllable commutation circuit. This circuit is analogous with three phases uncontrollable commutation circuit, but the converter in the circuit is changed from diode to thyristor, and can go through external assistant circuit to control to make and break of the thyristor. As shown in figure 4.2, the function method of thyristor commutation circuit and diode commutation circuit are quite different.

1. If the positive voltage between an anode and a cathode of the diode commutation circuit is higher than the barrier voltage of it's PN junction, the diode will be guide circuit, and when the control pole of the crystal thyristor commutation circuit does not trigger the

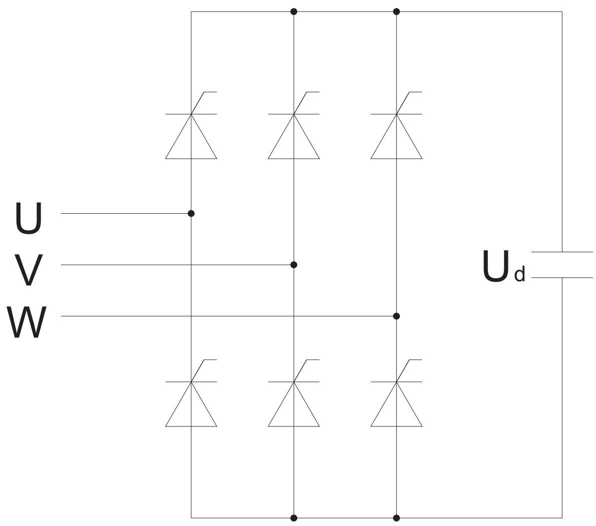


Figure 4.2: Three phases controllable commutation circuit

signal, as long as the positive voltage between an anode and a cathode of it is lower than the voltage of breaking down the pipe, the thyristor then will not be in on-state.

2. The condition that makes the thyristor circuit conduction:

   - At positive voltage between an anode and a cathode: for the diode commutation circuit, if the voltage is about 0.7 V, the on-state condition is obtained. For thyristor commutation circuit, generally, voltage set is at 6V up.
   - The control pole of the thyristor triggers the signal voltage, generally, it is impulse trigger, and the impulse voltage requires some certain range and width, because it needs certain range to counteract the barrier voltage of PN junction, and if there is no certain width, it will not have enough time to let guide circuit spread from one spot to all of PN junction. Generally, the requirement for the range is 3∼5V, the width is 4∼10 us, and trigger electric current is 5∼300 mA.

3. Control angle α is the parameter that derives from the control action of alternative current voltage of thyristor. When half cycle of sine voltage increases to thyristor, it will have the basic qualification to establish forward conduction state at the thyristor. At this random time of half cycle, we can trigger the thyristor. The angle between alternating current sine wave forward voltage at thyristor passes 0 up and thyristor triggers and takes guide circuit is starting to conduct is called delay angle (firing angle) α (distance $\overline{AB}$, see figure 4.3). By controlling angle α, variable output voltages can be obtained.

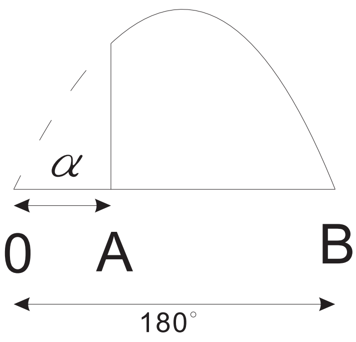


Figure 4.3: Delay angle

Due to the different types of load, DC output voltage have two kinds:[15]

Ohmic-inductive load and ohmic load by $\alpha \leq 60°$

$$U_d = \frac{1}{\frac{\pi}{3}} \cdot \int_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha} \sqrt{2} \cdot U_{UV} \cdot sin\omega t \cdot d\omega t = 2.34 U_V \cdot cos\alpha \tag{4.3}$$

Ohmic load by $\alpha > 60°$

$$U_d = \frac{1}{\frac{\pi}{3}} \cdot \int_{\frac{\pi}{3}+\alpha}^{\pi} \sqrt{2} \cdot U_{UV} \cdot sin\omega t \cdot d\omega t = 2.34 U_V \cdot [1 + cos(\frac{\pi}{3} + \alpha] \tag{4.4}$$

From formula 4.3 and 4.4, it can be seen that three phases uncontrollable commutation circuit actually is one special form of three phases controllable commutation circuit, or we can say that the three phases uncontrollable commutation circuit is three phases bridge type controllable commutation circuit in the situation when thyristor trigger angle α is $0°$. In the modern industrial production, although the price of thyristor is more expensive than diode, the thyristor has the advantage of control.

4.1.2 Inverter

An inverter is an electrical or electro-mechanical device that converts direct current (DC) to alternating current (AC). The resulting AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

The application of inverter is very wide. At the present time, already many power sources exist. For example battery, solar power battery etc, all are direct current power sources. When anyone needs these electrical sources to supply power to alternating current load, all of these have to go use an inverter. In addition, for many situation, the fundamental frequency power supply 50Hz that is supplied by electrical network, does not fulfill special requirements, it needs to use alternating current → direct current → alternating current frequency conversion circuit to transform the electric power. For example, in order to increase the temperature of the induction

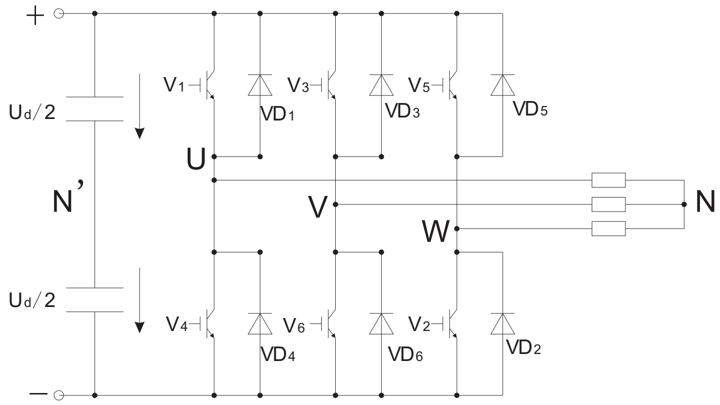


Figure 4.4: Three phases bridge type inverter

furnace we need high frequency electric source. Some loads used fundamental frequency power supply, but strictly require the stability of the power supply's frequency, minimized waveform distortion etc, at this time also needs to use alternating current → direct current → alternating current frequency conversion circuit to improve the quality of power supply. Among them, alternating current → direct current is called rectifier, and direct current → alternating current is called inverter.

4.1.2.1 Three phase inverter

Three-phase inverters are used for variable-frequency drive applications and for high power applications such as HVDC power transmission. A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For a basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60° point of the fundamental output waveform. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square-wave such that the harmonics that are multiples of three are eliminated as described above. When carrier-based PWM techniques are applied to six-step waveforms, the basic overall shape, or envelope, of the waveform is retained so that the 3rd harmonic and its multiples are cancelled and in addition further harmonics, especially the lower order ones like 5, 7, 11, 13...are minimized.

Among the three phases inverter circuit, the one which will be applied most is three phase bridge type inverter circuit. To use power transistor as controllable element of three phase bridge type inverter circuit as displayed in figure 4.4. The basic working mode of this inverter circuit is 180° conducting mode. It means that conducting angle of every power transistor is 180°. In the same phase, upper and lower of two thyristor alternating do conducting, and the time of each phase starts to conducting is different from 120°. Each conversion will be carried out in the same phase, between upper and lower of two thyristors.

Figure 4.5 shows the working wave form of three phases bridge type inverter circuit, for easy analysis, direct current side in the picture, assuming one mid point N', and show the three

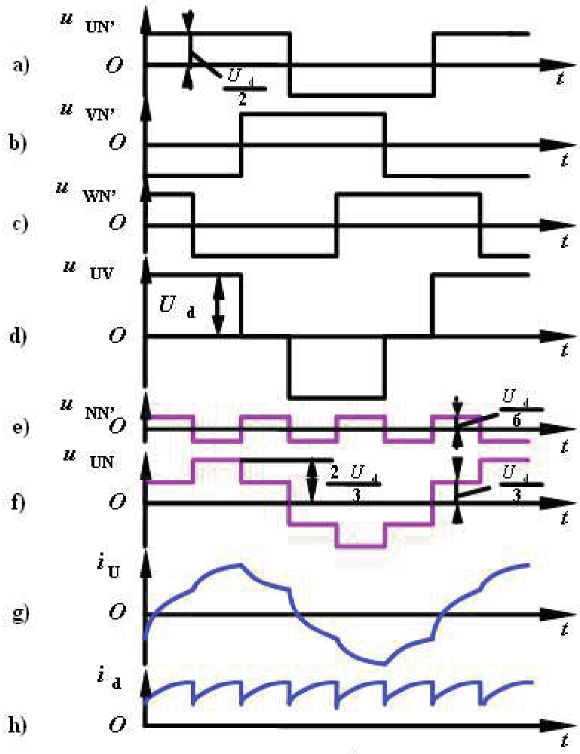


Figure 4.5: Waveform of three phases bridge type inverter [16]

phases output with phase U, phase V, and phase W. For phase U, when the thyristor V_2 gets guide circuit, $u_{UN'} = \frac{u_d}{2}$, when the thyristor V_4 gets guide circuit, $u_{UN'} = -\frac{u_d}{2}$, and $u_{UN'}$ is rectangular wave. Phase V and phase W are analogous with phase U. The waveforms of $u_{VN'}$, $u_{WN'}$ are identical with $u_{UN'}$. The difference of phase in sequence is 120°.

Load line voltage:

- $u_{UV} = u_{UN'} - u_{VN'}$
- $u_{VW} = u_{VN'} - u_{WN'}$
- $u_{WU} = u_{WN'} - u_{UN'}$

Load phase voltage:

- $u_{UN} = u_{UN'} - u_{NN'}$
- $u_{VN} = u_{VN'} - u_{NN'}$
- $u_{WN} = u_{WN'} - u_{NN'}$

The voltage between load middle point and power supply middle point:

$$u_{NN'} = \frac{1}{3}(u_{UN'} + u_{VN'}u_{WN'}) - \frac{1}{3}(u_{UN} + u_{VN} + u_{WN}) \tag{4.5}$$

When three phases load are symmetry,u_{UN}+u_{VN}+u_{WN}=0, then:

$$u_{NN'} = \frac{1}{3}(u_{UN'} + u_{VN'} + u_{WN'}) \tag{4.6}$$

waveform as shown in figure 4.5, it also is rectangular wave, but its frequency is three times of $u_{UN'}$'s, amplitude is $\frac{u_d}{6}$.

When the load is known, the waveform of i_U in figure 4.5 can be derived from the waveform of u_{UN}. The waveform of i_V, i_W and i_U are the same. The difference of phase in sequence is 120°. By appropriate adding of three phases currents, we can get direct current side current i_d. i_d gets every one pulsation within each interval of 60°. DC Voltage side has no pulsation. The power that was transmitted from DC side to AC side by inverter is also pulsating.

Figure 4.6: SIEMENS 6SE70 converter

4.2 Siemens 6SE70 Converter

Siemens 6SE70 series converter shown in figure 4.6 is typical for a class of 400V frequency conversion equipment. It integrates rectifier, inverter and DC link with direct current port. It can be used to do the conversion of AC→AC or DC→AC. Two kinds outline of 6SE70 are often seen. Among them, the output power for model Compact is 2.2kW $\sim$ 37kW, and the outlet power for model Chassis is 45kW $\sim$ 2300kW. The load power of motor for this UPS system is 10 kW, therefore, Compact model can be used for AC→AC conversion. [17]

6SE70 converter description as shown in figure 4.7. It includes the port of three phase voltage inlet U_1,V_1,W_1, and three phase outlet U_2,V_2,W_2. Besides, there are C+ and D- for DC link. The unit can be operated from a DC system with voltages from 510V to 650V [18]. It can be used to be connected to external equipment. When the power network is working normally, power network voltage is connected to converter by U_1,V_1,W_1. After filtering, going through rectifier and inverter inside the converter the output supply voltage for the load is internally connected to U_2,V_2,W_2. When the power network is broken, the battery voltage from C+ and D- port of DC link will be connected to converter, and after the inverter inverts and exports three phases voltage to supply the load from U_2,V_2,W_2. When the power network recovers to normal working, U_1,V_1,W_1 will be connected to power network again, and supplies the power to the load. At the same time, the batteries switch into the state of charging.

4.2.1 Adjustment before using 6SE70

Before using of 6SE70 converter, we have to take it to do the test by connecting the input port U_1,V_1,W_1 of converter to 400V voltage of power network. The fan inside the converter will

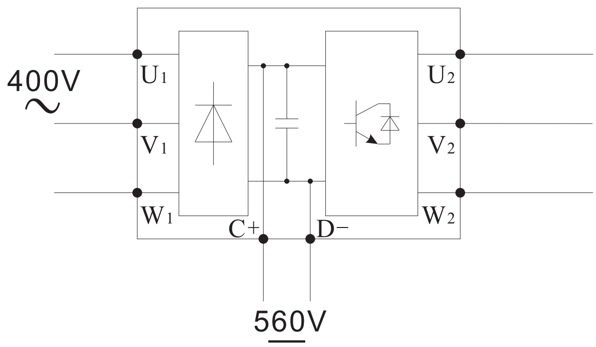


Figure 4.7: Schematic of SIEMENS 6SE70 converter

immediately start to work, at this time, the converter is in disconnection state. After measuring, the voltage of output port U_2, V_2, W_2 is about 0.6V, the voltage of C+ and D- port of DC intermediate link is 540V. After the converter turns on, the voltage of DC intermediate link is 560V (the commutated part of the converter is diode commutation circuit, therefore, the voltage of DC intermediate link is a fixed value), the formula is followed by 4.1. The voltage of output port U_2,V_2,W_2 can be changed by setting of certain parameters (introduced later). Through RS232 interface and monitor drive software, the converter can be connected to the computer. This enables the converter to accept parameter setting on the PMU panel and also provides better visual convenient by using computer to set the parameter of converter.

4.2.2 Factory settings

Before using the converter, we have to set the converter to restore factory setting (except for new converter), in order to let all parameter values of the converter to be restored to the state of factory setting. The method of practical setting is shown in table 4.1.

Parameter number	Description
P053 = 6	**Grant parameter access** 6: Parameter changes permitted via PMU and serial interface SCom1 (OP1S and PC)
P060 = 2	**Select Fixed settings menu**
P366 =0	**Select desired factory setting** 0: Standard with PMU
P970 = 0	**Start parameter reset** 0: Parameter reset 1: No parameter change

Table 4.1: Factory setting parameters

After following this method for setting the parameters, the converter will restore the initial state of all parameter settings. [19]

4.2.3 System settings

After the converter restores to factory setting, it can be used normally. Before using it, the system needs to be set, so that the converter can normally work for the load motor. The practical setting method as shown in table 4.2.

Parameter number	Description
P060 = 3	**Menu selection Quick parametrization**
P071 = 400	**Input unit line voltage in [V]**
P095 = 10	**Type of motor** 10: Asynchron/sync. IEC (international standard)
P100 =1	**Control mode** 1: v/f open-loop control
P101 =	**Enter the rated motor voltage in [V]** as per rating plate
P102 =	**Enter the rated motor current in [A]** as per rating plate
P104 =	**IEC motor: cosφ** as per rating plate
P107 =	**Enter the rated motor frequency in [Hz]** as per rating plate
P108 =	**Enter the rated motor speed in [rpm]** as per rating plate
P109 =	**Enter the motor pole pair number** (is automatically calculated)
P115 = 1	**Calculate motor model** 1: Automatic parametrization
P370 = 1	**Start of quick parametrization** 0: No parameter change 1: Parameter change in accordance with selected combination of parameter modules
P060 = 0 or 1	**Return to the user menu or Parameter menu** 0: User parameter 1: Parameter menu

Table 4.2: System setting parameters

All the above setting is finished in the state of converter turning off. [20]

After finishing P060 parameter setting, if the system does not display error, it means that the setting is finished. The converter can be connected to load motor and start up of the converter for normal operation can be initiated.

4.3 The Structure of UPS System

4.3.1 Grid power supply system

In normal situation, the power supply source of load motor comes from power network. After 400V voltage of power network goes through the converter for rectification and inverting, according to the parameter setting inside the converter, it supplies the required power to the 10kW asynchronous motor.

4.3.2 Battery power supply system

In the situation that the power network works normally, the battery should be in the status of charging (see chapter 3). When the power network is malfunction, the battery should immediately cut in the direct current links of the converter, and after passing the inverter and turn into three phase alternating current to continue supply power to load motor.

However, the battery power source cannot supply power with no limit for load motor. When the voltage power network cannot recover for along time, and the battery voltage is under specific value, if it still continues to supply power to the load, not only it cannot fulfill the load under rated condition for working, it also can be harmful to the battery (battery works under very low voltage will be seriously decrease the working life of the battery). Therefore, at this moment, the battery must be disconnected from the converter, until the battery has been fully charged before using it again. The device controls if batteries are working or not.

The battery charging device has been already introduced in chapter 3, it has output rating voltage about 54V. This voltage can be series connected for four batteries to charge. The theoretical value for batteries being fully charged is $54 \div 4 = 13.5$V. Total batteries are 40 pieces, total series connection voltage is $13.5 \times 40 = 540$V. DC link of the converter is 560V, a little bit higher than battery voltage. Therefore, the relay that connects the battery and DC link of the converter can be designed in figure 4.8.

The red curve in figure 4.8 shows battery voltage, and the voltage when the battery was fully charged the average value is 540V. The green curve shows the direct current voltage of converter. The yellow curve shows the minimum allowance voltage U_{Bmin} for the battery when it is in the status of working. Hereon, the setting for the minimum allowance voltage for the battery when it is in the status of working is 13V, $13 \times 40 = 520$V. After the converter starts up, the DC

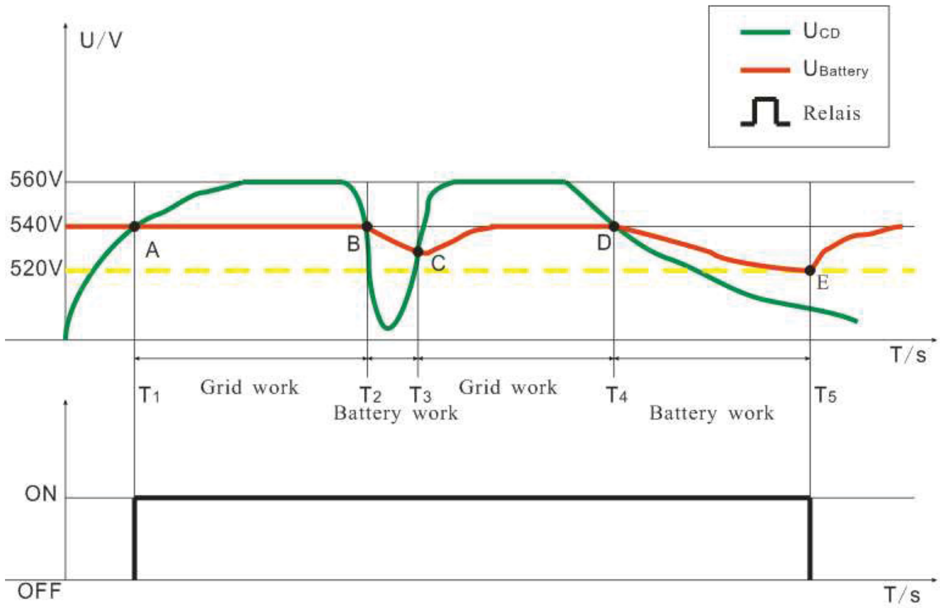


Figure 4.8: Scheme of grid or battery alternatively working

voltage follows the capacitor charging inside the converter and is gradually increasing. When the voltage of direct current U_{CD} is higher than battery voltage (point A in the picture), the relay that is located between the battery and direct current of the converter can be closed (tuned on). At this time $U_{CD} > U_{battery}$, power supply fed by power network. At the same time, there is a diode between the battery and DC link of the converter, there is no current flow from U_{CD} port to battery.

When the power network is malfunction for a short time, the voltage of direct current U_{CD} begins to drop. When U_{CD} voltage drops below battery voltage (point B in the picture), the diode that is located between the converter direct current and battery starts conduction. Due to battery, it continues to supply power to the load, it demands relay A to continue to conduct. After a short time of malfunction, and the power network recovers again, when the power network voltage is increased to the position C in the picture, the battery will stop to supply the power, and switch to the status of charging until the battery is full, and power network continues to supply power to the load.

When the power network is malfunction for a long time, the direct current from rectifier is 0. The battery continues to supply the power to the load through the converter (point D in the picture), as the extended time for the battery to supply the power. The battery port voltage decreases to the minimum voltage U_{Bmin} of allowance battery working, as point E in the picture. After that, the battery stops continuing to supply power to the load, and switches to the charging status, relay A disconnects, and load motor stops running. After the battery is charged fully again, if required the battery continues to supply power to the load for a period of time.

As mentioned above, the practical process of relay A turn on and turn off when controlling the relay A, precaution have to be taken for some conditions as the following:

1. When the converter starts up, the direct current voltage U_{CD} is higher than the battery voltage U_B, and the battery voltage U_C is higher than the minimum voltage for working battery U_{bmin}, relay A is in on-state.
2. After the power network falls off, it means that the direct current voltage U_{CD} changes from being higher than the battery voltage to be lower than the battery voltage: relay A is not allowed to turn off. Otherwise, the battery cannot continue to supply power to the load after this.
3. When the battery voltage has gotten lower than the reference voltage (relay A was disconnected) and for this idling state condition (current=0) the battery voltage moves to be higher than the reference voltage, relay A doesn't allow auto restart. Otherwise, the evident of that relay A being frequently started up will appear.

From the conditions above, we can see that condition 1 and condition 2 are about relay A turn on or turn off, and it is in mutual conflict. If it is only the signal of the different voltage to control relay, it will not work. It was already introduced in chapter 2 about two CD4093 can form up to be one memory function, and it can be used here.

As shown in figure 4.9, two CD4093 forms up to be Schmitt Trigger [11][21], imported port is input, and exported port is output, and another on-off control port is reset. When HI signal is input to input port, input port will not change, and when input LO signal to input port, output port will export HI signal. After this, if HI signal is input to input port again, the output port will store last output signal. It still has no change if maintaining output HI signal. The method to let output port exporting LO signal again is to reset the reset port (press on-off K). This method can make output port resume to LO signal. This kind of Schmitt Trigger that has memory function can be applied when designing the control circuit of relay A.

After having the blueprint as shown in figure 4.8, we have to follow this blueprint to design the circuit, and the circuit diagram is as shown in figure 4.10. Firstly, two different amplifier V_1 and V_2 monitor battery and DC link at the same time, ratio multiple is 100 times. After the battery is fully charged, V_2 will export 5.4V of voltage. When the power network works normally, V_1 will export 5.6V, and V_3 is the voltage follower. By the adjustment of positive pole input port rheostat, V_3 will get between 4.2V and 6V any voltage at output port. This voltage can be called reference voltage, and it is the minimum battery working voltage. Then, U_{ref} compared with the battery voltage allows a decision whether the battery can continue using or stop immediately to charge the battery. As introduced before, the minimum voltage required by the battery working, as each battery is 13V, total is 520V, hereon to set V_3 to 5.2V, it means that minimum batteries' voltage is 520V. V_4 is used to compare the battery voltage and DC link voltage, and make a decision if supply power by power network or battery. When U_{CD} is higher than U_B, V_4 will export positive voltage, then go through V_5 comparator, import -15V from V_5, L_1 light on, means that, right now the power network supplies power to the load. At X_1 input LO signal, X exports HI signal, and stores it in CD4093. After the comparison of battery

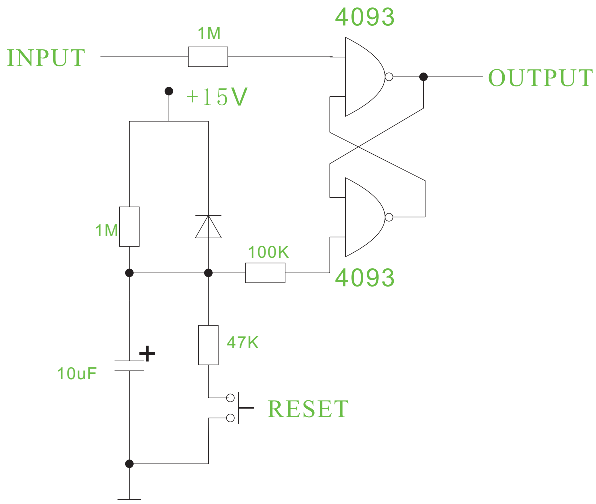


Figure 4.9: Memory function circuit by two CD4093

voltage and reference voltage, it goes into comparator V_6. When the battery voltage U_B is higher than the reference voltage U_{ref}, V_6 exports -15V, L_2 light on, means that, right now the battery is in the status of work allowance. V_6 output LO signal after the not-gate CD4049 becomes to HI signal, this HI signal on the one hand, as an input of 3-input and-gate CD4073, on the other hand, as the Schmitt Trigger input goes to Y_1. When Y_1 input signal HI, Y output keeps on the original state, here the signal Y must keep LO signal state, so that when Y_1 input LO signal, Y signal will be HI output, signal state has changed, and signal through after CD4049, becoming the third CD4073 input. Output of CD4073 as relay A control signal, HI means turn on, LO means turn-off. When the grid voltage fault, L_1 is off, batteries supply to the load, at this moment the X and Y keep the original HI state, Z signal due to the battery voltage is still higher than the reference voltage U_{ref} for HI state, relay continue on; when the battery voltage drops below the reference voltage U_{ref} when, Y_1 input LO signal. Then Y signal output HI and keep it, W output LO signal, relay off.

Note: Before system starts, it is necessary to press the two switches K_1 and K_2 in figure 4.10 to ensure that the two light L_3 and L_4 are lighted, the purpose of K_1 and K_2, through the adoption of the RESET, making X and Y first LO state. Otherwise, the logic is invalid. K_1 control after the first order of K_2 (the first light L_3, L_4 later). After relay A is turned off, either the grid is resumed to supply, or grid is shut down, load requests batteries for short-term supplying. Then system needs to be manually re-started.

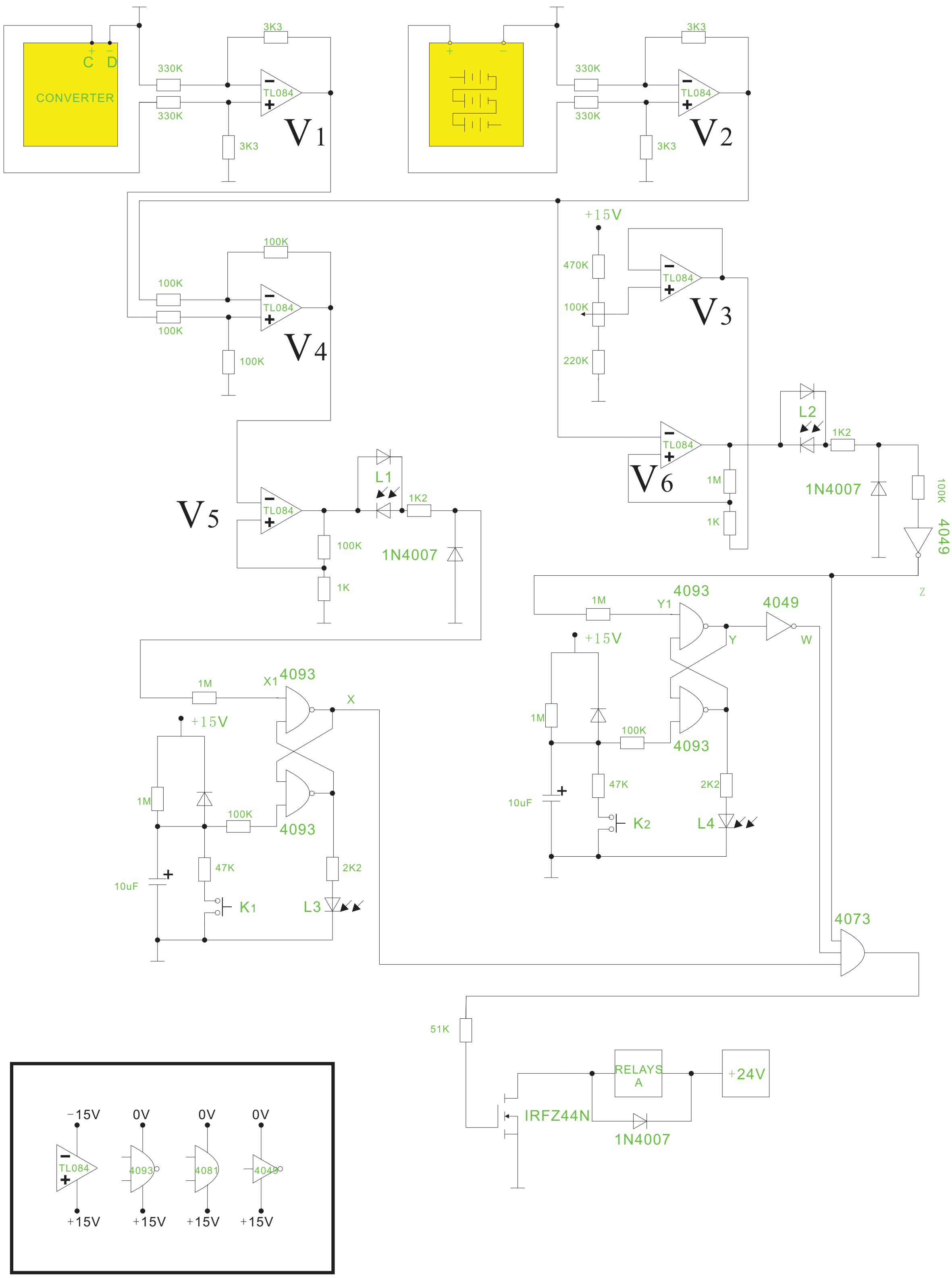


Figure 4.10: Circuit of grid or battery operation

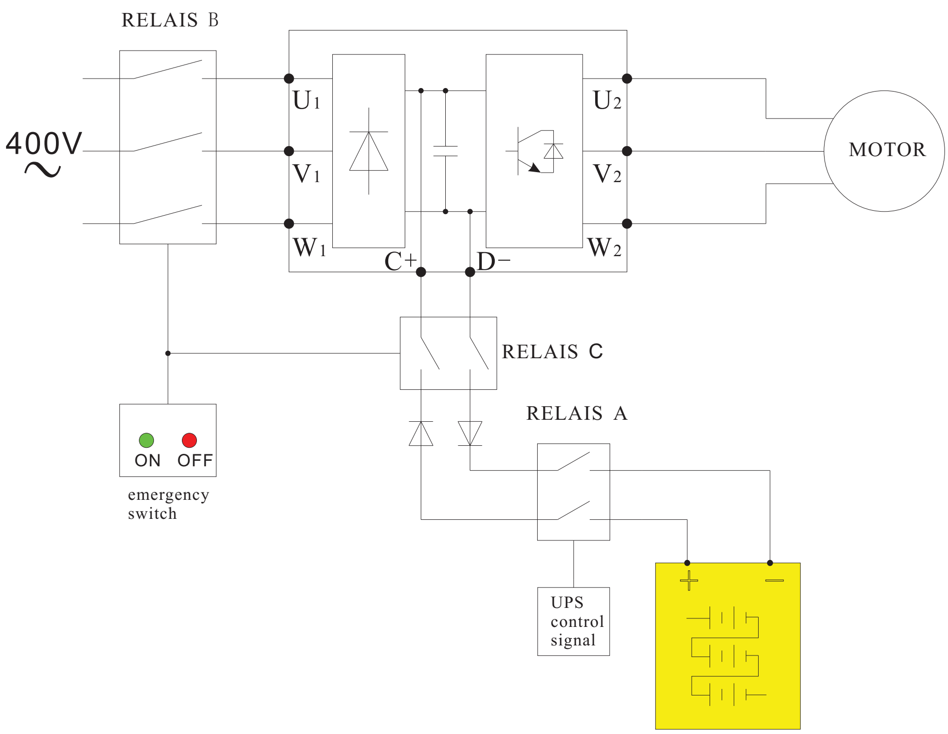


Figure 4.11: UPS system structure

4.3.3 Emergency switch

If the system would immediately interrupt during the normal operation, means that neither grid nor batteries are supplied to the load, just between the grid and the converter. Between the converter and batteries two switches (relay B and relay C) can be installed, (see figure 4.11), then through a control signal at the same time relais A and C are turned on or off.

Emergency switch control circuit can be achieved with two CD4093, circuit diagram as shown in figure 4.12. Before the operation of the system, press K_1, X gets HI output signal, the signal controls at the same time the relay B and C turn on, L_1 lights. When the system must be maintained, press K_2, X gets LO output signal, relay B and C turn off, L_2 lights, at the moment no power is supplied to the load, it can be carried out maintenance operations.

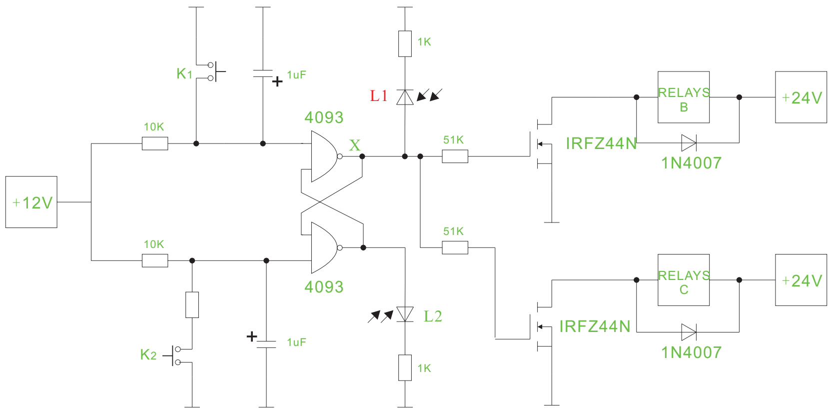


Figure 4.12: Relay control circuit of emergency switch

Chapter 5

Conclusion

This thesis covers the application of UPS system in industrial environment. There are two key contents, one is the test of battery, the important part of UPS system, and the other one is the establishment of UPS system.

When the battery is tested, it should be simulating the operation at the condition that the battery really supplies the power to the UPS, so that it can follow the 50Ah result to discharge the power. After calculating the discharged time, the characteristic of the battery discharging will be known, and the judgment can be made if this battery can be used in the normally working of UPS system.

When the UPS system is established, it requires high precision of difference amplifier to operate the voltage monitoring for battery and converter. Therefore, the amplifying character and the offset of the voltage compensation is further studied, and the detail of the battery charging system is covered deeper, including single battery voltage monitoring system and the voltage balancing system between the batteries. This can make the battery unit safe and reliable for charging. For the selection of the converter, after comparison, the SIEMENS 6SE70, more commons in the market, is chosen to be the main research object, for different loads, to operate the corresponding parameter setting.

The battery to be used in this test is an assemblence of old batteries, Therefore, it did not follow the theoretical value to charge and discharge in the testing. The discharging test is between 11V and 11.7V. The nameplate of the battery is 12V50Ah, but actually, the battery can maintain 30 minutes for 50A of discharging, and after full charging, it cannot reach 13.5V for each piece as the charger efficiency, and will get different voltage dropping. But if it follows 30 minutes of the UPS system working requirement, these batteries can be continued to be used, and will not over-heat or danger of unstable discharging.

For the battery capacity characteristics researching, a high number of batteries are measured with different constant currents. This can save a lot of time, but the result is not exact, because each battery features are not the same. A more accurate method for battery capacity research is to select one single battery to measure the charging and discharging process with different constant current again and again.

The UPS system is very widely applied in all various industries, according to the number of the application of the load of power adjusted battery, but the level of the present technology still cannot use the battery for the very big power load. The UPS system in this thesis is applied in asynchronous motor. If other type of converter is used, UPS system can also drive the synchronous motor, direct current motor, and apply to other type of load. If the new battery is used in the industry production process, it will make the UPS system be more safe and reliable.

The battery charging system that is mentioned in the thesis also can be applied to solar energy, wind energy or hydro-electric power systems, as an energy reserve unit.

During the test and thesis modifying, Prof.Weiss gave a lot of very valuable advice and support, Electrical Engineering of University of Leoben gave a very good hardware condition, my mentor DI.Kayhan INCE gave me many help in the process of the test, and helped me modifying my thesis serious. Hereon, I would like to express my appreciation from the bottom of my heart again.

Appendix A

Results of battery discharging with 50A

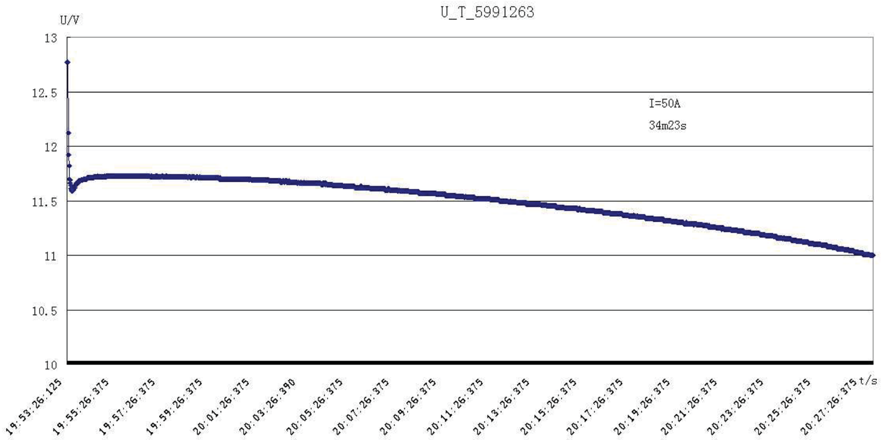


Figure A.1: Test result of 5991263 discharging

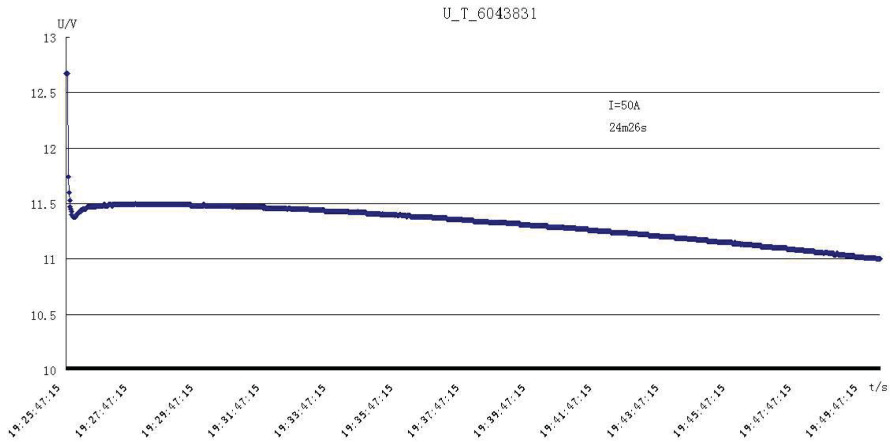


Figure A.2: Test result of 6043831 discharging

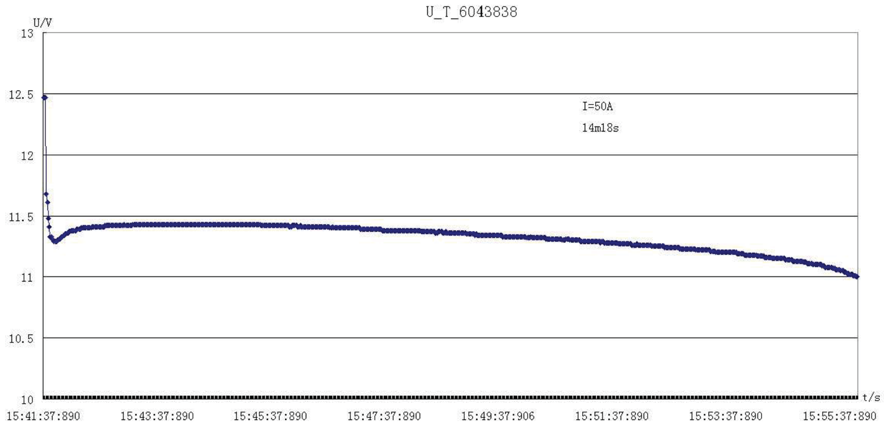


Figure A.3: Test result of 6043838 discharging

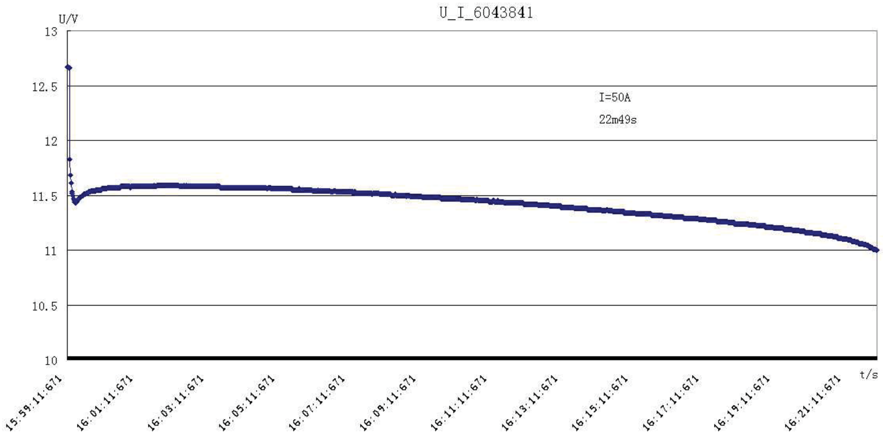


Figure A.4: Test result of 6043841 discharging

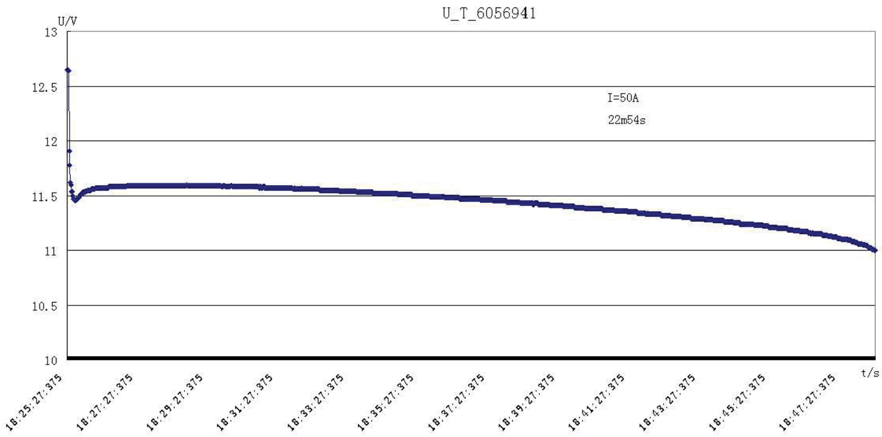


Figure A.5: Test result of 6056941 discharging

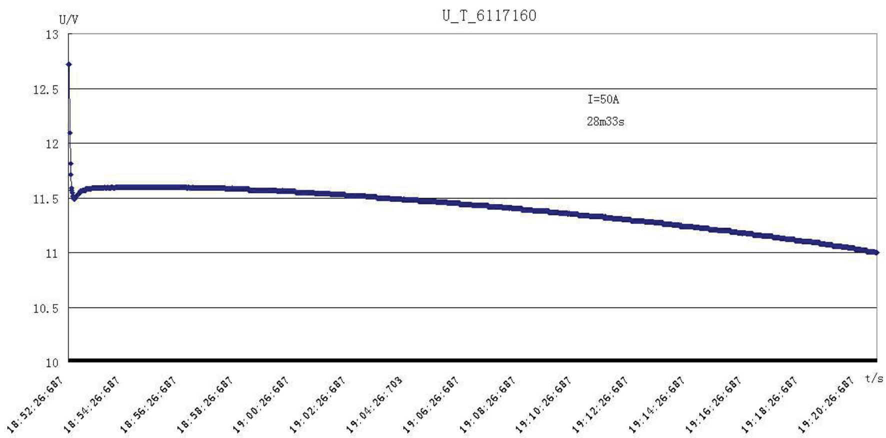


Figure A.6: Test result of 6117160 discharging

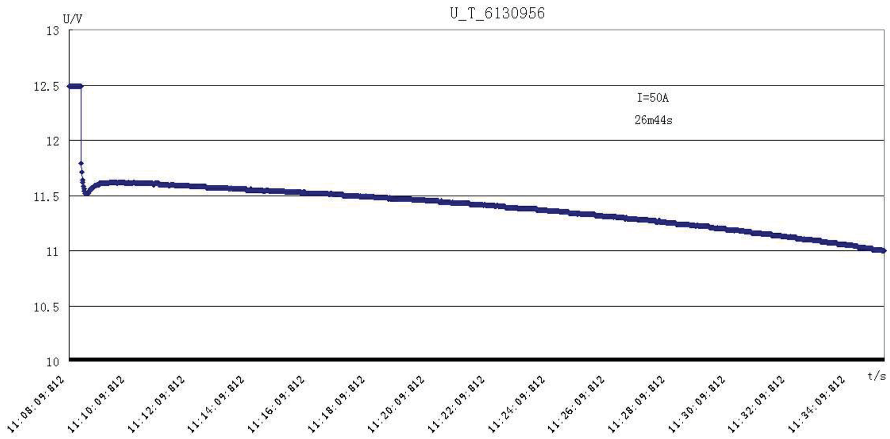


Figure A.7: Test result of 6130956 discharging

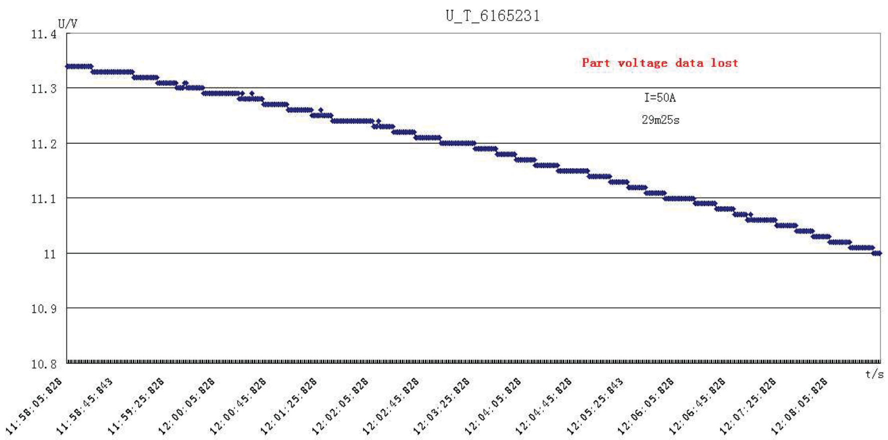


Figure A.8: Test result of 6165231 discharging

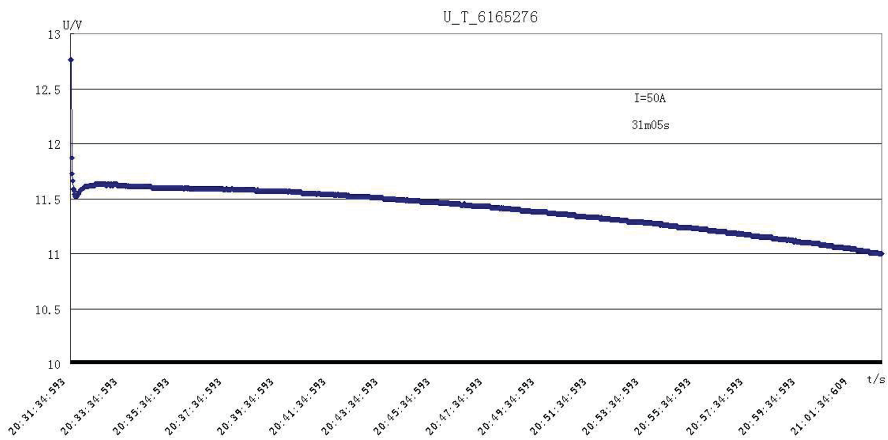


Figure A.9: Test result of 6165276 discharging

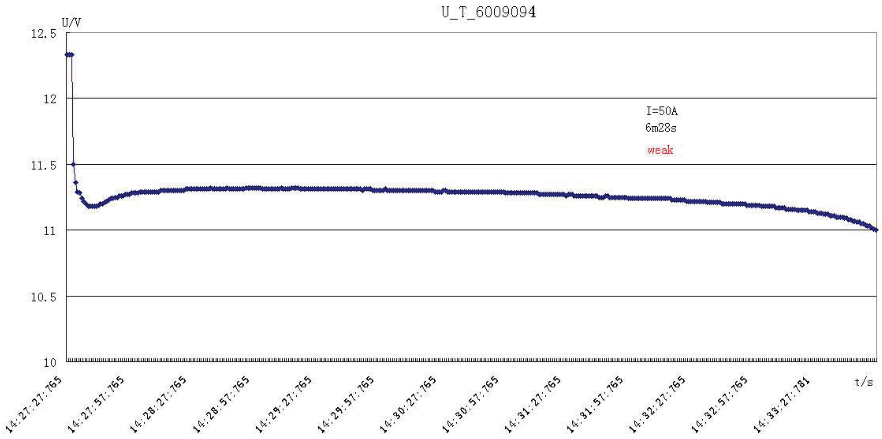


Figure A.10: Test result of 6009094 discharging

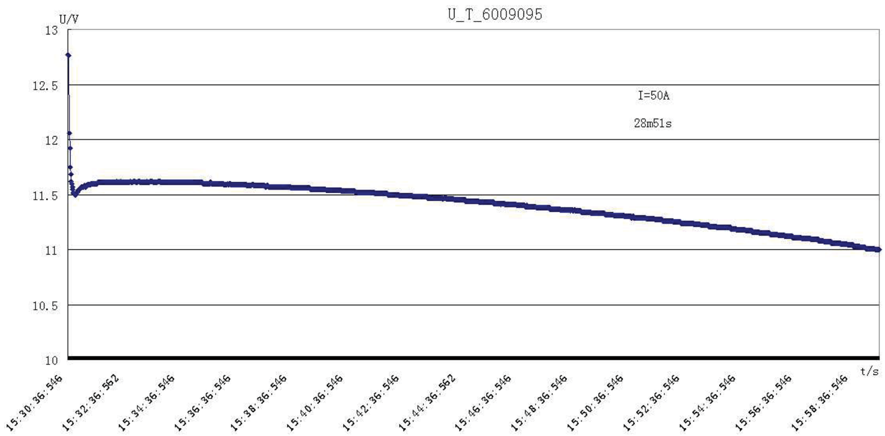


Figure A.11: Test result of 6009095 discharging

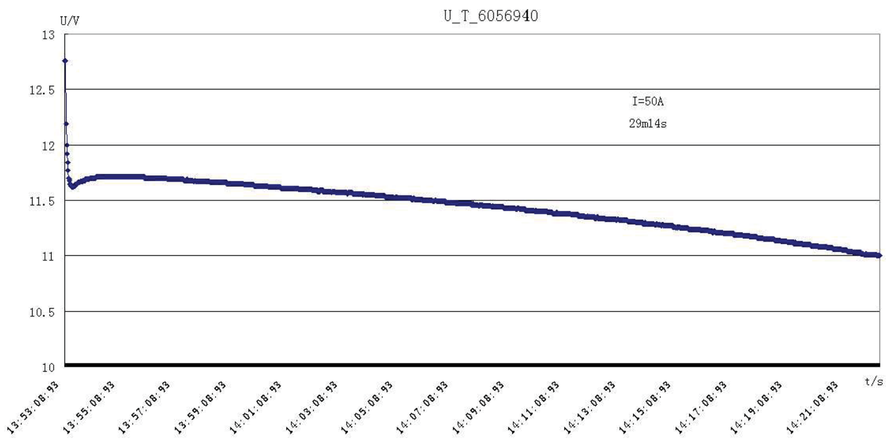


Figure A.12: Test result of 6056940 discharging

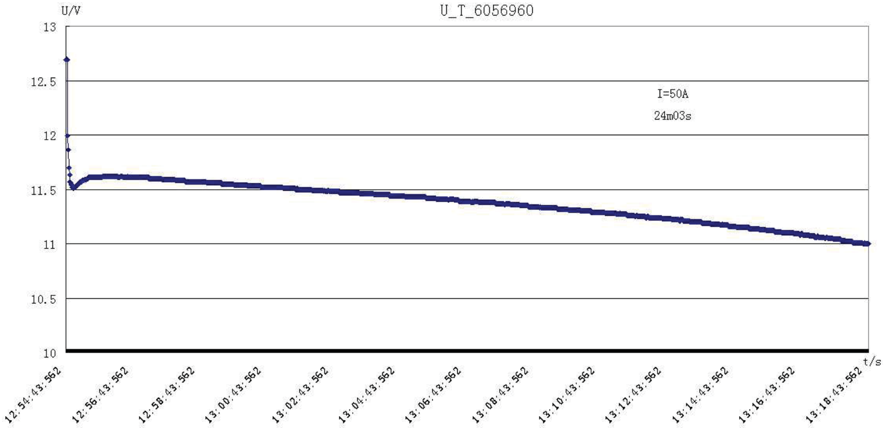


Figure A.13: Test result of 6056960 discharging

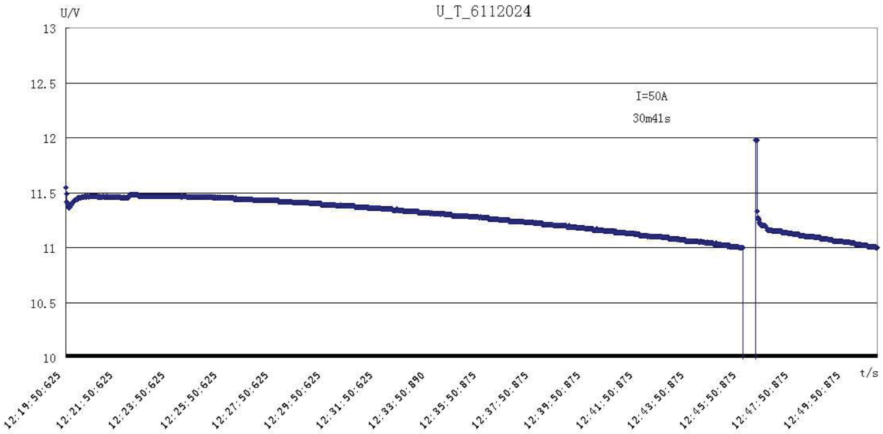


Figure A.14: Test result of 6112024 discharging

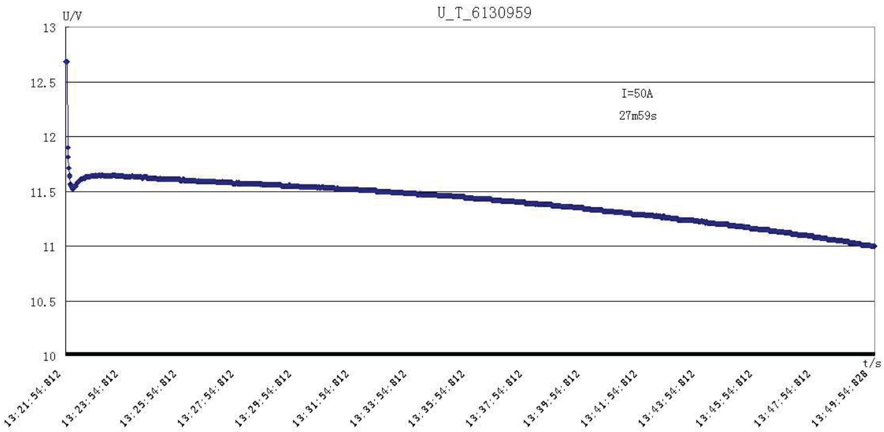


Figure A.15: Test result of 6130959 discharging

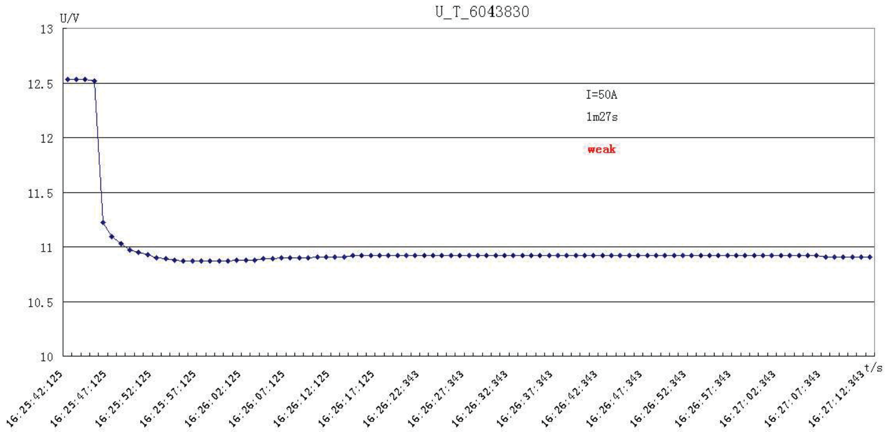


Figure A.16: Test result of 6043830 discharging

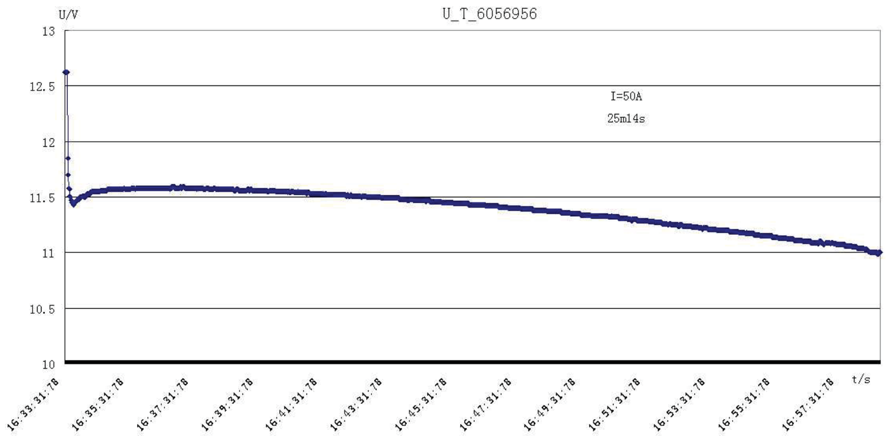


Figure A.17: Test result of 6056956 discharging

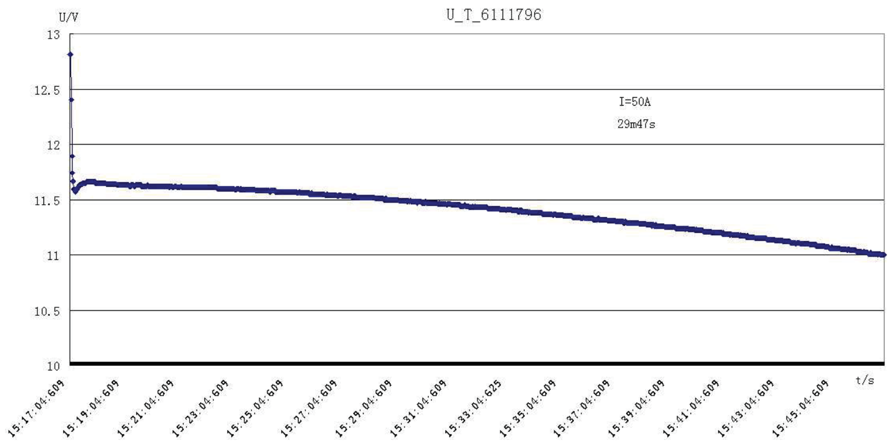


Figure A.18: Test result of 6111796 discharging

Appendix B

Results of battery discharging with 30A

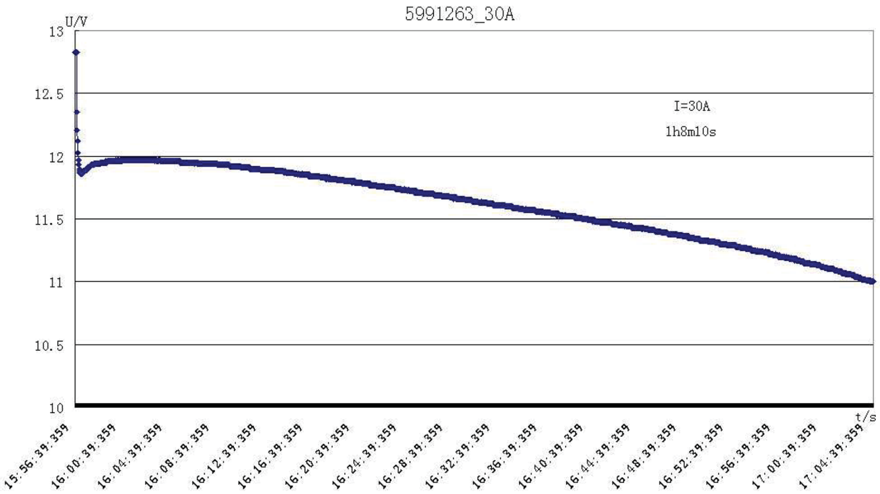


Figure B.1: Test result of 5991263 discharging

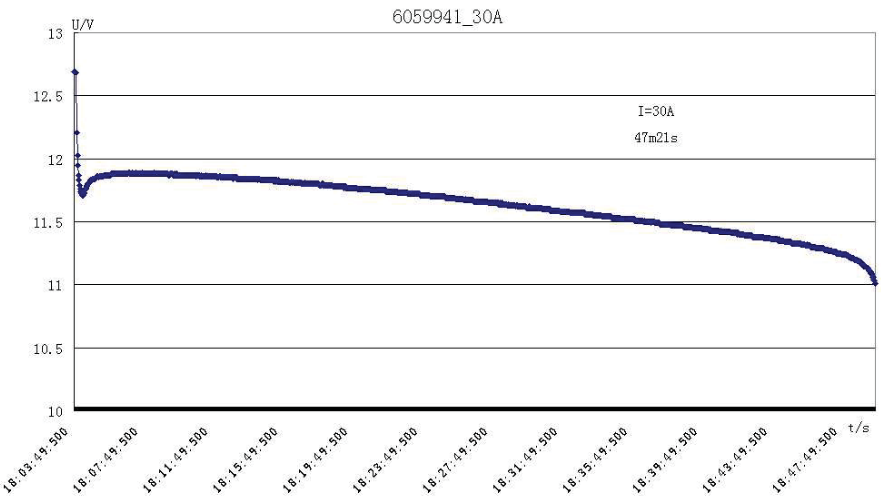


Figure B.2: Test result of 6055941 discharging

Appendix C

Results of battery discharging with 20A

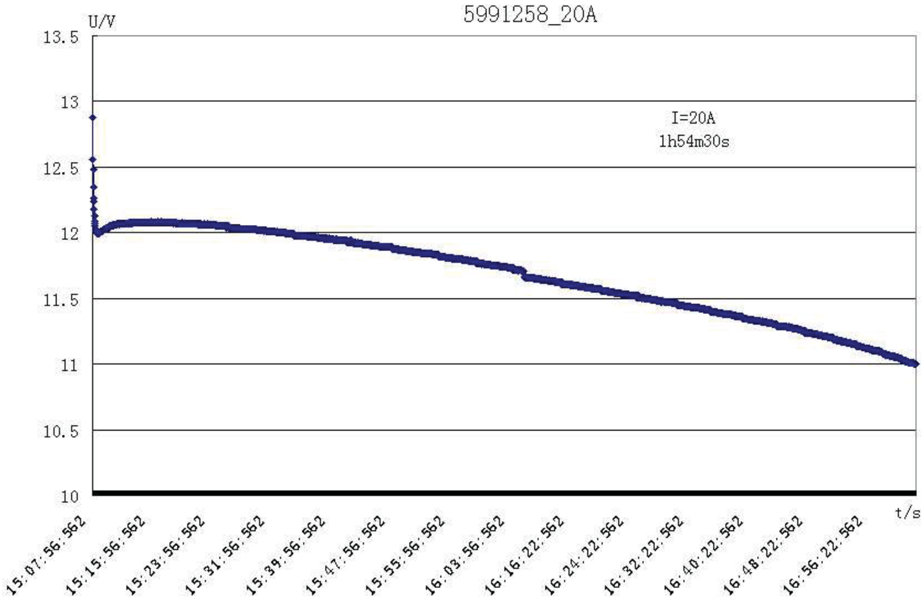


Figure C.1: Test result of 5991258 discharging

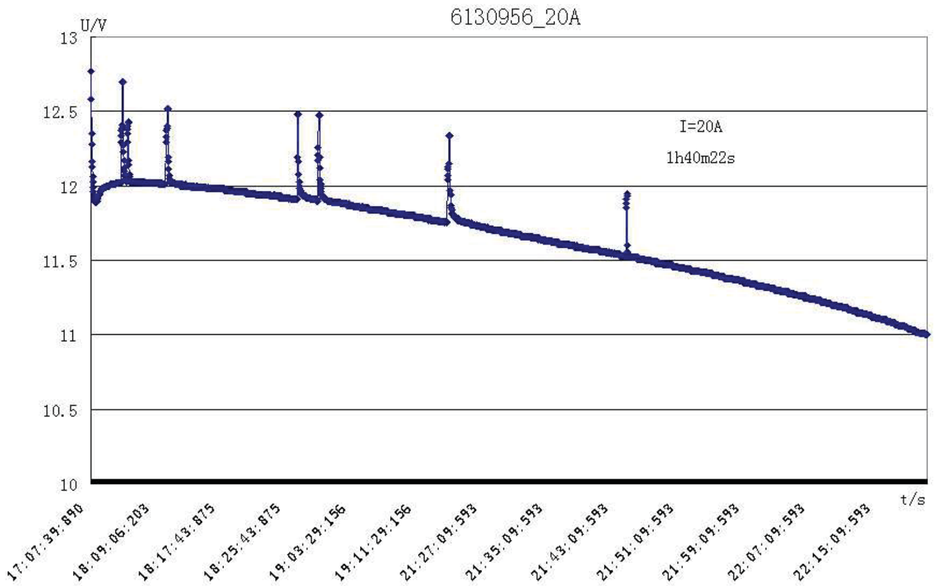


Figure C.2: Test result of 6130956 discharging

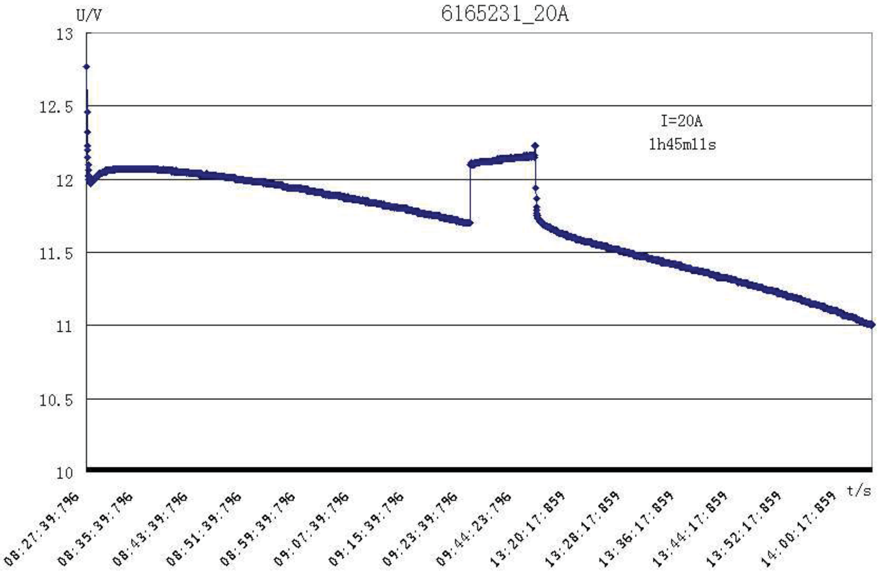


Figure C.3: Test result of 6165231 discharging

Appendix D

Results of battery discharging with 10A

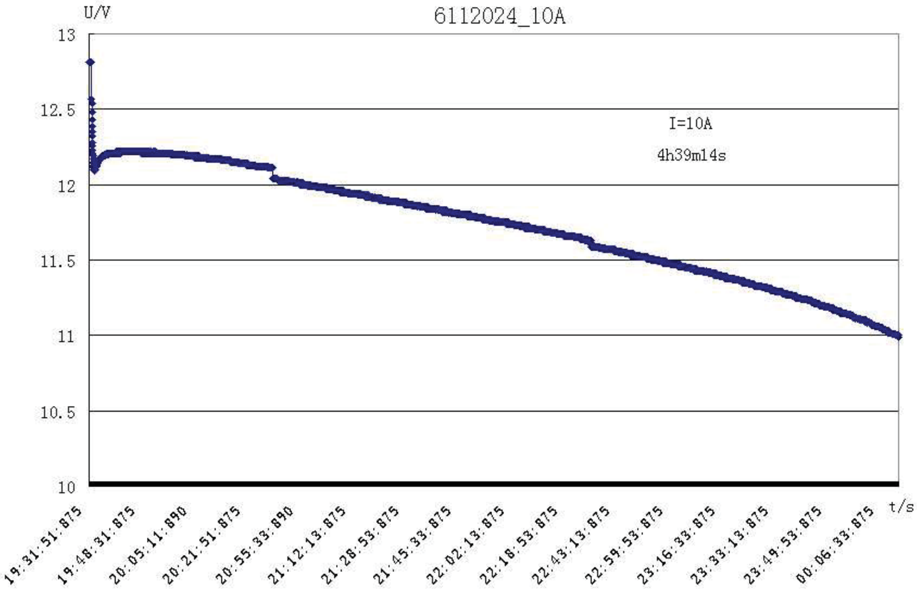


Figure D.1: Test result of 6112024 discharging

List of Symbols

Symbol	Value	Unit	Description
U		V	voltage
I		A	current
P		W	power
R		Ω	resistor
k			10^3
m			10^{-3}
μ			10^{-6}
n			10^{-9}
M			10^6
T		$^\circ$C	Temperature
f		Hz	frequenz
C		F	Condenser

Acronyms and Abbreviations

AC . . . . . Alternating Current
DC . . . . . Direct Current
ADC . . . . . Analog Digital Converter
PTC . . . . . Positive Temperature Coefficient
NTC . . . . . Negative temperature coefficient
UPS . . . . . Uninterruptible power supply
MOSFET . . . . . Metal oxide semiconductor field effect transistor
GTO . . . . . Gate Turn-Off thyristor
GTR . . . . . Giant Transistor
IGBT . . . . . Insulated Gate Bipolar Transistor
HI . . . . . High
LO . . . . . Low
PWM . . . . . Pulse Width Modulation
PMU . . . . . Parameterizing unit
rpm . . . . . Revolutions per minute
IEC . . . . . International Electrotechnical Commission
HVDC . . . . . High voltage direct current
MCT . . . . . MOS Controlled Thyristor
IGCT . . . . . Integrated Gate Commutated Thyristor
PN . . . . . P-type and N-type semiconductors
PC . . . . . Personal computer
Vcc . . . . . IC power supply pin
TTL . . . . . Transistor-transistor logic
COMS . . . . . Complementary Metal Oxide Semiconductor
RC . . . . . Resistor-capacitor
EWB . . . . . Electronics Workbench
SCR . . . . . Silicon Controlled Rectifier

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Bibliography