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Solar Charge Controller in Solar Street Light

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Abstract

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Abstract

Recently, with the rapid development of scientific technology, the conventional energy cannot meet the requirement of human beings. People are looking for the utilization of renew energy. Solar energy as a new clean energy has attract the eyes of people. The applications of solar energy are popular to human society. Solar street light is a good example.

This thesis will focus on a deeper research of the popular and ubiquitous solar street light in China. However, solar charge controller as a core determines the quality of solar street light, therefore it is worthwhile to make a research. The controller is based on microcontroller, which using PWM pulse modulation control and protection technology. In order to achieve charge and discharge control. The microcontroller sends all kinds of wresting signal according to the charge and discharge parameter of voltage and current.

This thesis also gives the the block program and the circuitry to explain the working principle of the system clearly, and there are also some calculations which can show the economical value of solar street light.

Solar charge controller is a core of the system, and this design gives an excellent example in solar street light. It is valuable to make a promotion to the market, which can give the elevation of efficiency than the traditional controller.

Keywords
Solar Batteries, Solar Charge Controller, Lithium Storage Battery, Microcontroller

CONTENTS

SYMBOLS AND ABBREVIATIONS

DC	Direct Current
AC	Alternating Current
PV	Photovoltaic
VRLA	Valve-Regulated Lead–Acid
MPPT	Maximum Power Point Tracking
PWM	Pulse Width Modulation
MOSFET	Metal-Oxide-Semiconductor Field-effect Transistor

1 INTRODUCTION

Energy is the important material basis of economic and social development and the improvement of people’s living standards, the energy issue is a crucial national issue. With the rapid development of scientific technology and global economy, the demand for energy is also growing. Since the world oil crisis in the 1970s, people really realize that fossil fuel reserves are limited, the energy crisis is imminent. From a global view, it has been proved that the reservation of disposable conventional energy is about to run out in the near future. The energy issues are highlighted, which shows not only in the lack of conventional energy, but also on the pollution of ecological environment due the development and utilization of fossil fuels. This has brought some problems, for example, the sulfur dioxide and particles in the atmosphere has increased, which contributed to the formation of acid rain in some areas. And annual carbon dioxide emissions have also brought greenhouse effect, which caused the global warming and natural disasters. Al-though conventional energy has brought rapid development to human society, it also brought unprecedented difficulties and challenges to human society. These issues will eventually force people to change the energy structure, and ask people to look for a new way to deal with energy problems.

Therefore, human beings are beginning to emphasis on nuclear energy, solar energy, wind energy, geothermal energy, hydropower energy, biomass energy and other re-new-able energy resources. The utilization of renew energy is increasing as the pro-portion of renew energy consumption is significantly improved. Among them, solar energy as a new green renew energy, compared to other new energy, is the ideal and convenient. The two main usages of solar energy is solar thermal power genera-tion and solar photo-voltaic power generation. China's usage of low-temperature solar thermal has already entered a considerable scale; the related technology research is more mature. The development of photovoltaic is developed quickly in the world; the so-called "photovoltaic" is a form of electricity of converting sunlight directly to electricity.

This thesis will focus on a deeper research of the popular and ubiquitous solar street light in China. Solar Street light uses sunshine as the light source, charges during the daytime and illuminates at evening. The system is complete and stable, and has good efficiency. Comparing to the conventional street light, it can save more electricity and maintaining fees. Currently the practicality of solar lights has been fully recognized by people. This thesis describes the design of solar street light controller based on microcontroller. The controller can automatically identify 12V and 24V battery and achieve the scientific management of the battery which can indicate overvoltage and low-voltage running state. The system is also equipped with two loads output, and each current of load can reach up to 5A. The two loads can be freely to set to lit simultaneously, lit-sharing and lit individually modes. Meanwhile, the controller can prevent the load over current and short circuit, and should have a higher degree of automation and intelligence.

2 SOLAR ENERGY

Solar energy, which comes from radiant energy and heat form the sun, is the most important energy in renewable energy. It becomes the part of human being's life and brings a lot of convenience. Solar energy has many significant advantages compared to the conventional energy, for example, it is very rich for supplying the human usage for many years, non-polluting which it will not generate waste water, air pollutants to influence the ecological balance, and no area limitation means even in remote areas with poor communication.

2.1 Developing History of Solar Energy

The history of solar energy can be divided into 6 phases:

The first phase (1900-1920): At this phase, the main focus of the world was solar power plant, but the concentrating ways were diversiform, and the industries began to use flat-plate collector and low boiling-point working fluid. The device was gradually expanded and the maximum output power was 73.64kW. The purpose is practical, but the cost was still high. There were two typical device constructions. One was solar pumping system built in California in 1901, with a truncated cone concentrator and the maximum power is 7.36 KW. The others were five sets of two-cycle solar engine built in United States between 1902 and 1908, with flat collectors and low boiling point working fluid. (Taiyangneng 2011.)

The second phase (1920-1945): In the past twenty years, the research was at low ebb. The number of people participated in studies and research projects greatly reduced. The reason for that is great utilization of fossil fuels and the World War II (1935 to 1945). The solar energy could not solve the urgent need for energy, thus this made solar energy research gradually had being neglected. (Taiyangneng 2011.)

The third phase (1945-1965): At these twenty years after World War II, some far-sighted persons had noticed oil and gas sources were being rapidly reduced. They advised people to pay attention to this problem, and promoted the recovery and carried out research work on solar energy. In 1945, Bell labs developed practical silicon solar cells, which laid the foundation for the large-scale application of photovoltaic power generation. (Taiyangneng 2011.)

The fourth phase (1965-1973): At this stage, the development of solar energy research was slowing, mainly due to the use of solar technology was in the growth stage and not yet matures. With the large investment, but the effect is not ideal. It was difficult to compete with conventional energy sources; therefore it could not get support of public, business and government. (Taiyangneng 2011.)

The fifth phase (1973-1992): The development and utilization of solar energy boomed in the 1970s, like CPC, vacuum tube, amorphous silicon solar cells, photolysis of water into hydrogen, solar thermal power. When it went into the 1980s, the situation gradually dropped into the trough due to the nuclear power. (Taiyangneng 2011.)

The sixth phase (1992-Now): Utilization of solar energy in the world has entered a new period of development, its features are: solar energy utilization closely integrated with the world's sustainable development and environmental protection. It allows global co-operative to achieve the world's solar energy development strategies. The goal of solar energy development is clear, mainly focused on effective measures to ensure the long-term development of solar energy. Unprecedented international cooperation in the field of solar energy is active, expands the scale, the effect is obvious. (Taiyangneng 2011.)

2.2 The Future Development of Solar Energy

From the global perspective, green energy and sustainable development are the two major issues in 21th century. Under the dual constraints of limited resources and strict environmental protection requirements, the development of the global economy has become a hot and difficult problem. And energy problem is more urgent, which is reflected not only lack of conventional energy, but also the environmental pollution, global warming and other issues due to utilization of fossil energy. Therefore, in order to solve the above the problem to achieve sustainable development, people can only rely on scientific and technological progress, to depend on the mass utilization of renewable energy.

However, solar power as an inexhaustible, clean and green energy will be an unprecedented development in the 21st century. Particularly in usage of solar cells, there are not any harmful gases including carbon dioxide, which will greatly improve the ecological environment. It can help to solve the problem of global warming. The solar energy is expected to become an important energy and occupies a pivotal place in the renewable energy market.

3 SOLAR STREET LIGHT

Solar Street light bases on the radiation of solar light. The equipment is easy to build without complex and expensive pipeline lying; the layout of lighting can be adjusted. In the figure 3.1 is shown one layout of the solar street light. The light has better security, energy-saving and non-pollution. The operation is automatic without manual operation. The machine is stable and reliable, thus it can save electricity and has low maintenance fees.

Figure 3.1 Solar Street light *(Haisheng 2014.)*

3.1 Introduction of Solar Street Light

Solar street lights use crystalline silicon solar cells to generate power, maintenance-free VRLA batteries (gel batteries) to store electrical energy and super bright LED lamps as light sources. The charge and discharge by the intelligent controller is used to replace the traditional public power lighting. The devices are built without laying cable, AC power supply and electricity fees. But they have DC power supply and photosensitive control. It can be widely used in urban primary and secondary roads, residential areas, factories, tourist attractions, car parks and other places.

3.2 Working Principle and Characteristic of the Solar Street Light

Solar street lights consist of solar panel, lighting fixture, rechargeable battery, controller, and pole.

The working principle is that solar panels absorb the sun’s radiation during the daytime and convert it into electrical energy. Then the electricity through the charge controller is stored in batteries. At night, when the illumination is gradually reduced, the controller detects the action and the battery provides power to the lamp. After 10 hours of battery discharge, the action will stop, battery discharge will also end. The main role of the controller controls the lights on and off, while preventing the battery overload and extends battery life.

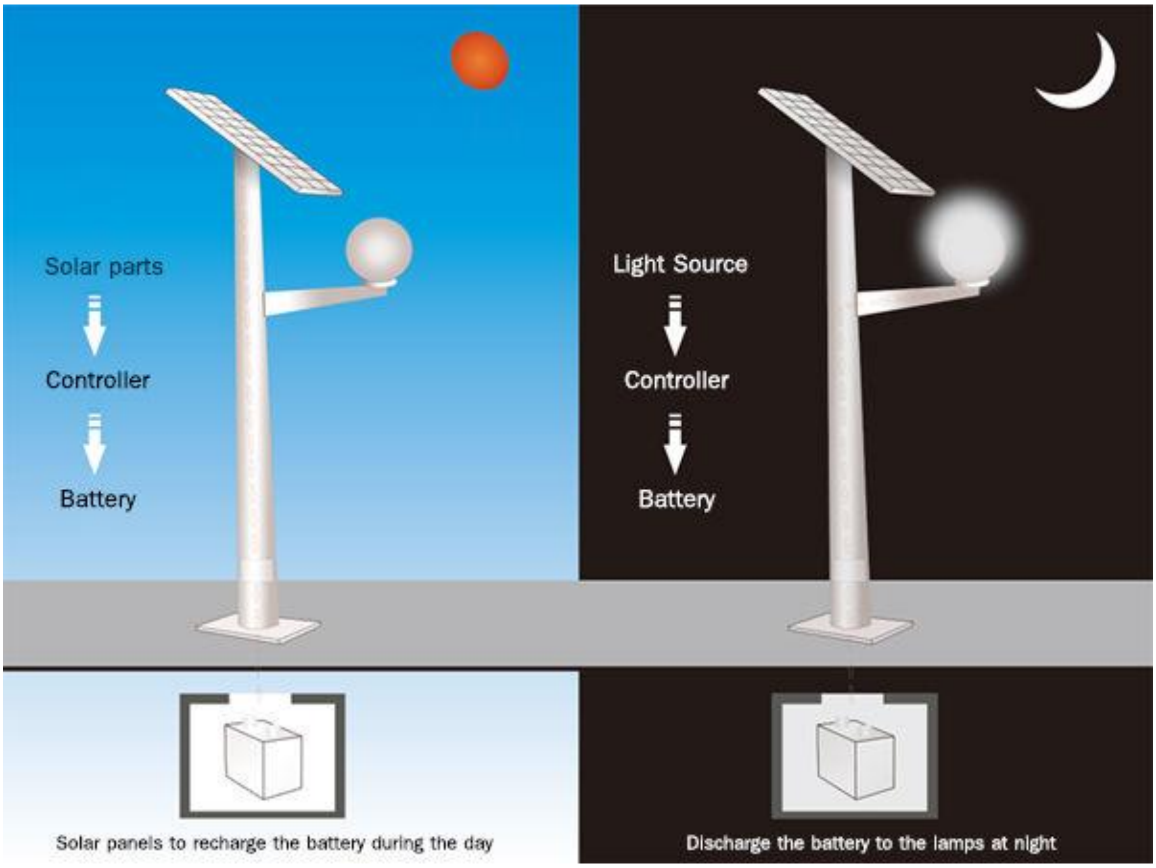

Figure 3.2 Solar street light working principle. (Alibba 2014)

The characteristics of solar street light are very obvious, which can be listed in several ways.

1) Large power supply. The brightness is equal to incandescent 150W-250W/h. When it is illuminated 10 hours a day (6 hours normal lighting, 4 hours energy-saving lighting), it can work within nine consecutive rainy days. (Baidu 2014)

2) Applying the intelligent controller. The light can be effective in saving energy, increasing the effective illumination time and reducing electricity costs. (Baidu 2014)

3) Central controller unit utilizes TEC1208-type chip, and establishes global annual sunshine time data in different latitudes. When it puts into the practice, types the

latitudes that the area desired, the ambient light can be automatically tracked in many years. (Baidu 2014)

4) Solar street lights use solar photovoltaic cells provide electricity. Solar energy as a new green energy is abundant and inexhaustible. (Baidu 2014)

3.3 Configure Calculation of Solar Street Light

1) Calculate the current of solar street light.

For example, 12V battery systems, two 30W LED, the total power is 60W.

Current= 60W÷12V ＝ 5 A

2) Calculate the battery capacity needed:

For example: cumulative illumination time needed for the full load is 7 hours (h) at night;

Continuous rainy days are 5 days. (5 days plus 1 day before rainy days, counts 6 days)

Battery capacity= 5A × 7h ×（5＋1）d ＝ 5A × 42h ＝210 Ah

Furthermore, in order to prevent battery overcharging and over-discharging, charging of battery achieves about 90% in general; discharge to the remaining is 20%.

So, in the real situation, the true efficiency of 210Ah is 70%. (Huang 2012,12)

3) Calculate peak demand for solar panels (WP): (Huang 2012,12-13)

Cumulative illumination time needed for the full load is 7 hours (h) at night;

Solar panels receive an average effective illumination time is 4.5 hours (h) per day;

At least 20% of the demand is stored for solar panels.

Usually the total working voltage is between 17,3V and 18,0V. In China, 17,4V is usually taken in the normal situation.

$$WP \div 17.4V = (5A \times 7h \times 120\%) \div 4.5h$$

$$WP \div 17.4V = 9.33A$$

$$WP = 162\ (W)$$

According to the power of the solar panels, the area of the solar panels is S=power/1000/efficiency of solar panels=162/1000/70%=0,23m^2.

Also in solar street light component, there are line loss, the different power consumption of the ballast or constant current source and controller. In the practical applications, the loss may be about 5% -25%. So 162W is only theoretical value, in the real situation, it is needed to increase the value. (Huang 2012,20-21)

In order to understand this calculation clearly, the following example is good to give a proper explanation. (The area is in China)

This solar street light is based on constant current, constant voltage and adjustable power integrated controller. It can reduce power consumption and components costs.

1. LED lights, one-way, 40W, 24V system.
2. Local daily calculation of the effective illumination is 4h,
3. The daily discharge time is 10 hours (From 7:00 pm - 5:00 am, for example) by the controller at night
4. Rainy days are 5 days(plus the consumption of one extra day, counts for 6 days)

Current = 40W÷24V ＝1.67 A

Battery capacity＝ 1.67A × 7h ×（5＋1）d＝ 1.67A × 42h＝70 Ah

Actual battery capacity = 70Ah battery plus 20% reserve capacity and plus 5% loss

The actual battery capacity = 70Ah ÷ 80% × 105% ＝ 92Ah

The actual battery is 24V / 92Ah, the two batteries is needed, the total power: 184Ah

Calculation of solar panels:

1. LED light is 40W, current: 1.67A
2. The daily discharge time is 10 hours; the actual discharge time is seven hours.
3. Electricity reservation of battery is 20%
4. The local effective lighting is 4h per day

WP ÷ 17.4V = (1.67A × 7h × 120%) ÷ 4 h

WP = 61W

The actual loss is less than 5%

Actual demand of solar panels = P*efficiency=61W × (100%+5%) = 64W

The actual solar panels needed is 24V / 64W, so two 12V solar panels is applied, the total power is 128W

The total component price can be given by the following list:

The price of the solar street light is 1800 Yuan.

The price of installation is 2000 Yuan.

The total cost is 3800 Yuan (450 Euros).

Suppose the distance between solar street lights is 25m, there will 40 solar street lights in 1km. So there are 80 solar street lights in both roads. Then the total cost is 80*450=36000 Euros. According to the statics of Chinese ministry of communications, the total roads is 4, 2375 million Km, the total price of Chinese road is 152,55 billion Euros(if every road would use the solar street light).

The total street light in China is about one hundred million or more, and annual growth rate is 20%. If one hundred million street lights can be converted to 60 million 250-watt lights, then 60 million streets are all changed into solar LED lights, so the total power can be saved about 15 million kilowatts. Assume that every street light is working 12 hours a day, in a year, there would be 65.7 billion KWh of electricity saved. Usually the normal price of 1KW/h is between 0, 52 Yuan and 0, 62 Yuan in 2013, than 0,57 Yuan is average price. So 37,5 billion Yuan (4,5 billion Euros) is saved in one year because the solar street lights do not need electricity fees due to absorb sunshine.

4 SOLAR STREET LIGHT CONTROLLER

In solar street light systems, solar street light controller is a core component of the system. It is responsible for charging battery and discharging to the load. This thesis will focus on solar street light controller based on microcontroller, which using PWM pulse modulation control and protection technology. In order to achieve charge and discharge control, the microcontroller sends all kinds of wresting signal according to the charge and discharge parameter of voltage and current. The efficiency of the system can run steadily. At the same time, MPPT（Maximum Power Point Tracking） solar controller is designed to make the system operate smoothly. MPPT solar controller is updated product of the traditional solar charge controller. MPPT means the real-time power voltage of solar panels is able to be detected by controller, and the maximum voltage and current values is tracked (VI). Therefore it could prove charging the battery with the highest efficiency of the system.

Figure 4.1 The MPPT solar controller (MPPT 2014.)

4.1 The Block Program of Solar Charge Controller

The circuit block program of solar charge controller is as below. Solar panels receive sunshine and convert the solar energy into electricity, and charge the lithium storage battery through the solar charge controller. The lithium storage battery discharges LED lighting circuit via the controller.

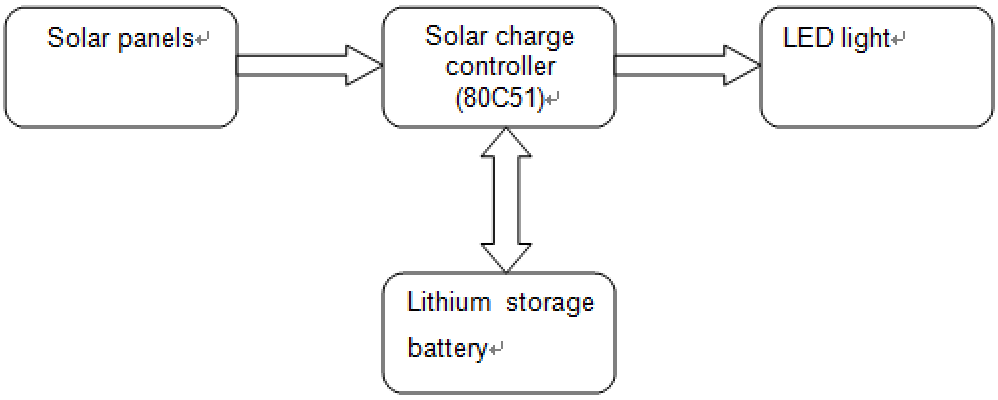

Figure 4.2 Block program of solar charge controller

Microcontroller is the core of solar street light control system. The performance of solar controller designed quality is related to the whole system whether it can operate properly. The core of the controller is 80C51. It is currently one of the largest integrated peripheral modules and the most powerful microcontrollers. It is an 8-bit high-performance microcontroller. It uses a Harvard bus architecture and RISC technology. It has high instruction execution efficiency and low power consumption, accompanying with flash program memory. It equipped with 5 interrupt sources and 40 DIP （dual In Line packages） pins. It is also embedded 8 ten-digital precision AD converters and two output pulse fondue waveform CCP modules. The controller's job is primarily to achieve the control of solar panels during the daytime to charge the battery control and discharge the battery at night. (Baidu 2014.)

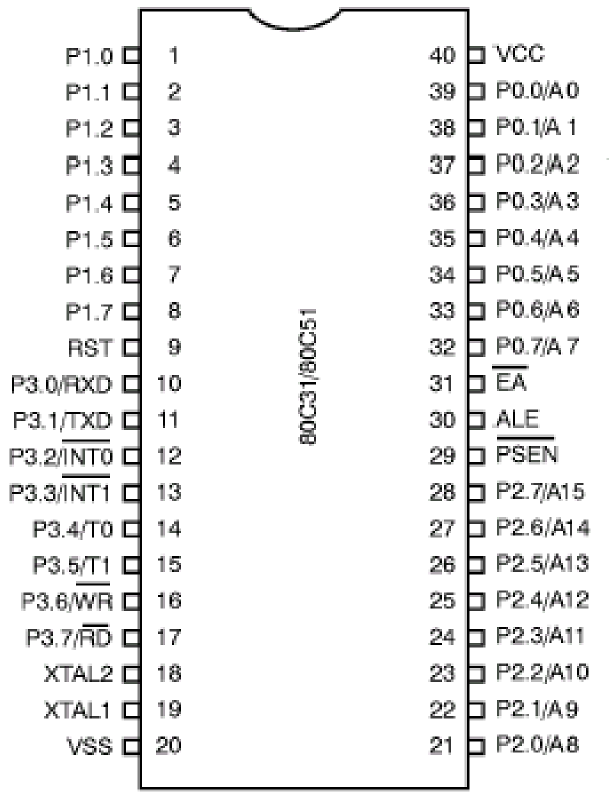

Figure 4.3 80C51 - CMOS Single-Chip 8 Bit Microcontroller (Futurlec 2014.)

4.2 Components of the Circuit Unit and Working Principle

There are several components in the block program. This part is focus on the each critical module in the system. First, make an introduction of the solar cell (lithium batteries) on the unit circuit, whose types, functions and features are described in detail. Following explore each unit circuit includes the charging and discharging circuit of controller, MOS driver circuit, display circuit.

4.2.1 Introduction of the Solar Battery

Solar photovoltaic systems are the use of solar cells made of photovoltaic principle directly converting solar energy into electrical energy. A solar cell is the minimum unit for the photoelectric conversion. Its size is from 4 cm^2 to 100 cm^2. The voltage of solar cell is from 0.45V to 0.50V, generally it is not used alone as a power source. After the solar cell is in series, parallel, and package, then there is a solar cell module. Its power is from a few watts to several hundred watts, which can be used alone as a power source. Solar cells are connected in serial, parallel and mounted on a bracket, and then they become a large solar cell array. The output can be a few hundred watts, kilowatts or greater powers. They are the power generator of photovoltaic power plants. The common solar cells are mainly silicon solar cells. There are three existed commercialization of silicon solar cells in the world: monocrystalline silicon solar cells, polycrystalline silicon solar cells and amorphous silicon solar cells. (Liu 2010,06-08)

Monocrystalline silicon solar cell is currently one of the fastest developing solar cell. Its structure and manufacturing process has been finalized, the products have been widely used for space and ground. This solar cell uses high purity silicon rod as raw material, the purity is 99.999%. In order to reduce production costs, and now solar terrestrial applications, are using of solar -grade silicon rods, the material performance has been relaxed. Although manufacturing cost of monocrystalline silicon solar cell is high, but the photoelectric conversion efficiency is highest, the highest can achieve 24%. Nowadays the polycrystalline silicon solar cells use polycrystalline materials, mostly they are consisted of a collection contains a lot of single crystal particles, or waste silicon materials and metallurgical grade silicon materials. Then they are melted and casted, and finally injected into a graphite mold. As them are cooled and slowly solidified, the multicrystalline silicon ingots can be got. The ingots can be casted into cube shape which is easy to be processed into square solar cells. Also this can improve material utilization and easy assembly. The manufacturing process of polycrystalline silicon solar cells is almost the same as silicon solar cells, but the photoelectric conversion efficiency is only about 12%, slightly lower than silicon solar cells. However its materials are easy to get, the power consumption and the overall production cost is lower, thus it gets a lot of development. (Liu 2010,09-11)

In photovoltaic systems, the protection of solar cells should be pay attention to. This protection is divided into chemical protection and electrical protection. Chemical protection refers to considering its ability of anti-corrosion, windproof, hail suppression and rain tight in packaging and setting solar cells. Electrical protection means when connecting bypass diodes, the two connections cannot be reverse. Under some certain conditions, the solar battery module in a series branch circuit is shielded, and this part will be used as a load to consume the energy of other solar cell modules produced. The solar modules will generate heat, this phenomena is called the hot spot effect. In order to prevent the solar cell module damaging due to the hot spot effect, it is necessary to connect a bypass diode in parallel between the positive and negative sides of the solar cell. In the solar cell, there is also a anti-reverse charging diode, also known as a blocking diode, and its role is discharging by the solar panels, in order to avoid the electricity loss on rainy days and at night, or a short-circuit fault of solar panels. Anti-reverse charging diode is responsible for unidirectional conductivity effect in series of the solar panels. In the large systems, it also should be anti-thunder.

4.2.2 The Characteristics of Lithium Storage Batteries

Lithium storage batteries are commonly used in solar street light. Lithium storage batteries have light weight, large capacity, memory-less effect, etc, which are usually applied in the solar street light system. The capacity of lithium storage lithium battery is 1.5-2 times than the same weight of nickel-hydrogen battery. It also has a very low self-discharge rate. In addition, lithium batteries seem that they do not have toxic substances. But for lithium battery charging process, the requirement is more stringent. The factors affecting the life of the battery are: depth of discharging and the degree of over-charging. In the photovoltaic system, the depth of battery discharge is not constant, and it varies with weather conditions and season. In a clear summer day, the depth of discharge is lower. However, on a gloomy winter day, the depth of battery discharge is greater. Over- charge level also varies with the season and weather. In the winter, the battery may never be charged fully as before. In the summer, the battery can often be full. To prolong battery life, the battery must be properly controlled to discharge and recharge. When the battery is discharged to a certain degree, the discharge should be stopped to prevent over-discharging for reducing battery life. However, when the battery is charged to a certain extent, it should be noticed to stop charging and reduce the charging current due to prevent overcharging of the battery to bring the unreasonable damage. Here is a figure that shows the charging curve of lithium battery.

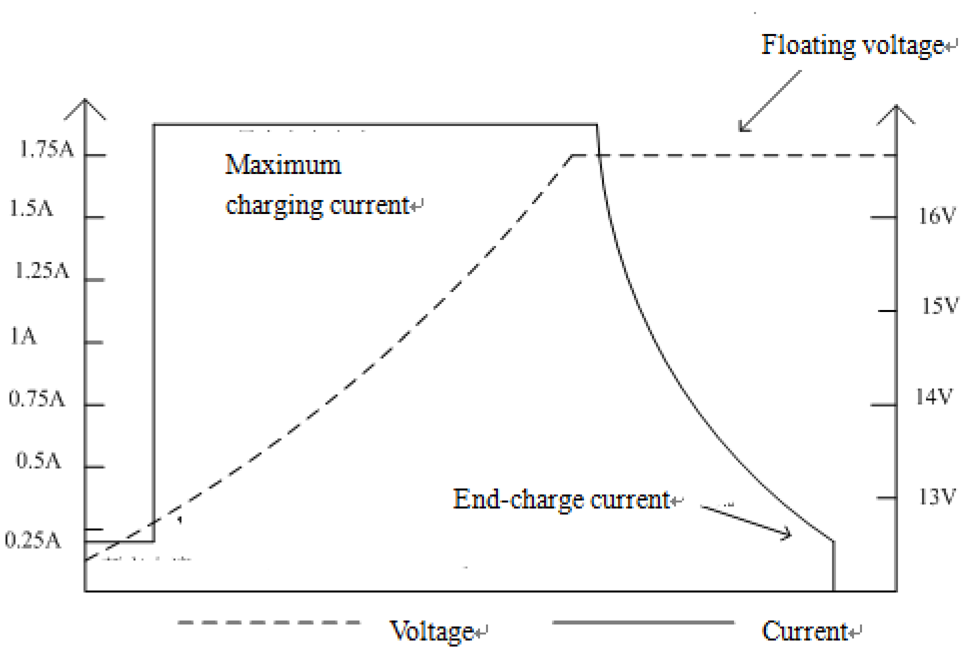

Figure 4.4 Charging curve of lithium battery

The charging process of lithium storage battery:

(1) When starting charging, the power of battery is low, and then a small current (about 0.24A) is applied to start charging, his process is called trickle charging. If the voltage is higher than 13V, it is not necessary to perform this step.

(2) When the voltage of battery is greater than 13V, it is good to start with a large current charging and this process is called constant current charging. As for charging, the voltage of battery is gradually increased.

(3) When the battery voltage reaches full or near full state, the full charge voltage is about 16.8V. Then it is time to start constant voltage. When the current is reduced to about 0.25A, the charging is end.

4.2.3 Charging and Discharging Circuit of Controller

The new designed solar charge controller has many functions. There are several functions which are needed in the charging and discharging circuit.

1) Voltage protection: When the battery voltage is below the voltage protection value, the controller will shut down two side loads and stop power supply. If it continues to discharge, the battery could be damaged due to over-discharge. Usually the value of the standard voltage protection is 10.8V, the voltage protection parameters in solar street light is 10.8V-14.7V (adjustable). (Zhang 2006,40-41)

2) Safety anti-thunder protection: TVS lightning protection tube is adopted to ensure the related safety components, which is currently more advanced technology.

3) Load protection of Short-circuit, protection of load current and battery's polarity: abandon common fuse protection alone, and it has changed to acquire better protection through rapid induction of software. This method has proved the associated device not damaged, and ignored the artificial possibility of changing the false fuse.

4) Back discharge protection: In order to prevent loss of batter's capacity, it is good to get better protection by back discharging to the batteries. The discharge over-current protection is usually 11.5A.

5) Temperature compensation: Battery has negative temperature characteristics. At the room temperature (25 ℃), with additional 1 ℃ added, the voltage of 12V battery is reduced about 0.014-0.018V. This controller will give voltage compensation; on the one hand, it can ensure the battery work in constant voltage environment, which can extend its life. On the other hand, it can prove that it will lack electricity due to lower voltage in the high temperature of summer. (Zhang 2006,42-43)

6) Low-voltage and saving energy protection: When the battery voltage is below 12V, which means the stored battery is low. And then the controller will turn off this street light, keep the other street light open. By this way, it could prove the illumination time is prolonged. The specified low voltage protection is 12.0V-14.7V adjustable. (Zhang 2006,43-45)

7) Protection of trickle charging: When charging the battery, once the battery's voltage is reaching a peak, the battery will generate dehydration or lose control if it is continuously charged with the high voltage. However, the battery is not saturated if stop charging. This controller will drop into 1V when the voltage is at the peak, then allow the battery to enter trickle charging state. It can ensure that the battery can be stabilized in full state, while it also avoids dehydration or loss of control, which similar to the charge cycle of the battery. It could not only promote efficient protection of the battery, but also enhance the battery charge cycles to acquire a longer life. The specified protection value of charging current is 15A. (Zhang 2006,47-49)

8) Large immediate current protection of load: When the low-voltage sodium lamps, Electrode-less lamp and other load start to work, the transient current will reach about 3-5 times than the normal current. The controller and related components can be extended the life through the relevant protection settings.

9) Flexible power adjustment settings: The LED light on the two sides of road can be adjusted freely. It is possible to achieve reduction of energy consumption by reducing load of the current. Even applying electrode-less lamp, low-voltage sodium lamp and halide light, when few pedestrians are on the road at night, one-side road lamp can be closed, to achieve maximum power saving.

10) Constant current LED source transformation: LED light is likely to cause serious damage or decay if the current is unstable or too large. The common method is adding a constant current LED driver to keep constant current, but the cost of constant current LED source is expensive. This controller is fit for the parameters of 12V/24V LED lights and can be adjusted to a constant current output.

Every time period can be adjusted, this design could not only reduce current source link failures may occur, but also greatly reduce the design cost of battery.

11) Waterproof protection: Waterproof performance is generally poor, but poor thermal performance is found with waterproof controller. The waterproof performance is better if using aluminum coating

The circuit of charging and discharging of controller is as below:

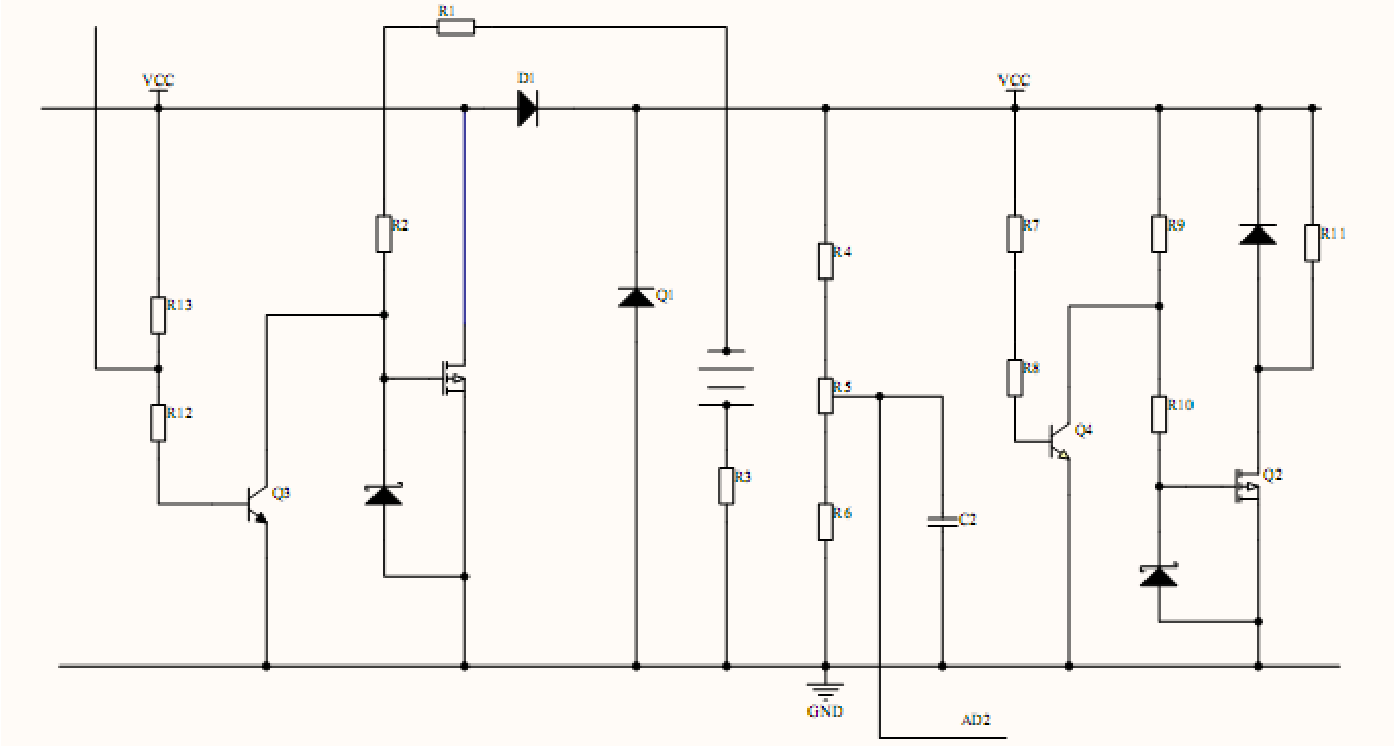

Figure 4.5 Charging and discharging circuit of controller

Microcontroller is responsible for charging and discharging to drive Q1 and Q2.

(1) When the battery's voltage is in normal state, the charging driving MOS transistor Q1 (IRFZ44) by microcontroller controlling refuses high level signal, however the transistor Q3 is connected, and duty cycle of PWM is zero. Then the solar batteries are charging battery with constant current. When the voltage of battery reaches 13.6V, Microcontroller will control charging driving Q1 to be high level, Q3 is turned on, and Q1 is turned off. By controlling the duty cycle, Q1 can achieve the control of on-off. This time is called constant voltage with floating charging. When the current drops to a certain value, it's time to start the constant current charging; once the battery voltage reaches the floating point of 14.4V when overcharging, then constant trickle charging is beginning. When the current of trickle charging drops to a small value, Q_1 will start short circuit protection. When the battery volt-

age drops to a given value, Q_3 is turned on again, Q1 is turned off, then the system returns to the normal state of charging.

(2) When the voltage of battery is under normal state, the discharge driving MOS transistor Q2 (IRFZ44) is low level, transistor Q4 is rejected, Q2 is turned on, then the output of load is normal; when the battery voltage drops below the given point, the discharge driving Q2 by microcontroller controlling is low level, Q4 is turned on, Q2 is turned off, then there is no output . When the voltage of battery reaches 12.6V, microcontroller make discharge driving Q2 becoming low level, Q4 is turned off, MOS transistor Q2 is turned on, then the load gets its power supply.

4.2.4 MOSFET Driver Circuit

When choosing the switch, the inconsistent power between load and solar batteries should be considered. It is possible to use MOSFET as switch. If the power of MOSFET is low, the temperature factor is to be considered, there should be radiator to release extra heat. In order to improve reliability of the circuit and reduce costs, a lot of testing data shows which MOSFET is fit for the particular current.

1) When the current is 3A, the type of MOSFET can be IRFZ44, IRF540, IRF530, 50N60, etc.; there is no need for radiator.(Chen 2006,56)

2) Within the scope of 5A current, it is necessary to add a small radiator. (Chen 2006,56)

3) When the current is 8A, the type can be 2807, 3205,150,064 etc. The small radiator is also needed. The capacity is large, but the price is high; (Chen 2006,58-59)

4) When the current is above 10A, there should be large radiator to reduce the theat. (Chen 2006,59)

According to the current scope, MOSFET IRFZ44 is better. Drive signal is sent by the microcontroller, the electrical level is TTL level. While it is not possible to directly drive MOSFET, the transistor is helpful to convert electrical level.

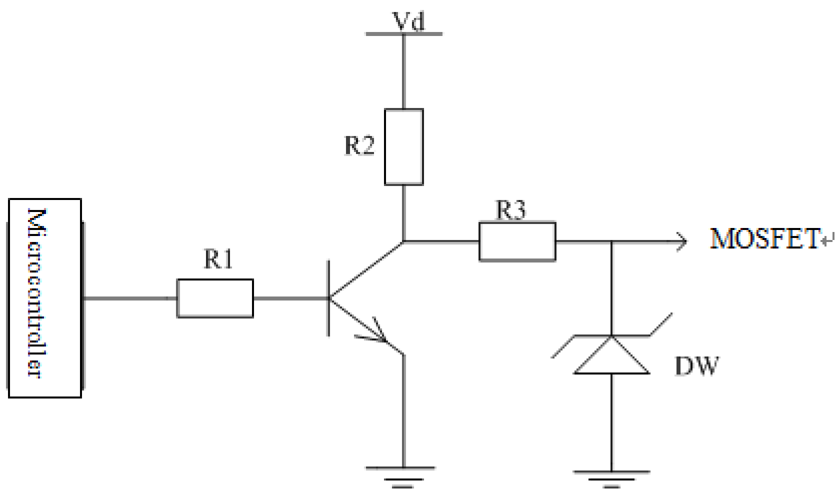

Figure 4.6 MOSFET driver circuit

In the figure 4.6, Vd is positive voltage of batteries, R1 is the base current limiting resistor of transistor. R2 is the collector resistor. DW is 18V Zener diode, together with R3 limits the voltage G of control signal is less than 18V. The output signal is opposite G-end signal. When the output of microcontroller is "1", G is 0V, voltage of MOSFET is Vd.

4.2.5 Display Circuit

Nowadays, most solar street lights use LED as a light source due to many reason. Such as long life which can reach more than 100,000 hours, and low operating voltage which is better for solar street lighting system. In particularly, LED technology has implanted its key breakthrough, which the characteristics have been greatly improved over the past few years. There is a greater performance in costs and functions. Its advantages are as follows:

1) Energy-saving: The light color of LED is close to natural light. When compared with the HPS (high-pressure sodium) light, the lower light intensity is needed on LED light than the HPS light within the same brightness. For example, the 98W of LED Street light in the road, its lighting efficiency is equal to 250W high pressure sodium lamps. (Baidu 2011)

2) Long life: As high-power LED Street light consists a lot of LED light source. Even if the individual light does not work, it cannot have too much impact on the whole system. Unlike HPS lights, if one is broken, the whole system is in a big trouble. So the reliability of high-power LED lights is more stable than HPS lights. The life of high-power LED Street light is up to 50,000 hours, which is ten times than the HPS lights. (Baidu 2011)

3) Decent color rendering properties: The color rendering properties of high-power LED street lights is much higher than HPS light. The HPS lights use metal sodium vapor as a light source, the color of lights single and yellow, and it is further different from sunshine. While the LED lights emit white lights, the color is more

real, there is no danger of ultraviolet rays and infrared lights, and also they do not attract insects.

4) No flash: High-power LED lights use DC as power supply, coupled with the unique constant current devices, which can prove high-power LED Street light emit constantly and complete free-flicker.

5) Quick response: HPS lights have delayed effects, when starting ignition, the luminous flux can reach 90% of the normal brightness within 15 minutes. While the high-power LED lights can reach the normal brightness immediately, and do not have delayed phenomenon. This system is convenient to implement the intelligent control and more energy-efficient. (Baidu 2011)

6) Safety: LED lighting is a solid-state lighting, which can effectively prevent shack and explosion. The system is suitable for large highways and even higher security areas, such as tunnels and mines.

7) Excellent heat dispersion: the temperature of LED's PN junction does not exceed 75 ℃ due to structural design with low thermal resistance and good heat dispersion, thus it can ensure luminous efficiency and working life of LED light. (Baidu 2011)

This controller uses two dual-color LED light-emitting diodes as indicators; LED1 displays charge status, LED2 displays discharge status.

a) When charging the battery, if the voltage was lower than 13.0V, LED1 was red; when the voltage was between 13.0-13.6V, LED2 was orange; when the battery voltage was higher than 14.4V, LED1 was green.

b) When discharging the battery, if the voltage was lower than 11.1V, LED2 was red; the voltage was between 12.2-12.6V, LED2 was orange; When the voltage was higher than 12.6V, LED2 was green.

The color of red means the voltage is sufficient, orange means that the charging or discharging condition is operating and green means that the voltage is enough.

This controller with two dual-color LED light-emitting diodes is very intuitive, which is better to replace the previous multiple indicators.

5 THE DECTION OF CURRENT AND VOLTAGE OF THE LITHIUM STROAGE BATTERY

This part focuses on the detection of lithium storage battery, because it is an important part in solar street light. It can be charged to store energy, which is the power supply of the load. It connects the solar charge controller and decides the efficiency of the controller. So the detection of lithium storage battery is necessary.

5.1 The Detection of Voltage of the Lithium Storage Battery

80C51 microcontroller is equipped with 4-way 8-bit A / D converter, the range of converter's input voltage is between 0V and 5V. The range which converted corresponding to the digital is between 0 and 255. The highest value of the battery voltage Vd is defined as 25.5V, which is needed to convert it to 0 ~ 5V by resistance. The Circuit is shown in the figure 5.1.

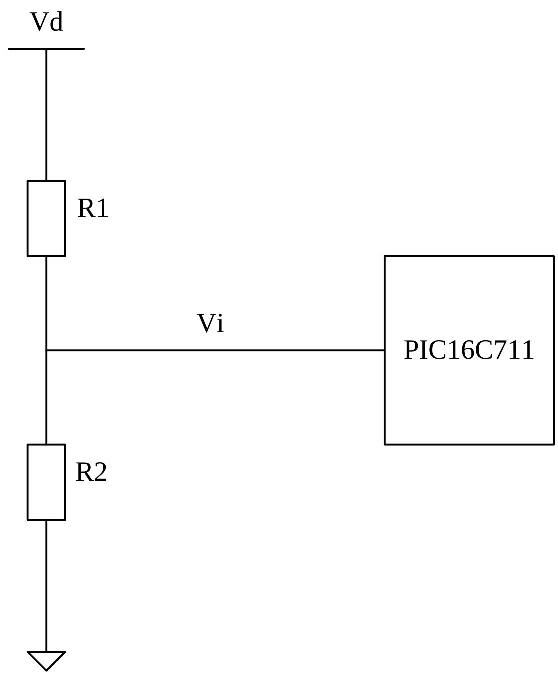

Figure 5.1 The detection circuit of lithium battery’s voltage

$V_i = R_2 / (R_1 + R_2) \times V_d$, suppose R2 = 20KΩ, R1 = 82KΩ, so it can be concluded Vi = 10/51Vd. So when the voltage of battery Vd is between 0Vand 25.5V, the analog voltage Vi is between 0V and 5.0 and digital D is between 0 and 255.

When the computer chooses random value X, the formula for calculating the battery voltage is: Vx = X/10V. The digital fluctuation range of A / D converting is ± 1LSB. Therefore, the fluctuation range of voltage is ± 0.1V.

5.2 The Detection of Current of the Lithium Storage Battery

It is hard to detect the relatively large DC, but this design uses a small resistor R (0.05Ω) to detect current. The voltage across the small resistor is amplified by the op amp, after the A / D converter, it will be inputted into microcontroller. The voltage measured divides the magnification, then the actual voltage can be got, and finally the size of the current can be calculated according to the Ohm's law U = I / R.

The problem with a small resistor to detect the current is: the value of a small resistor will change. Absolute linear resistor in fact does not exist. For example, the resistance of most metals conductors is increasing with increasing temperature, when the current passes through the conductor, a little electrical energy can be inverted into heat energy. This will make the temperature of the metal conductor increase, the resistance is not constant, but changes with current or voltage. The charging current detected in the system is different from the actual charging current, but there is a common rule that the larger the current detected, the greater the deviation. But there is a linear relationship between them. This is because the small resistor is not constant with temperature changing. Table 5.1 is a collection of experimental data measured of current on a microcontroller and the actual current.

Table 5.1 Comparison of actual circuit and measured circuit

Actual circuit	Measured circuit	Actual circuit	Measured circuit	Actual circuit	Measured circuit
0.09	0.04	0.30	0.34	0.46	0.58
0.10	0.06	0.31	0.36	0.47	0.60
0.11	0.06	0.32	0.38	0.48	0.62
0.13	0.08	0.33	0.38	0.49	0.62
0.17	0.16	0.34	0.40	0.50	0.64
0.18	0.16	0.35	0.42	0.51	0.64
0.19	0.18	0.36	0.42	0.52	0.66
0.21	0.20	0.37	0.44	0.53	0.66
0.22	0.22	0.38	0.46	0.54	0.70
0.23	0.24	0.39	0.48	0.55	0.70
0.24	0.26	0.40	0.58	0.56	0.72
0.25	0.26	0.41	0.50	0.57	0.74
0.26	0.28	0.42	0.52	0.58	0.76
0.27	0.30	0.43	0.54	0.59	0.78
0.28	0.32	0.44	0.56	0.60	0.78

There is a linear relationship between the two series of data, firstly dealing with the data of actual circuit. Assuming that the relationship is: y1 = a1 • x + a2. Then the coefficients can be calculate a1 = 0.0100 and a2 = 0.2100. Therefore, this data may be expressed by the relationship y1 = 0.01x +0.21. The figure 5.2 can show this relationship clearly.

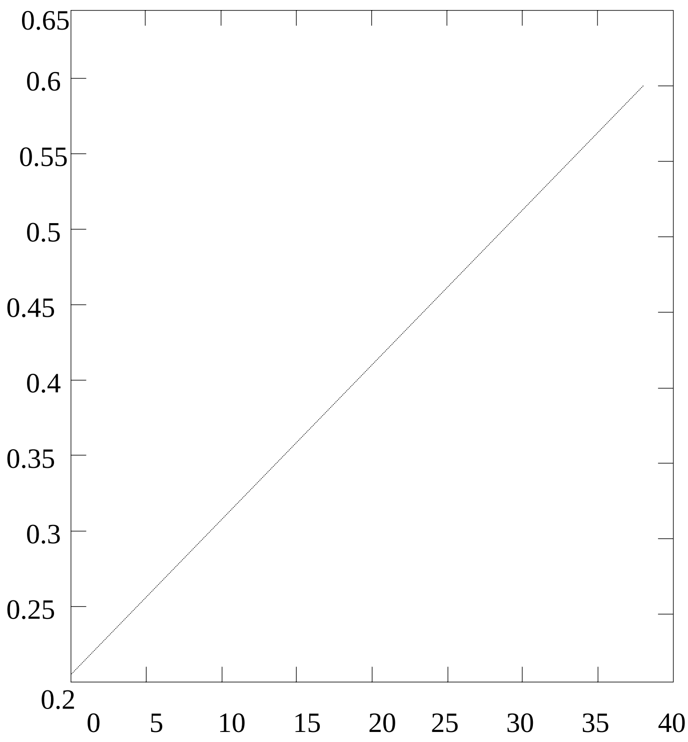

Figure 5.2 Linear fitting curve of real circuit

With the same way, it is easy to calculate the relationship of measured circuit. The relationship of measured data is y2=0.0147•x+0.2109. The figure 5.3 can also give a good explanation.

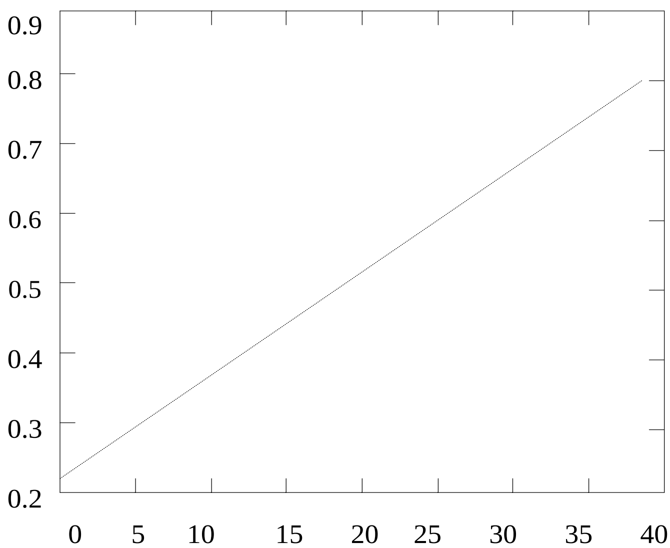

Figure 5.3 Linear fitting curve of measured circuit

Combing y1 and y2, it is easily to get the relationship between them, which can be explained y1=0.680272•（y2-0.2109）+0.21, y1 means the real circuit, y2 means the measured circuit by microcontroller. So when the measured data is got, the real circuit can be got by the above formula.

As for how to combine y1 = 0.01x +0.21 and y2=0.0147•x+0.2109, we can calculate by following:

x=(y2-0.2019)/0.0147

y1=0.01*((y2-0.2019)/0.0147)+0,21

then y1=0.680272•（y2-0.2109）+0.21

6 THE THEORY OF CIRCUITRY

This part focuses on the circuitry diagram and systematic diagram of solar street light system. From the macro view, it can be easily to understand the work principle of system and functions of each component. The circuitry will show how the system is connected and prove the stability of the system,

6.1 The Circuitry Diagram

The circuitry diagram is as follow:

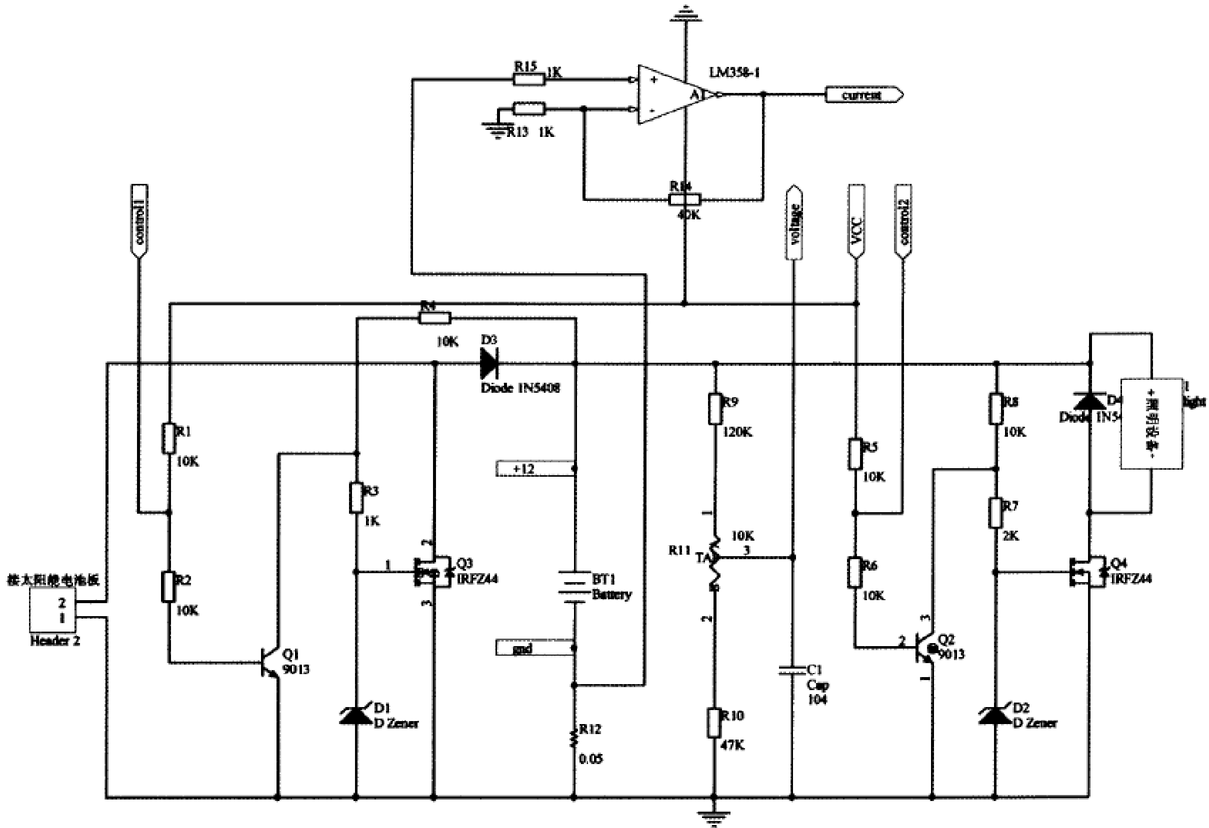

Figure 6.1 Circuitry diagram of solar street light

Solar panels receive sunshine and convert solar energy into electrical energy. Micro-controller is responsible for sending signals according to the collected parameters of charge and discharge voltage and current, and implementing charge-discharge control. This makes charging and discharging system can run efficiently and also protect the lithium battery, so that it can extend the useful life of the whole solar street lighting system. Solar LED street light system consists of solar panels, LED street light controller, lithium batteries and LED lights module. In the whole system, solar charge controller is in the core position, which directly determines the quality of the work performance of the entire system. This design of the controller is using PWM charging technology as the core, equipped with the battery overcharge and over-discharge protection, solar overvoltage protection and short circuit protection.

6.1.1 Solar Charge Control

The program uses PWM pulse modulation control and protection technology, this method can not only effectively protect the battery and prevent overcharging, but also start fast and smooth battery charging . The PWM control is to control the duty cycle of output waveform, but does not change the cycle by turning on and off the switching tube to control charge and discharge. When the battery voltage is below 13V, the microcontroller outputs a pulse corresponding to the duty cycle, so that controls the switch transistor (Q1) in order to control the switch of FET IRFZ44 (Q3). So that the charging current is 0 .24 A, this time is called pre-charge state. When a voltage is higher than 13V, a high-level will be sent by microcontroller (PWM duty cycle is equivalent to 1) , transistor (Q1) is turned on , FET IRFZ44 (Q3) is in a truncated state, this time with the greatest current to charge batteries by solar panels is called constant current charging. When the battery voltage is close to or equal to 16.8V, by controlling the duty cycle, it can also control the FET IRFZ44 (Q3) to achieve on-off control, this makes the state of charge lie in a constant floating state. When the current is less than a specified value (0.24A), the microcontroller outputs a low level, so that the FET IRFZ44 (Q3) is fully turned on, therefore the charge of battery is end.

6.1.2 Discharge Control to LED Light

When the pin output of LED is high level (5V) by the microcontroller, the transistor Q2 will be conducted, the voltage of transistor collector E becomes low (approximately 0V). At this time, the gate voltage of FET (Q4) will be very low and the FET is turned off, the current which flows through the light reduces to zero. On the contrary, when the pin output is low (0V), the transistor Q2 will be turned off, the voltage of E-collector is high, then the gate voltage of FET (Q4) will be high, FET is turned on, the current which flows through LED lights is high, lights will be turned on.

6.2 The Working Principle of Circuitry

Solar Charge system consists of solar panels, lithium storage batteries, controller and load. The system principle diagram is shown in Figure 6.2. The core device of the circuitry is 80C51; 8-bits flash microcontroller with 4-way A / D conversion and 13-channel I/O port devices. 80C51 microcontroller has mall size, low price, full-featured, and stable performance, which has good value in the microcontrollers. 80C51 micro-controller is to make a judgement through the parameters of solar panel voltage, battery voltage and charge-discharge current, so that it can control T1 and T2 on and off, which is better to achieve a variety of control and protection.

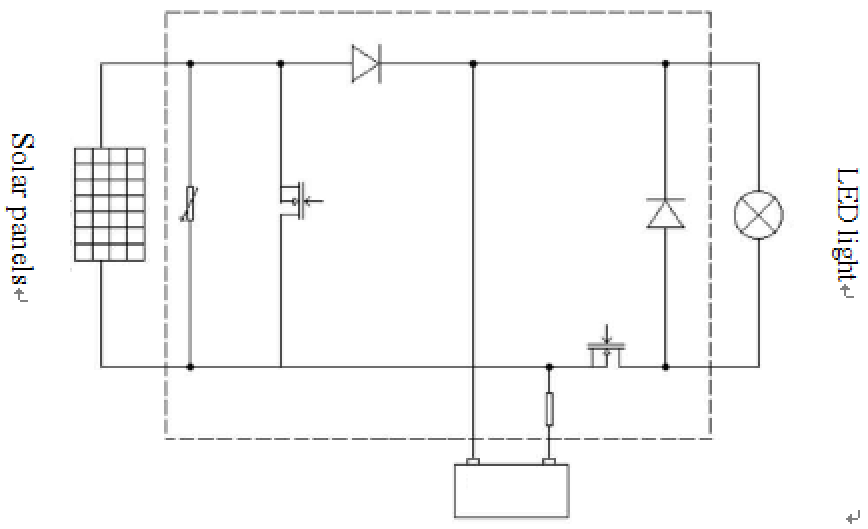

Figure 6.2 Working principle of solar charge controller

From the Figure 6.2, the controller is the button which connects the solar panels, batteries and loads together. The brief functions of solar charge controller in this circuit can be summarised as follow.

1) Overvoltage protection: When the battery voltage is higher than a certain value, charging will be stopped.

2) Low-voltage protection: When the battery voltage falls below a certain value, discharging is also ended.

3) Resume charging: When the battery voltage falls below a certain value, the controller can resume charging automatically.

4) Discharge recovery: When the battery voltage is above a certain value, the discharge will be restored.

5) Status indication: The conditions of solar panels power supply and load connection should be detected.

6) Lightning protection: Because solar panels are placed outdoors and there is a certain height from the ground. It is vulnerable to get touch with lightning, the lighting protection is needed.

Therefore, the controller is the important component in the circuitry. In order to prove the whole system run smoothly, this designed controller should meet the requirement of the above condition. But the controller can also use the existed hardware to increase detection function of daytime and night, so that it is easy to cut off the load during the daytime and switch the light automatically at night. This can be as an extension to meet the all the needs of customers.

7 CONCLUSIONS

Nowadays, with the shortage of conventional energy, it has caused the attractions of people to solar energy applications. The systems with solar panels, charge controller, batteries and other products have a relatively mature development, and many experts have preceded some deep research in this respect all over the world. The thesis is focus on solar charge controller for battery charging and discharging, the functional requirements of controller and how to protect the circuit. Also in order to explain the working principle, the circuit diagram is designed to meet the requirements of every detail. The controller is so important to be applied to solar street light system as it connects every critical component in the system.

This new designed controller based on microcontroller is for the special requirement of lithium storage battery. Firstly, when researched the charge and discharge process of lithium storage battery and made an analysis of a variety of factors which influenced the life of lithium storage batteries. Secondly, the overall design of solar charge controller was designed. Finally, the controller selected 80C51 microcontroller as a core through a PWM output to control the on-off switch of MOS transistor, and thus it can control the charge and discharge process.

This design of solar street light charge controller is a useful attempt for solar street light. This controller has improved the traditional technique, but there are still some designs needed to improve. For example, thus the protection of lithium storage batteries is complete, but the leakage of electricity of the lithium batteries is still referred.

However, this controller is still better to be applied to the solar street light. It can make the system more efficient and stable. As the core of the system, the quality of the controller is determined the performance of the solar street light. This design is giving an excellent example of how to control the system. The traditional controller cannot meet the needs of human. So it is valuable to make a promotion to the market, which can give the elevation of efficiency than the traditional controller.

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