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Study on the Power Source of Patrol Robot

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Abstract

The patrol robot needs pollution free and efficient power source. The power source, introduced in this paper, can solve this problem. The power source adopted solar battery and super capacitors as the main module. Super capacitors were divided into two groups, in order to ensure that a group of capacitors charging and another group of capacitors power supply. The voltage of super capacitors needed to be balanced in case the super capacitors were damaged. In order to ensure the quality of the output power of the power source, DC-DC converter was adopted. The experimental results validate that the power take-off of robot is enhanced, and the voltage of super capacitors is balanced, and the power requirement from the power system is reduced.

Keywords*: solar energy, super capacitor, power source, hybrid*

1. Introduction

With the development of social economy, the urban scale expands increasingly. The demand of the security automation of urban is increased by people. The patrol robot is integrated with environment perception, route planning, dynamic decision-making, behavior control and alarm device, and is adapted to regular patrol, fixed-point monitoring or mobile patrol which is a feasible solution. The power of most patrol robot is supplied by the battery which has limitation of number of charge time, and has water pollution, as well. The heavy current cannot be provided by the battery either which is badly needed by the patrol robot when it is started, and accelerated. The battery is charged by the power system that will cause heavier load of the power system. Solar energy, which is a kind of energy that clean and free, can be collected by the power source which is introduced in this paper, and can be stored by the super capacitor. Super capacitor can be charged ten thousands of times which more than the battery. The heavier current can be provided by the super capacitor than the battery which makes patrol robot get better grade ability and accelerating ability. In this paper, the energy is stored in the super capacitor which is coming from solar energy and power system. The performance of the patrol robot can be improved by the solar energy-super capacitor hybrid power source. The power source will be introduced, as follows.

2. Power Source and Balance between Super Capacitors

2.1. Power Source

The power source is consisted of solar battery, super capacitor, and control system and energy regulator, shown as Figure 1. The super capacitors are divided to two groups, capacitor group one and capacitor group two, one group is working at charge state as other is working at discharge state [1-3]. The solar energy cannot meet all the power requirement of the patrol robot. The power system is needed by the power source, too. Therefore, the power source is charged by both solar battery and power system.

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TM5320LF2812A is indexed in the control system. The main tasks of control system is ensure the quality of power coming from solar battery through a DC-DC converter, and control the output power through two DC-DC converter, and exchange the information with the driver, and keep balance between super capacitors, and ensure the quality of the output power through the energy regulator [4]. The control system need detect the current power of the motor, and match the power with the requirement of the drive, and then give the order to the system.

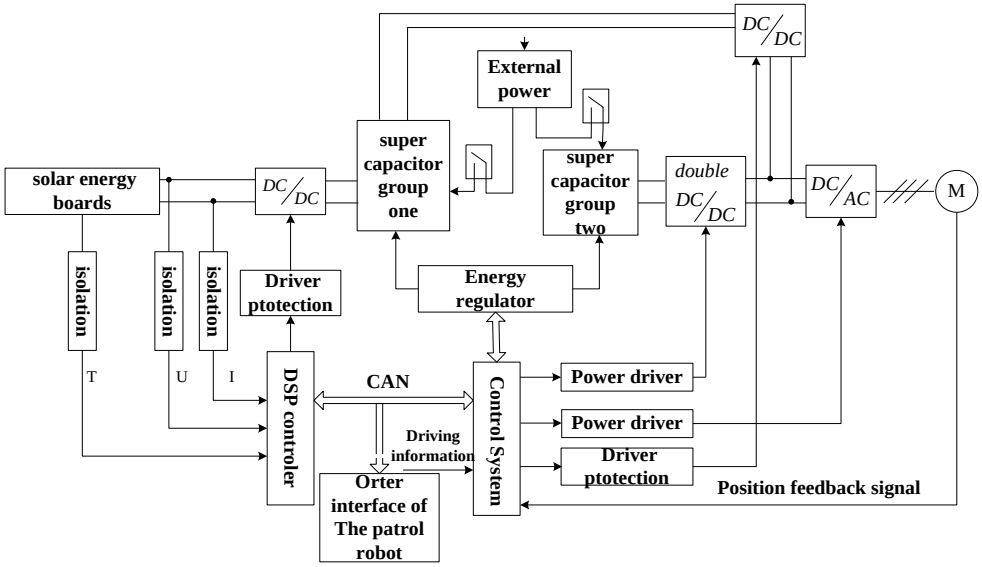

Figure 1. Structure of System

2.2. Power Supply

The solution introduced in this paper remedy the shortage of the solution three, and solves the problem of balance of super capacitors [5-8]. The circuit of the solution is shown as Figure2.

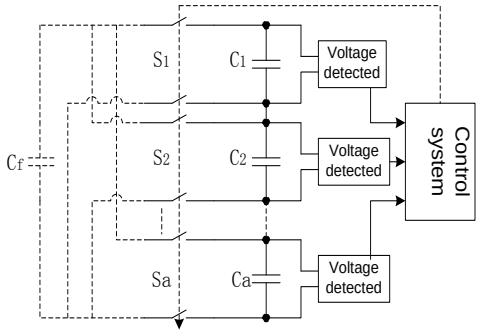

Figure 2. The Structure of the Balance of the Super Capacitors

Using super capacitor to provide power to the patrol robot, the enough power can be provided which is meet the requirement of the patrol robot, but the difference of the character of each single super capacitor makes the difference of the voltage of each single super capacitor which can reduce the life span of super capacitors, and depress the efficiency of the system. Therefore, the necessary measure must be taken to make the voltage of super capacitor close to other's as possible when the super capacitor working at discharge state.

Nowadays, there are three efficiency and typical solutions among all the solutions which can keep the balance between the super capacitors. Solution one is connect a divider resistance on the super capacitor [9-11].Solution two is connect a conductor on the super capacitor. Solution three is index a third-party capacitor. Solution one and solution two are the way that waste energy which consume the extra energy makes the voltage of super capacitor drops, in order to keep the balance of the super capacitors. Solution three is the most efficiency solution in the three solutions, and it is a workable solution in theory. However, there is a great disfigurement when the solution is reacted. The choice of the third-party capacitor is a big problem. If the value of the third-party is small, the influence of the voltage of super capacitor is small, too. If the value of the third-party capacitor is big, the charge time will be too long. The workable of the solution three is denied.

The C1 to Ca are super capacitors. A store super capacitor is indexed in the system which is connected to each super capacitor in the system through MOSFETs, and its value must be close to the value of each super capacitor [12]. After super capacitors working at discharge state for a little while, the change of voltage of each super capacitor can be detected by the energy regulator, and the extra energy is transmitted from super capacitor to the store super capacitor by the energy regulator, and the energy stored in the store super capacitor can be supplied to the load of patrol robot.

3. The Procedure of Power Source and Balance of Super Capacitors

3.1. The Procedure of Power Source

The procedure of power source is shown as Figure 3.The power requirement coming from driver is expressed by the Pd. The power of super capacitor group one and super capacitor group two are expressed by the Pb1 and Pb2. The velocity of patrol robot is expressed by the Vche [13].

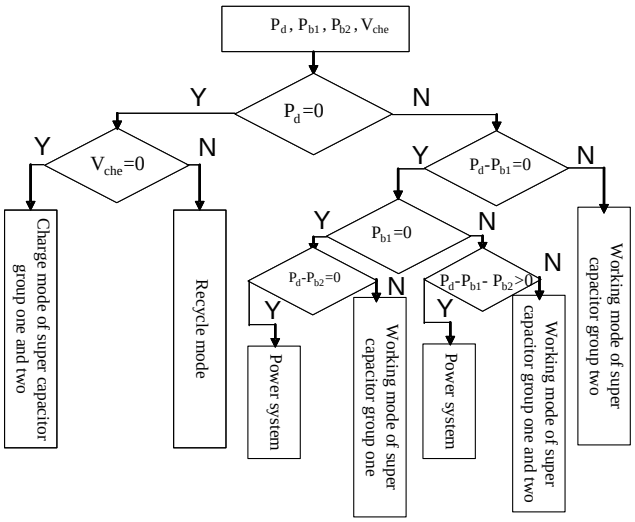

Figure 3. Procedure of Power Source

The super capacitors are divided into two groups. Super capacitor group one is charged by solar battery and power system. Super capacitor group two is charged by power system. Energy is supplied to the motor through DC-DC converter [14-18]. The information of voltage and current can be detected by the control system, and the requirement of driver can be detected by control system, too. Therefore, the power requirement can be calculated out. After detected the energy in the super capacitors, and

matched it with the power requirement, the decision will be made by the control system that the super capacitors are working at charge state or discharge state.

3.2. Choose of Balance Capacitor

In the procedure of balance, the balance capacitor is parallel connecting to a single super capacitor through a MOSFET, assuming that the resistance of wire and MOSFET are ignored, and MOSFET is switch, and the equivalent circuit is shown as Figure 4.

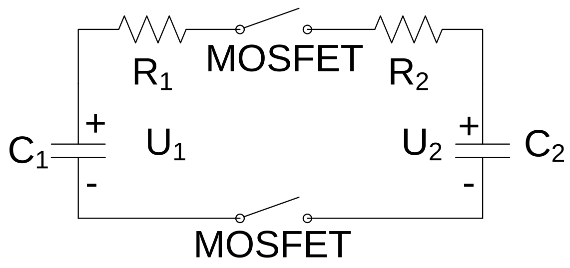

Figure 4. Equivalent Circuit of Capacitors Parallel Connection

In the Figure 4, C_1 balance capacitor, R_1 is equivalent resistance of C_1, C_2 is a certain single super capacitor which is need to be parallel connected to the balance capacitor, R_2 is equivalent resistance of C_2. Assuming that the voltage of C_1 and C_2 are U_1 and U_2 before the MOSFET enable, and $U_1 > U_2$, then after MOSFET enable, C_1 charging and C_2 discharging, according to the tree-element method, this is the variety of voltage of C_1 and C_2 on the time [19-21].

$$u_1(t) = \frac{C_1U_1 + C_2U_2}{C_1 + C_2} + \frac{C_2}{C_1 + C_2}(U_1 - U_2)e^{\frac{-(C_1+C_2)t}{(R_1+R_2)C_1C_2}} \qquad (1)$$

$$u_2(t) = \frac{C_1U_1 + C_2U_2}{C_1 + C_2} - \frac{C_2}{C_1 + C_2}(U_1 - U_2)e^{\frac{-(C_1+C_2)}{(R_1+R_2)C_1C_2}} \qquad (2)$$

Therefore, the current, from C_1 to C_2, is

$$i(t) = \frac{U_1 - U_2}{(R_1 + R_2)}e^{\frac{-(C_1+C_2)t}{(R_1+R_2)C_1C_2}} \qquad (3)$$

The changing rate of voltage of C_1 is du_1/dt, and the changing rate of voltage of C_2 is du_2/dt, then expressions of these changing rates of voltage are

$$\frac{du_1}{dt} = -\frac{U_1 - U_2}{(R_1 + R_2)C_1}e^{\frac{-(C_1+C_2)t}{(R_1+R_2)C_1C_2}} \qquad (4)$$

$$\frac{du_2}{dt} = \frac{U_1 - U_2}{(R_1 + R_2)C_2}e^{\frac{-(C_1+C_2)t}{(R_1+R_2)C_1C_2}} \qquad (5)$$

The time of balance procedure determined by the inner resistance and capacity of these capacitors, when the two capacitors are parallel connected in order to voltage balance. To the chosen super capacitor, the inner resistance and capacity of the super capacitor is fixed, therefore, it is the only way to reduce the time of balance procedure by select a certain balancing capacitor. According to the (4) and (5), the inner resistance not only affect the charge/discharge time constants of two capacitors, and also affect the initial velocity of voltage change of two capacitors, the smaller the inner resistance, the bigger the initial velocity, and the smaller the decay time constant, and the faster the decay velocity of

voltage changing velocity. It does not affect the initial velocity of the balanced capacitor voltage change.

According to the above analysis, inner resistance of balance capacitor should be as far as possible, in order to improve the initial velocity of balance. Time constant decrease will cause the velocity of balance decay, and the two parallel capacitor switching frequency can be changed by the control algorithm to solve the problem. For example, make the time that the two capacitors are parallel less than one time constant, and disconnect, and then connect.

When choosing a balance capacitor, the capacity of the capacitor can neither too big nor too small. The capacity is larger, the slower the decay velocity of the voltage changing velocity of the balanced super capacity. The balance capacity not only charge up the super capacitor which voltage is lower than the balance capacitor, but also make the super capacitor discharge which voltage is higher than the balance capacitor, at this time, voltage of balance capacitor is needed to growth as soon as possible. According to the (4), when the capacity increases, the initial velocity of voltage increase of balance capacitor will be decrease.

In addition, in the charging process of capacitor group, balance capacitor need frequently switch to the super capacitor with highest voltage, to reduce the charging time, reduce impact on other capacitors. In order to make the voltage of balance capacitor close to the voltage of super capacitors, after the charging procedure, the capacity of balance capacitor should be smaller than the capacity of super capacitors. At last, a balance capacitor was chosen, and the capacity of the balance capacitor was three-quarters of the capacity of super capacitors.

3.3. Balance Control Algorithm

The super capacitor group balance management system include data of capacitor group acquisition, the data include main voltage, main current, the voltage of super capacitor and balance capacitor, balance current and temperature of capacitor box, balance control and communication.

Judging from the value and the direction of main current of super capacitors that the balance control program can tell what status of super capacitors are, recharge or discharge, and then a control algorithm will be adopt to fit for a certain status.

Status 1, super capacitors are under the charging status, flow diagram of control program is shown as Figure 5.

In the diagram, U_{full} is the voltage of super capacitor when it full charged. u_{new} is the new highest voltage of super capacitor appears in balance procedure under the charging status, u_{old} is the voltage of balance capacitor and the super capacitor which was connected, just now. According to the Figure 5, when super capacitors are charged up, relay, controlled by controller, depend on the certain condition, will parallel connect the balance capacitor to the super capacitor which's voltage is highest. As balance capacitor, some power energy must be maintained by the balance capacitor, therefore, balance capacitor have not independent charger.

The condition that the balance capacitor parallel connect to super capacitor with the highest voltage is $\delta u = f(\Delta u)$, and $\Delta u = U_{full} - u_{new}$, it is the difference between the voltage after the super capacitor is charged up and the new highest voltage of super capacitor, $\delta u = u_{new} - u_{old}$, that is the difference between new highest voltage of super capacitor and the voltage of balance capacitor and super capacitor which is connected. Function $f(\Delta u)$ is

$$f(\Delta u)=\begin{cases}\frac{1}{4}\Delta u, & \Delta u \geq 6V \\ \frac{1}{3}\Delta u & 6V > \Delta u \geq 2V \\ \frac{1}{2}\Delta u & 2V > \Delta u \geq 1V \\ 0.5 & \Delta u < 1V\end{cases} \tag{6}$$

This method of balancing can make the balance capacitor is full charged, but also protect the super capacitor with the highest voltage from damage by over charged.

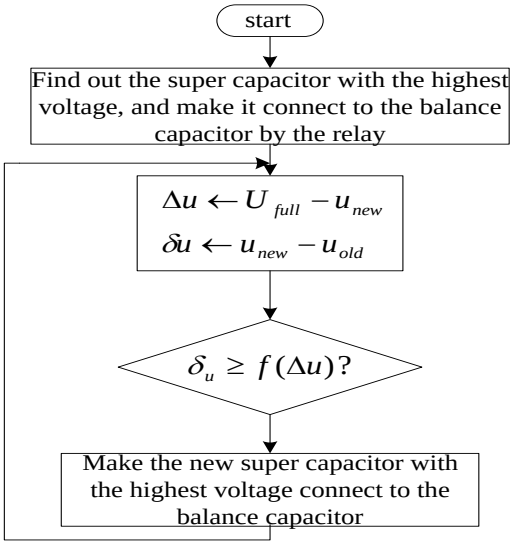

Figure 5. Balance Control Program Diagram in Charge Procedure

Status 2, super capacitors are under the discharge status, the control program diagram is shown as Figure 6.

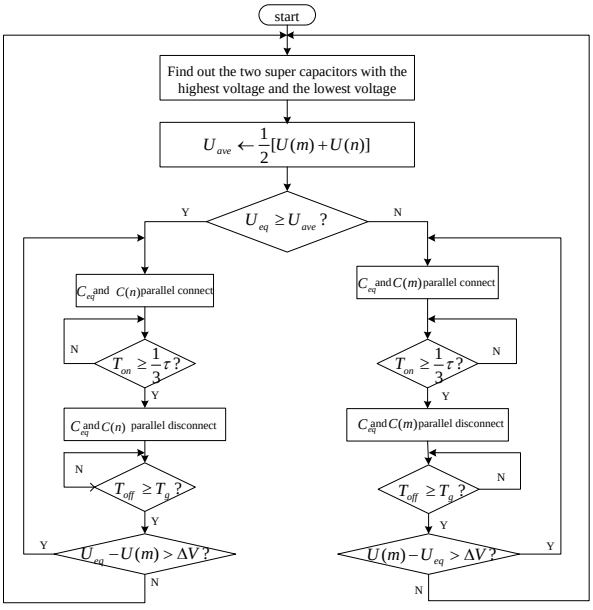

Figure 6. Balance Control Program Diagram in Discharge Procedure

m and n are serial numbers of the super capacitor with the highest voltage C(m), and the super capacitor with the lowest voltage C(n). U(m) is the voltage of the C(m), U(n) is the voltage of the C(n), and U_{ave} is the average value of U(m) and U(n). C_{eq} is the balance capacitor, and the voltage of balance capacitor is U_{eq}. Ton is the time which C_{eq} parallel connect to C(m) or C(n), τ is time constant of charge-discharge, T_{off} is the time of C_{eq} disconnect with C(m) or C(n) after parallel connect, T_g is disconnect time limitation.

When super capacitors are under discharge status, the balance control program will find out the serial number of the super capacitor with the highest voltage, and the number of the super capacitor with lowest voltage, and figure out their average voltage, and then compare it with the voltage of balance capacitor. The balance capacitor will be parallel connected to the super capacitor with the lowest voltage, and charge up the super capacitor, when the voltage of balance capacitor is bigger or equal to the average voltage, otherwise, the balance capacitor will be parallel connected to the super capacitor with the highest voltage, and discharge the capacitor. In order to enhance the velocity of balance, the connection and disconnection are periodically, and do not wait voltage of balance capacitor close to the connected super capacitor. The relay will be disconnect when the connect time is bigger or equal to the third part of the charge/discharge time constant. The balance capacitor will be parallel connected to the same super capacitor if the difference between the voltage of balance capacitor and the highest voltage of the super capacitor, or the lowest voltage of the super capacitor, is bigger than the limitation ΔV, otherwise the serial numbers of the super capacitor with the highest voltage and the super capacitor with the lowest voltage will be found out, and execute the procedure above, again, when the time of disconnection is bigger or equal to the time limitation T_g, T_g is set by the period of cycle detection.

Status 3, super capacitors are under the standing status, the balance control program is similar to the discharge status.

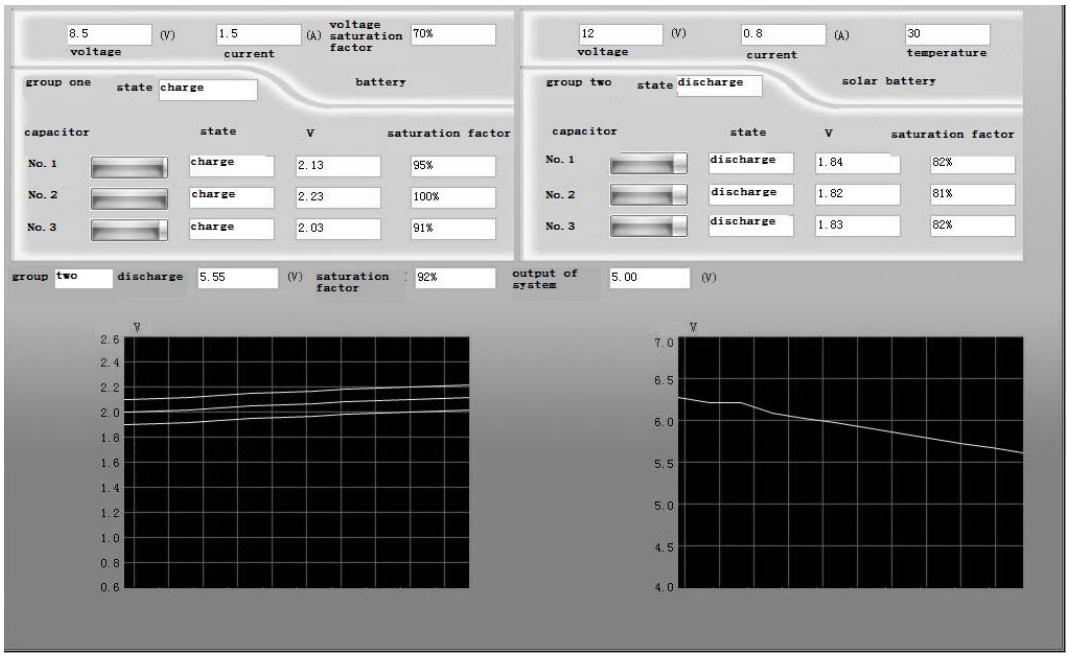

Figure 7. Detect Software on the Computer

3.4. Super Capacitors Monitor System

Super capacitors monitor system is set up in the monitor room. Super capacitors monitor system can display the state of the state of each super capacitor, shown as Figure7

4. Conclusions

A new type of power source of patrol robot is introduced in this paper which consisted by super capacitor and solar energy mainly. A problem of balance between super capacitors is solved in this paper that makes the quality of output power of the power source introduce in this paper is good. According the detected data, shown as Figure al5, the power source can work well in the patrol robot.

Acknowledgments

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