**Energy**

***<Battery charge profile design>***

A battery charging profile should be created to guarantee that the cells may be charged to their full capabilities while staying within the constraints of the batteries and solar panels. The capacity of the cells should be determined before developing the battery charging profile.

There are two ways to charge cells, namely, constant current and constant voltage. A mixture of constant current and constant voltage is used instead of the provided code (which only used constant current to charge the cells).

Constant current is employed when the cell is nearly empty, as constant voltage may cause the battery to overheat when charging [1]. However, when the battery has been charged to 3500mV (around 90%), we should apply contant voltage to fully charge it to avoid overcharging.

The cell capacity measured by the given code is 502mAh while the one that measured by constant voltage and constant current is around 565.07mAh. Figure 1 shows the different performance of two charging methods

Chart, line chart

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Figure1: Cell1 cc&cv comparison

The capacity of the cell obtained after adding constant voltage is greater than the capacity obtained by using constant current alone. The constant current cannot fully charge the battery for this reason.

***<SOC>***

A combination of voltage lookup tables and coulomb counting were used to estimate soc.

To obtain the voltage lookup table, we must first completely charge a cell and then discharge it. We measure the average value of the recorded cell voltage and find the associated soc at this voltage by stopping the discharging process for every 10s and take the measurements.

Chart, scatter chart

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Figure2&3: Cell Voltage measurement

From Figure2&3, we choose 3540mV since the average value of different cells in state2 is around 3540mV.

|  |  |
| --- | --- |
| SOC (%) | OCV (open circuit voltage)(mV) |
| 100 | 3540.0 |
| 90 | 3242.5 |
| 80 | 3234.4 |
| 70 | 3216.8 |
| 60 | 3209.3 |
| 50 | 3198.2 |
| 40 | 3186.4 |
| 30 | 3168.7 |
| 20 | 3135.4 |
| 10 | 3088.3 |
| 0 | 2500.0 |

In our code, the boundary between each OCV value is modified to make the range more uniform. The algorithm will always check the value of the soc at the start of the charging process.

The voltage lookup table has been added to state 0 (Figure 4) to check the initial soc value at the beginning of charging process.

Then, then soc during charging process can be calculated by coulomb counting:

Where coulomb counting measures the current drawn out of a cell and integrates the current over time in order to estimate soc.

***<Battery balancing algorithms>***

Diagram

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Figure4: State Diagram of three cells in parallel

We chose to use three cells in parallel in our design. As a result, in addition to ensuring that each cell has a similar voltage at the start of the charging process, balancing is also required during the charging process.

As shown in Figure 4, for constant current charging state. We charged the batteries for 60 seconds and then measured each cell for 5 seconds respectively. The average value of each cell is then calculated, and we proceed to the comparison state. In the comparison state, we check whether the difference between the mean of two cells is greater than 500mV to see if we need to balance the cell. If this is the case, the higher-voltage cell will be discharged. It will return to state 4 after discharge to see if the difference between the other cell voltages is more than 500mV. The is an individual discharging state for all the possible combinations of 2cells.

***<PV MPPT algorithms>***

Characterize PV panels:

The form of a PV cell's IV characteristic is that of a non-ideal current source [3], in which the current decreases gradually at first and then rapidly as the voltage across the source rises.

Our target is to convert as much sunlight as possible into useable energy, hence the key question is where to operate on the IV characteristic to maximize the IV product. By characterizing the PV panel, we can find the voltage with largest power. The PV panel is characterized by connecting different values of loads to buck and boost mode and measures the current and voltage by using multimer. The voltage that can provide largest power is 4.7V.

Chart, scatter chart

Description automatically generated

Figure5: PV characteristic

The characteristic of PV panels may vary in different environments. Therefore, we need to build a feedback system to maximize the value of the output to discover the right operating point considering temperature and irradiance may fluctuate. As a result, perturb and observe method is used to implement the MPPT. [3]

In our code, the MPPT algorithm has been added inside of the constant current, if the measured current is smaller than 200mA, the algorithm will do MPPT. Otherwise, it will do constant current.

By using perturb and observe method, the maximum power point can be found by comparing the present and previous power value and vary the PWM accordingly. By varying the PWM, we are changing the resistance of the load, therefore, the value of current and voltage will be changed as well. We are using the buck mode, if the present power is larger than the previous power, the PWM will be decreased by 0.005. If the present power is smaller than the previous power, the PWM will be increased by 0.005. The 0.005 is selected since it is a reasonable range where the settling process of the values can be observed.

The reason why we add MPPT is because PID controller will get itself into a problem when the PV voltage starts to fall. It will ask for more duty cycle which will not increase the current so it will ask for more and more until the duty is maxed and the current is zero.[2]

***<Circuit Design>***

Diagram

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Figure6: Circuit diagram

The cells are connected in parallel since we need to make sure that even if one cell broke, the whole system can still operate on the Mars. Besides, cells in parallel are easier to balance. The reason is that parallel cells will balance automatically, but we must make sure that before charging, there is no large difference between the voltage of all the cells. Besides, by connecting the cells in parallel the total current capacity of the system is increased, even if one cell broke, the only effect is that the total cell capacity decreases.

The PV panels are connected in parallel since the nominal voltage, 5V is enough for our system to operate, and PV panels in parallel can provide larger current which enables the whole system to work even in a cloudy day.

***<SOH>***

State of health is a figure of merit of the condition of a cell compared to its ideal conditions.

In the first place, the Overvoltage/Undervoltage of each cell is monitored by adding an error state for every single cell.

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Figure 7: Prevent overvoltage/undervoltage

Secondly, the internal resistance of cell, which increases after a long term of charging. As a result, the capacity of the cell will decrease gradually after multiple cycles of charging and discharging. [4] [5]

The soc of cell degrades after being charged for multiple cycles.

Besides, the battery balancing algorithm is implemented in the state machine (Figure 4) to prevent overcurrent.

For the battery temperature, a temperature sensor may be added to make sure the cell has not been overheated for a long time. Besides, a fan may be added to the rover to assist heat dissipation.

***<How Energy connects with the whole system>***

Energy part is connected to the Rover through UART port.

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Figure 8: How energy talks to control part

When the control component sends the instruction ‘c,' the battery will enter state 0(Figure5), which is the state where the initial soc value is read, and enter state 1(Figure 5), which is the constant current charging state, as shown in the state machine with three cells.

If the control part delivers the command ‘r,' the soc value is read and passed to the command part. If the letter ‘s' is received, the battery will cease charging and enter a rest mode. Besides, after receiving ‘d’, the battery will be discharged by the drive sub module. Because it cannot be tested with drive sub module. Therefore, in the code, the discharging process is imitated by a constant current mode with a reference current of -350. 350mA is the value of current that drive sub module will use while the rover is moving. To make sure all the cells have not been overvoltage/undervoltage, the battery should be balanced while discharging as well.

The soc value can be used to estimate the range that rover can move by using this equation:

Where

We decide to place the PV panels on the rover since the rover's range will be limited if it has return to the charging station when the battery is low. If the PV panels are placed on the rover, however, the rover will be able to stop and charge anytime the battery is low.

On the other hand, having a static charging station can reduce the weight of the Mars rover. And the charging station can be added with other functionality like checking if everything on the rover functions normally.

Citation:

1. [1] (Battery Charging Methods & Terminology - Helios Power Solutions, 2021)
2. [2] (P.Clemow, “Current through PV panels”,Piazza.com, 2021)
3. [3] (T.Green, Photovoltaic Energy, EEE, Imperial, 2021)
4. [4] (State of health - Wikipedia, 2021)
5. [5] (Stafl Systems Calculating the State of Health, 2021)
6. [6] (soc versus cycles - Google Search, 2021)