

Balancing Strategy Design of Supercapacitor Backup Power System Based on BQ76907



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Abstract

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BQ76907-Q1 is a 2S–7S low-power battery monitoring and protection device, and supercapacitors have been listed as one of the supported objects in the datasheet. The device supports passive balancing initiated and controlled by the host, which can be implemented using integrated bypass paths or external balancing FETs. For systems requiring higher balancing currents, it is explicitly recommended to use external FET balancing circuits.

This paper targets a 5-series supercapacitor backup power system: the system provides a stable 12V charging power supply from vehicle 12V via Buck-Boost, and adopts a passive balancing scheme of external resistors plus MOSFETs. This paper focuses on how to better achieve the optimal scheme for all channels under the passive balancing architecture.

Table of Contents

1 Introduction	2
2 Passive Balancing Mechanism of BQ76907	3
2.1 Balancing Current Path	3
2.2 Balancing Current	4
2.3 Balancing Time Estimation	4
3 Particularity of Supercapacitor Systems	5
3.1 ESR and Voltage Recovery Effect	5
3.2 Impact on Balancing Strategy	5
4 Balancing Scheme Design	6
5 Reference Algorithm Implementation and Example	7
5.1 Algorithm Flow and Pseudocode	7
5.2 Design Example	7
6 Conclusion	9
7 References	9

List of Figures

Figure 2-1. Schematic Diagram of 5-Series Supercapacitor Balancing Circuit	3
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1 Introduction

In automotive electronic systems, backup power is often used for short-term power supply during main power failure, cold-start disturbance, communication retention, or fail-safe transition. Compared with lithium batteries, supercapacitors have high power density, long cycle life, and good low-temperature power characteristics, making them very suitable for short-term energy buffering scenarios. With the implementation of relevant safety requirements, it has become a mandatory requirement in automotive systems to use backup power to release and unlock door handles in the event of vehicle accidents and power outages. As a supercapacitor control and balancing chip, BQ76907-Q1 can well provide monitoring and protection for supercapacitor backup power supplies.

The device provides high-precision cell voltage measurement, SRP/SRN current detection, temperature sampling, and host-controlled passive balancing capabilities, so it can also be used for monitoring and balancing control of 5-series supercapacitor packs.

It needs to be emphasized that BQ76907 is essentially not an active balancing device. Its balancing capability is achieved by bypassing the current of a certain string of cells, that is, discharging the string of cells through a bypass branch, rather than transferring energy from high-voltage cells to low-voltage cells. This physical boundary determines the design direction of the balancing algorithm.

2 Passive Balancing Mechanism of BQ76907

2.1 Balancing Current Path

The datasheet of BQ76907-Q1 indicates that the device supports host-controlled passive balancing, which can be initiated via subcommands, supporting simultaneous balancing of adjacent or non-adjacent cells.

Below is a simplified structural diagram of the 5-series supercapacitor in the external FET + resistor passive balancing scheme. This diagram expresses the balancing current path, not a complete schematic diagram.

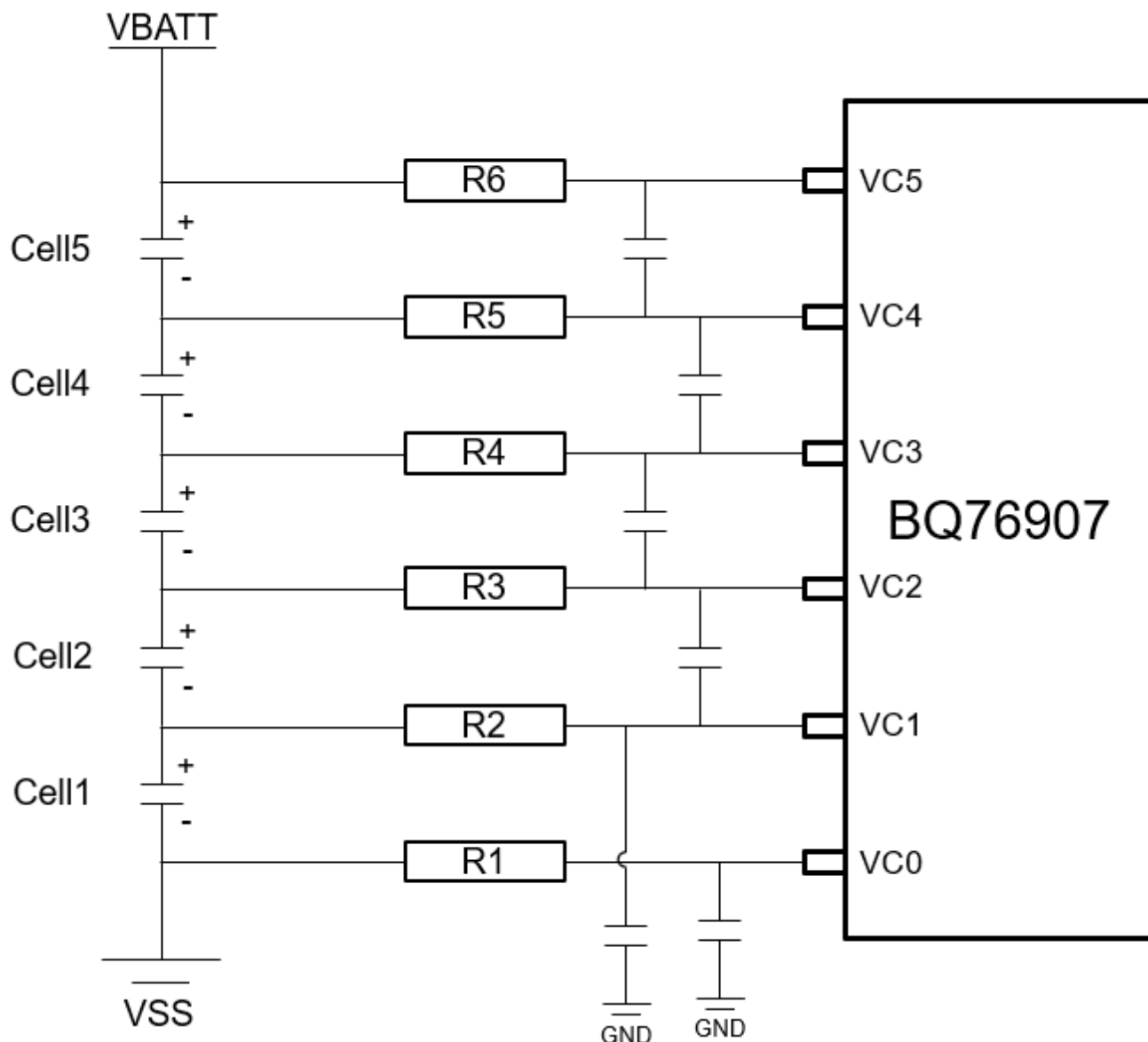


Figure 2-1. Schematic Diagram of 5-Series Supercapacitor Balancing Circuit

When the n-th string balancing is turned on, the current path is:

$$VC_n \rightarrow Q_n \rightarrow R_n \rightarrow VC_{n-1} \quad (1)$$

This means:

The balancing branch of Cell 5 discharges the energy of Cell 5 to the VC4 node

The balancing branch of Cell 4 discharges the energy of Cell 4 to the VC3 node

...

The balancing branch of Cell 1 returns the energy of Cell 1 to the VC0 node

This is a typical top-down passive discharge structure. The function of this structure is to reduce the energy stored in high-voltage cells, rather than transferring energy to low-voltage cells. This characteristic determines that passive balancing can only achieve a voltage reduction of high-voltage strings, but cannot directly increase the voltage of the lowest voltage string. Therefore, it will be reflected in tests as slow balancing speed and low efficiency.

2.2 Balancing Current

The balancing current is approximately:

$$I_{bal,n} \approx \frac{V_{cell,n}}{R_{bal,n}} \quad (2)$$

Wherein:

- $V_{cell,n}$ is the cell voltage
- $R_{bal,n}$ is the balancing branch resistance

For the same balancing resistor, high-voltage cells have a larger balancing current. Therefore, when multiple cells are balanced simultaneously, the voltage change rate of high-voltage cells is significantly faster than that of low-voltage cells.

2.3 Balancing Time Estimation

For supercapacitors:

$$I = C \cdot \frac{dV}{dt} \quad (3)$$

Substituting gives:

$$C_n \cdot \frac{dV_n}{dt} = -\eta_{CB} \cdot \frac{V_n}{R_{bal,n}} \quad (4)$$

Arranged as:

$$\frac{dV_n}{dt} = -\frac{\eta_{CB}}{R_{bal,n}C_n} V_n \quad (5)$$

Solving this first-order differential equation yields:

$$V_n(t) = V_{n0} \cdot e^{-t/\tau_n} \quad (6)$$

Where the time constant is:

$$\tau_n = \frac{R_{bal,n}C_n}{\eta_{CB}} \quad (7)$$

This indicates that:

The faster the balancing target, the smaller R_{bal} or the higher the effective duty cycle η_{CB} is required. Supercapacitor capacitance is proportional to the balancing time constant.

The engineering approximation formula can be obtained based on the above formula:

In a small voltage difference and short time interval, it can also be approximately considered that the current does not change significantly with voltage, at this time:

$$t_{bal} \approx \frac{C \cdot \Delta V}{I_{bal, avg}} \quad (8)$$

Further substituting the average balancing current:

$$t_{bal} \approx \frac{C \cdot \Delta V \cdot R_{bal}}{\eta_{CB} \cdot V_{cell}} \quad (9)$$

This formula is suitable for estimating how long it takes for a certain string to converge when it is higher than the lowest string by ΔV ; and what balancing resistor should be selected to achieve the target balancing time. This formula is only applicable in the range of $\Delta V < 100\text{mV}$, $V_{cell} > 1\text{V}$.

3 Particularity of Supercapacitor Systems

When applying the passive balancing architecture of BQ76907 designed for lithium-ion batteries to supercapacitor systems, two additional characteristics need to be noted. Supercapacitors do not have a voltage plateau region like lithium-ion batteries. The relationship between terminal voltage and stored energy is more direct, and the voltage difference ΔV itself is an effective and directly available balancing criterion; the leakage current dispersion of supercapacitors is usually more obvious than that of lithium-ion cells, and balancing requirements are not limited to the end of charging. In addition, the following two dynamic characteristics will directly affect the value selection method of the balancing criterion, but will not change the core balancing strategy recommended in this paper.

3.1 ESR and Voltage Recovery Effect

The terminal voltage of the supercapacitor can be expressed as:

$$V_{CELL} = V_{OC} + I \cdot ESR \quad (10)$$

Wherein:

- V_{OC} is the open-circuit voltage
- I is the current flowing through the cell
- ESR is the equivalent series resistance

When the system is in a charging or discharging state, the measured cell voltage does not completely represent its true energy storage state. If instantaneous voltage is directly used for balancing judgment, it may lead to incorrect balancing decisions. After the charge/discharge current is removed, the internal charge of the supercapacitor is redistributed, and the terminal voltage will slowly recover to a new stable value. This process is usually called the voltage relaxation effect (Voltage Relaxation). Therefore, making balancing judgments immediately after high-current working conditions end may overestimate or underestimate the actual voltage difference.

3.2 Impact on Balancing Strategy

The above two characteristics mean that the balancing algorithm should be based on voltage data close to steady state as much as possible for decision-making, rather than instantaneous sampling results.

Therefore, when designing the balancing algorithm mechanism, balancing judgment during high-current transients should be avoided; a relaxation time should be appropriately introduced; or current measurement results should be used for ESR compensation.

4 Balancing Scheme Design

In actual tests, if multiple strings of balancing channels are enabled simultaneously, the common phenomenon is that the voltage of the 1~2 strings with the highest voltage drops significantly, while the change of several strings with lower voltage is very small in a short time. The reason for this phenomenon is not that the device only turns on some channels—in fact, all enabled channels are conducting—but stems from the approximate relationship of the balancing current given in [Section 2.1](#): the balancing current is approximately proportional to the cell voltage. The higher the cell voltage, the greater the balancing current and the faster the voltage drops; the balancing current of the lower-voltage cell is correspondingly smaller, and the change is not obvious within the same observation time window.

If all cells are continuously balanced at the same time, the cell with the lowest voltage will also continue to be discharged, the total PACK voltage will drop faster, the voltage difference convergence efficiency will be relatively lower, and more available energy that could have been preserved will be lost. The root cause of this phenomenon is that the passive balancing of the BQ76907-Q1 cannot transfer energy from high-voltage cells to low-voltage cells, but can only discharge cells with higher voltages; letting the cell with the lowest voltage participate in balancing will not bring additional benefits, but will instead slow down the overall convergence efficiency. Therefore, balancing all channels simultaneously is usually not the optimal solution.

Therefore, this paper proposes that for supercapacitor systems, the balancing goal is not to increase the lowest cell voltage, but to reduce the difference between the highest cell voltage and the lowest cell voltage:

$$\Delta V = V_{max} - V_{min} \quad (11)$$

Therefore, a selective balancing strategy is recommended. First, identify the cell with the lowest voltage in the system:

$$V_{min} = \min(V_1, V_2, V_3, V_4, V_5) \quad (12)$$

Then calculate the voltage difference of each cell relative to the lowest cell:

$$\Delta V_i = V_i - V_{min} \quad (13)$$

Only set open/close thresholds with hysteresis for cells meeting the conditions, and the opening condition is:

$$\Delta V_i > \Delta V_{on} \quad (14)$$

This can prevent the lowest cell from being continuously discharged. Compared with all-channel simultaneous balancing, this method can reduce system energy loss and improve voltage difference convergence efficiency.

5 Reference Algorithm Implementation and Example

5.1 Algorithm Flow and Pseudocode

The system periodically executes the following steps:

1. Turn off all balancing channels;
2. Wait for voltage to stabilize;
3. Collect all cell voltages;
4. Calculate maximum and minimum voltages;
5. Determine whether the voltage difference exceeds the balancing threshold;
6. Turn on balancing for the target cell;
7. Re-measure after reaching the balancing time.

The reference pseudocode is as follows:

```
while(1)
{
    Disable_All_Balance();
    Delay(RELAX_TIME_MS);
    Measure_Cell_Voltages();
    vmax = Find_Max_Cell();
    vmin = Find_Min_Cell();
    if ((vmax - vmin) > BAL_START_TH)
    {
        Enable_Balance(vmax_cell);
        Delay(BALANCE_TIME_MS);
        Disable_All_Balance();
    }
    Delay(MONITOR_PERIOD_MS);
}
```

5.2 Design Example

This section provides a simplified design example to illustrate the relationship between the passive balancing current, supercapacitor capacitance, and target voltage difference. This example is for first-order estimation only; the actual system still needs to be verified by combining balancing resistor error, MOSFET on-resistance, PCB temperature rise, ADC sampling error, and supercapacitor ESR.

Assuming the system adopts a 5-series supercapacitor, the parameters of each capacitor are as follows:

$$C=100F$$

Assuming the voltage of a certain supercapacitor string is higher than the lowest string:

$$\Delta V=50mV$$

The goal is to eliminate this voltage difference through passive balancing. The amount of charge to be removed from the supercapacitor is:

$$\Delta Q=C \times \Delta V$$

Substituting the parameters:

$$\Delta Q=100F \times 0.05V=5C$$

If the average balancing current of the balancing branch is:

$$I_{BAL,AVG}=20mA$$

Then the ideal balancing time is:

$$t_{BAL} = \frac{\Delta Q}{I_{BAL,AVG}} = \frac{C \times \Delta V}{I_{BAL,AVG}} \quad (15)$$

Substituting the parameters:

$$t_{BAL} = \frac{5C}{0.02A} = 250s \quad (16)$$

That is, under the condition of an average balancing current of 20mA, eliminating a 50mV voltage difference of a 100F supercapacitor theoretically takes about 250s.

If the balancing current is increased to 100mA, then:

$$t_{BAL} = \frac{5C}{0.1A} = 50s \quad (17)$$

This result indicates that for large-capacity supercapacitor systems, the balancing time is mainly determined by the capacitance value and the average balancing current. If the goal is to shorten the balancing time, priority should be given to increasing the allowable average balancing current, while evaluating the power consumption and thermal design of the balancing resistor and MOSFET.

The instantaneous current of the passive balancing branch can be approximately expressed as:

$$I_{BAL} \approx \frac{V_{CELL}}{R_{BAL}} \quad (18)$$

If considering that the balancing switch is not continuously turned on 100%, an effective balancing duty cycle η_{BAL} can be introduced:

$$I_{BAL,AVG} \approx \eta_{BAL} \cdot \frac{V_{CELL}}{R_{BAL}} \quad (19)$$

Therefore, the balancing time can be further written as:

$$t_{BAL} \approx \frac{C \times \Delta V \times R_{BAL}}{\eta_{BAL} \times V_{CELL}} \quad (20)$$

Therefore, in supercapacitor systems, the balancing speed in the low-voltage range will slow down significantly. Even if the balancing channel is enabled, when the cell voltage is low, the voltage change may not be obvious in a short time due to the small balancing current itself. This is also one of the reasons why it is often observed in tests that high-voltage cells change significantly while low-voltage cells change insignificantly.

In actual algorithms, this design example also illustrates two engineering principles:

First, balancing judgment should not be based on voltage changes over too short a time. For 100F-level supercapacitors, even if a balancing current of tens of milliamperes lasts for several seconds, the voltage change may only be at the millivolt level, which is easily masked by sampling noise, ESR dynamic voltage drop, and voltage recovery effects.

Second, balancing control should adopt a threshold and hysteresis mechanism. For example, turn on balancing when the voltage difference of a certain string relative to the lowest string is greater than 50mV, and turn off balancing when the voltage difference drops below 20mV. This can avoid frequent switching of balancing channels caused by transient voltage errors.

6 Conclusion

BQ76907-Q1 supports host-controlled passive balancing and can achieve higher balancing current through external FETs, so it can be used for the monitoring and balancing of 5-series supercapacitor backup power systems.

The balancing of BQ76907 is essentially step-by-step downward passive discharge, not active energy transfer. When multiple strings of balancing are enabled simultaneously, all channels are working, but the high-voltage strings are most obvious due to the larger balancing current. Balancing all channels simultaneously is usually not the optimal solution because it will continue to lower the lowest string. For 5-series supercapacitors, the recommended optimal method is: perform selective balancing only on cells significantly higher than the lowest string, incorporate thresholds and hysteresis, and make periodic decisions by the MCU. If the goal is to shorten the balancing time, priority should be given to external FET balancing to increase the balancing current, and combine with CB_LOOP_SLOW to increase the effective balancing duty cycle.

The balancing mechanism analysis and control strategy given in this paper are not limited to the specific device BQ76907-Q1. For other devices adopting similar host-controlled passive balancing mechanisms, as well as supercapacitor or lithium-ion battery systems with different series counts, the analysis methods and algorithm frameworks in this paper also have reference value.

7 References

1. [BQ76907-Q1 2-Series to 7-Series Cell High-Accuracy Automotive Battery Monitor and Protector for Li-Ion, Li-Polymer, LiFePO4 \(LFP\), LTO Battery Packs, and Supercapacitors Datasheet](#)
2. [Understanding BQ76905, BQ76907 Voltage Sampling Measurement Loop](#)
3. [BQ76907 Technical Reference Manual](#)

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