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Charging Strategy of Supercapacitor in Photovoltaic Power Generation System

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Abstract: The charging efficiency of supercapacitor under different charging methods is analyzed by using the improved RC model of supercapacitor. A photovoltaic cell charging system for supercapacitor based on Boost cascade Buck converter (BOCBB) is proposed. The former Boost converter is connected to the photovoltaic power generation system, and the conductance increment method is used to track the maximum power point of the photovoltaic cell. The latter Buck converter uses a segmented charging strategy to charge the supercapacitor. Based on this circuit, a complete control method for the supercapacitor charging system is proposed. Finally, the charging efficiency of supercapacitor by photovoltaic cells under different lighting conditions is simulated and analyzed.

1. Introduction

The combination of photovoltaic power generation system and supercapacitor energy storage system can utilize the high power throughput capacity of supercapacitor to improve the overall characteristics of photovoltaic power generation system. A hybrid energy storage system for supercapacitor battery based on energy conversion model is proposed. The energy storage system can meet the requirements of series voltage range of supercapacitor in short-time high-power throughput process on the one hand, and maintain the DC bus voltage constant on the other hand^[1]. The hybrid use of storage battery and supercapacitor can give full play to the advantages of large specific energy of storage battery, large specific power of supercapacitor and long cycle life, greatly improving the performance of composite power supply^[2].

In this paper, three different charging methods and the charging efficiency of photovoltaic cells to supercapacitors are analyzed. Boost cascade Buck converter is selected and an optimized charging control strategy is designed. The MPPT control of photovoltaic cells is realized while the supercapacitors are charged efficiently. Simulation results verify the effectiveness of the proposed charging control strategy.

2. Study on charging efficiency of super capacitor

2.1. Improved RC model of supercapacitor

As shown in figure 1, the improved RC model of supercapacitor is composed of ideal capacitor C , series equivalent resistance R_s and parallel equivalent resistance R_p . Due to the addition of parallel equivalent resistance R_p representing the leakage current effect of supercapacitor, the model can more accurately describe the long-term operation state of the capacitor with a relatively simple RC circuit model.



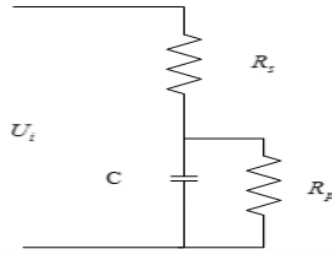


Figure 1. Modified RC model of supercapacitor

The model circuit belongs to a first-order full response circuit. By solving the formula of the first-order full response solution, the expressions of equivalent capacitance voltage and input current in the improved RC circuit model of supercapacitor can be obtained when the initial voltage is:

$$U_c(t) = \frac{R_p}{R_s + R_p} U_i \left(1 - e^{-\frac{t}{\tau}} \right) \quad (1)$$

$$i_i(t) = \frac{U_i}{R_s + R_p} + \frac{1}{R_s} U_i e^{-\frac{t}{\tau}} \quad (2)$$

$$\tau = \frac{R_s R_p}{R_s + R_p} C \quad (3)$$

2.2. Charging efficiency under constant voltage, constant current and constant Power

The charging efficiency curves under constant voltage, constant current and constant power charging modes are shown in Figure 2-4. Through the analysis of the efficiency curve, it can be seen that the charging efficiency of supercapacitor in constant voltage charging mode is only 50%. Under the constant current charging mode, the charging efficiency gradually increases and the final charging efficiency can exceed 90%, but the power of the charging circuit increases with the increase of the supercapacitor voltage, which requires high power of the charging circuit. Under the constant power charging mode, the charging efficiency increases with the increase of the supercapacitor voltage and is slightly higher than the constant current charging. However, the charging current is large due to the low terminal voltage at the beginning of charging, which requires higher current stress on the charging circuit. As can be seen from comparison, different charging modes should be used in different stages.

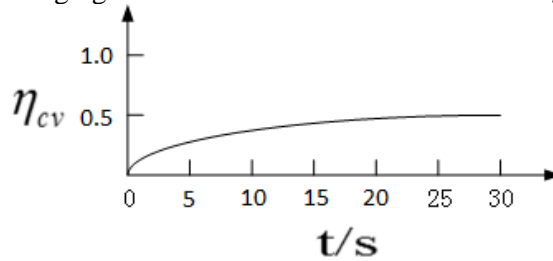


Figure 2. Constant voltage charging efficiency curve

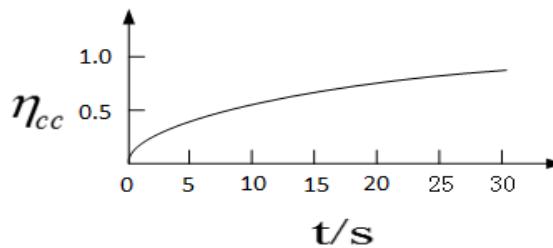


Figure 3. Constant current charging efficiency curve

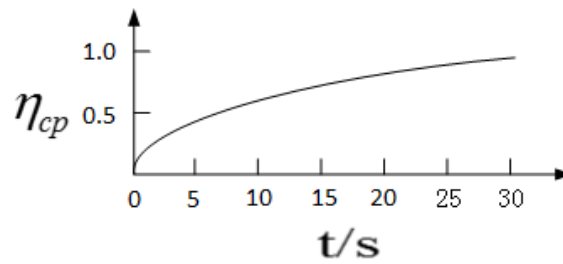


Figure 4. Constant power charging efficiency curve

3. Charging system structure and control strategy

3.1. Charging system structure

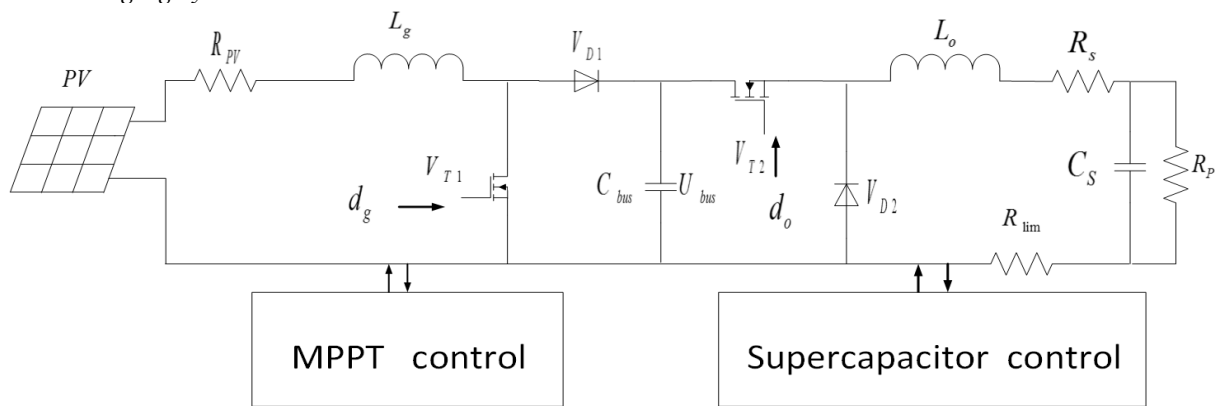


Figure 5. Structure diagram of charging system

3.2. Maximum power point tracking

The output power of photovoltaic cells shows a single peak characteristic with the change of terminal voltage, and the peak value is the maximum power point. MPPT control in charging system uses conductance increment method. The principle is to adjust the duty ratio D by detecting the current working voltage and current and comparing it with the working voltage and current of the previous second, so as to make the photovoltaic cell output the maximum power, as shown in the flow chart of conductance increment method in figure 6.

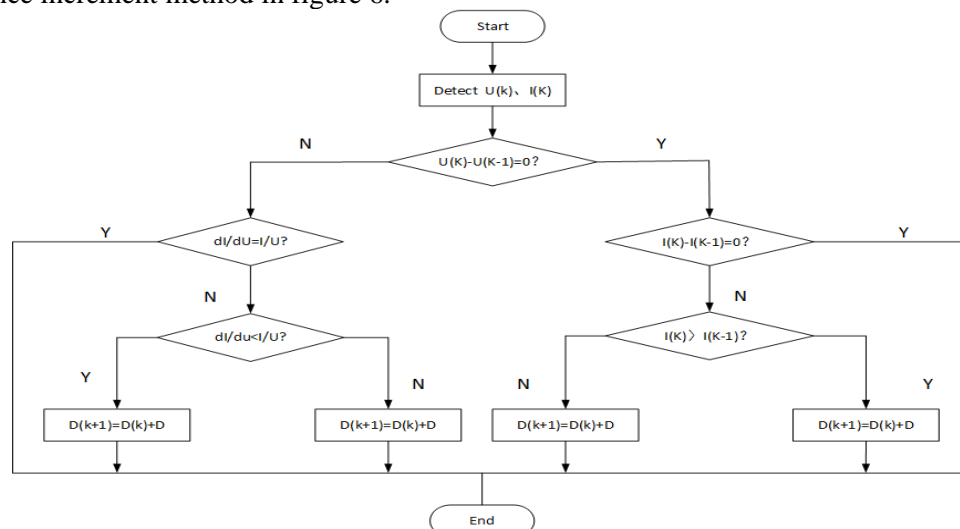


Figure 6. Flow chart of conductance increment method

3.3. Supercapacitor charging strategy

At the beginning of charging, the terminal voltage of the supercapacitor is low and the equivalent series resistance is small. In order to prevent the damage of the supercapacitor caused by excessive charging current, series current limiting resistance should be used and soft start charging method should be used. After the soft start is completed, the supercapacitor enters the constant current charging stage, at which time the supercapacitor cannot absorb the power generated by all photovoltaic cells within the maximum charging current range, and only needs to limit the charging current to the maximum charging current through the Buck circuit. When the supercapacitor can absorb the power generated by the photovoltaic cell within the maximum charging current range, charging enters a constant power charging stage, and the charging system collects the supercapacitor current and voltage, compares the supercapacitor current and voltage with the current and voltage detected last time, adjusts the duty ratio, and controls the charging current through a Buck circuit adjustment control signal.

4. Charge verification

4.1. Simulation verification

In MATLAB / Simulink, a simulation model of photovoltaic cell charging system for supercapacitor is built. The former Boost converter uses MPPT controller to control and track the maximum power point, and the latter Buck controller controls the charging of supercapacitor.

The MPPT controller is simulated for 2 s under constant illumination intensity, the waveforms of the supercapacitor terminal voltage, charging current and charging power are shown in figure 7, it can be seen that before the supercapacitor terminal voltage reaches 10 V, the supercapacitor is in the soft start and constant current charging stages. Under the combined action of current limiting resistance and constant current control, the supercapacitor is actually charged with constant current. The current limiting resistance in the soft start stage plays a role in limiting the charging current under the condition that the supercapacitor terminal voltage is very low. After the terminal voltage of the supercapacitor reaches 10 V, constant power charging is started, and the final charging power is stabilized at 317 W, which is 90% of the maximum output power of the photovoltaic cell. Figure. 8 shows the charging efficiency in this process. The charging efficiency is relatively low at the initial stage of charging, and finally the charging efficiency is stable above 90% with the increase of supercapacitor voltage.

At 0s, 2s and 4s, the illumination intensity is respectively set to 150 w/m², 200 w/m² and 300 w/m², and the obtained photovoltaic cell output power and supercapacitor charging power are shown in figure 9. It can be seen that the charging power of the supercapacitor can quickly track the maximum output power of the photovoltaic cell by using the charging strategy proposed in this paper, thus greatly improving the charging efficiency.

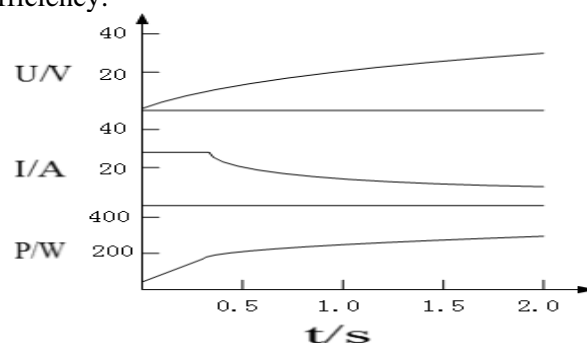


Figure 7. Charging voltage, current and power waveforms

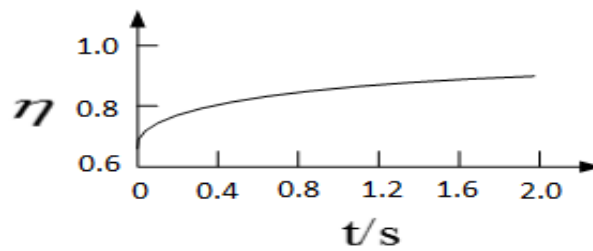


Figure 8. Charging waveform of supercapacitor

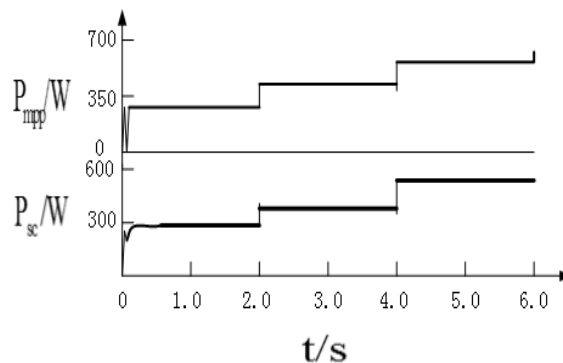


Figure 9. Photovoltaic cell output maximum power and supercapacitor charging power when illumination intensity changes

5. Conclusion

In this paper, different charging methods are used for the improved supercapacitor in different charging stages. The soft-start charging method is used at the beginning of charging. The soft-start charging ends when the terminal voltage of the supercapacitor reaches the minimum output voltage of the Buck converter, and enters the constant-current charging stage. As the capacitor voltage increases, the maximum power that the capacitor can withstand is greater than the output power of the photovoltaic cell, and enters the constant-power charging stage. The charging efficiency is greatly improved by using this charging strategy, and its feasibility is verified by simulation experiments.

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