Design of multi-stage charging power supply for TETS lithium battery based on PNGV model

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Abstract. In this paper, a multi-stage TETS charging system of the PNGV model of lithium-ion battery is proposed based on on the analysis of the equivalent circuit model of lithium-ion battery and the existing charging method. Using this system, the charging speed is increasing while the polarization and the temperature rising is suppressed. Taking into account the charging quality of the the lithium-ion battery, the actual charging curve is closer to the optimal charging curve in this system. Combining MATLAB and SIMPLORERMAXWELL multi-platform, the effectiveness of the scheme is verified by joint simulation. The simulation results have theoretical research and practical application value for the establishment of TETS charging system platform for lithium-ion battery.

1. Introduction
Lithium-ion secondary batteries are widely used because of high energy storage density and power density, especially in mobile devices, of which the technologies are rapidly developing. In order to achieve higher charging efficiency and longer cycle life, multi-stage charging mode is usually adopted [1-2]. From the perspective of different application conditions of TETS lithium battery charging, there are conventional charging, fast charging and ultra-fast charging.

In the past, inductive coupling and magnetic resonance charging systems are extensively studied. However, resonance parameters, coil design, efficiency analysis is usually concerned with. In these studies, simulation are usually carried out with resistances as the batteries, which results in an inability to match the true secondary battery [3-4]. Without scientific research platforms, scientific research on charging processes is rare.

In order to realize the multi-stage charging mode, it is necessary to design a reasonable multi-stage charging power supply with a reasonable charging method such as turbulent precharge to constant current charging to constant voltage charging to pulse discharge-steady current pulse. This kind of charging power supply can be designed at the front of the wireless charging system to supply power to the coupling coil. It can also be designed at the output of the coupling coil, which will increase the burden on the device and the complexity of the system [5-6].
With this method, a wireless charging system for an electric vehicle lithium ion secondary battery that is closer to practical applications will be successfully designed. This research will have the theoretical value and practical application value of the platform establishment.

2. The structure of TETS lithium battery charging system
The structure of the multi-segment power wireless charging system based on the PNGV lithium-ion battery model is shown in Figure 1. The system consists of programmable multi-stage charging power supply, electromagnetic coupling wireless power transmission coil, rectification and filtering unit, slow current limiting unit, battery stable micro-discharge unit, multi-cell series lithium-ion battery pack of PNGV model.

3. PNGV lithium ion battery model
The establishment of a mathematical model is the basis for the optimization of charge and discharge of a lithium battery. At present, there are several kinds of battery models mainly include: equivalent circuit model, electrochemical model, mathematical model and so on. The characteristics of the battery are linked to various parameters to simulate the dynamic characteristics of the battery in the equivalent circuit model, of which the physical meaning is clear. Therefore, the equivalent circuit model is adopted in this paper.

The PNGV model is shown in Figure 2. $U_{oc}$ is the open circuit voltage. $R_0$ is the ohmic internal resistance. $R_p$ is the polarization internal resistance. $C_p$ is the polarization capacitance. $I_L$ is the load current. $U_t$ is the terminal voltage. During the process of charging and discharging of battery, $C_p$ will discharge and charge, which will cause the load current to change, and the battery SOC will also change. Therefore, the PNGV model is an equivalent circuit model that can meet the dynamic and steady-state charge and discharge simulation requirements of a certain precision. In this paper, the lithium battery pack is made up of 82 lithium-ion batteries with a rated voltage of 3.5V. According to Kirchhoff laws, it can be inferred:
Figure 2. Model of equivalent circuit and simulation for PNGV

\[ U_{OC} = U_L + \left( \int I_L dt \right) + R_p I_p + R_o I_L \]  

4. Programmable implementation of multi-stage charging

Choosing a reasonable charging method is very important for speeding up charging and slowing down battery aging. When the battery is charged, if the charging current is too small, the charging speed of the battery is very slow, which seriously affects the charging efficiency; if the charging current is large, the side reaction in the battery is more, which accelerates the aging of the battery and affects the cycle life of the battery. From the perspective of battery performance status, this paper proposes a solution for programmable multi-stage charging power supply for lithium battery to be safely charged and prolonged life without losing the rapid charging.

For the simulation of the entire multi-segment power wireless charging system, Multi-platform co-simulation method is adopted. The multi-stage programmable power supply part is simulated in MATLAB software, while the modelling and finite element analysis of the electromagnetic coupling coil is partially completed by the software MAXWLL. The power circuit is partially completed by SIMPLORER, which is the main platform for the whole system simulation. MATLAB and MAXWLL are respectively called by SIMPLORER to realize multi-platform co-simulation of MATLAB, SIMPLORER and MAXWLL. The mechanism of the entire TETS multi-stage lithium ion charging system is shown in Figure 3.

Figure 3. MAXWELL-SIMPLORER-MATLAB joint simulation model for multi-stage power supply
The programmable multi-stage charging power supply consists of a triangular wave with a multi-segment frequency of 100 Hz and a voltage amplitude changing with time $t$. The charging current can be automatically adjusted according to the ambient temperature and the battery temperature to achieve the purpose of healthy charging of the lithium battery and prolonging the battery life. The programmable multi-segment charging power supply is written in MATLAB's M file and packaged as a sub-MATLAB/Simulink subsystem module. The programmable multi-stage charging power supply timing is as follows, and the voltage waveform is shown in Figure 4.

The process of healthy charging of WPT lithium battery can be divided into turbulent precharge stage, constant current charging stage, constant voltage and current limited stage, pulse discharging stage, and steady current pulse charging stage.

Turbulent precharge stage: in order to avoid the impact of large current charging on the battery, within 0 to 4s of charging start stage, the resistance of 1ohm is connected to slow down the increase of the charging current and the charging power, so that the battery voltage rises slowly, which giving the lithium battery a buffering and adaptation process.

Constant current charging stage: the charging current is kept at a large value to make sure that the charging power increases rapidly, and the battery voltage rises rapidly until the battery voltage reaches the upper limit voltage, and the constant current charging ends.

Constant voltage and current limited stage: When the battery voltage reaches the upper limit, the battery has been charged with 90% power, then the battery is charged at a constant voltage. The battery voltage remains unchanged and the charging current will decrease rapidly.

Pulse discharging stage: compared to the constant current charging stage, negative pulses discharge is joint in this stage. Between 45 to 50s, a 100 ohm discharge resistor is connected in parallel at the output of system. The reverse polarization effect is accompanied with the discharge, which reduces the influence of the polarization phenomenon caused by the large current charging and the temperature of the battery, thereby improving the system charging quality and prolonging the battery life.

Steady current pulse charging stage: after the pulse discharge stage, the system continues to charge with positive pulses. When the battery is fully charged, the charging current is reduced to zero and the charging process ends.

$$
\begin{align*}
    u &= \pm t (0 \leq t < 4) \\
    u &= 4 \pm 8 (t - 4) (4 \leq t < 5.5) \\
    u &= 16 \pm 20 (t - 5.5) (5.5 \leq t < 6) \\
    u &= 6 \pm 3.5 (t - 6) (6 \leq t < 30) \\
    u &= 80 (30 \leq t < 44.5) \\
    u &= 30 (44.5 \leq t < 53) \\
    u &= 55 (53 \leq t < 57) \\
    u &= 30 (57 \leq t \leq 60)
\end{align*}
$$

(2)
5. Simulation results

For the simulation of the whole multi-segment power wireless charging system, this paper adopts the multi-platform joint simulation is adopted in this paper. SIMPLORER performs transient simulation of the entire system by calling the programmable power supply in Matlab-Simulink and electromagnetically coupled wireless power transfer coil in MAXWELL. The contrast waveform of SOC and charging current is shown in Fig. 5.

According to the multi-platform simulation results, a classic lithium battery multi-stage charging curve can be clearly obtained. First, the charging current is slowly increased, so that the lithium battery has a buffering and adaptation process. At this stage, the SOC slowly rises, and the "charge preheating stage" can be achieved. Secondly, he charging current rises sharply and greatly into the constant current charging stage. It can also be seen from the SOC curve, at this stage, the battery power increases rapidly.
with the rapid increase of the charging current. The SOC can reach more than 90%. Thirdly, coming to the constant voltage and current limited stage the charging, current drops sharply. The SOC slowly rises and gradually approaches 100%. Then, the system performs a short negative pulse discharge on the battery for a short time. The SOC decreases slightly, and the system enters pulse discharging stage. That the short-time discharge of the battery reduces the influence of the polarization phenomenon and extends the battery life. Finally, after a few seconds standing, the battery is charged with a small positive pulse until the SOC reaches 100%, and the charging process of the entire system ends.

6. Conclusion
A multi-stage TETS charging system is proposed in this paper based on the PNGV model of lithium-ion. Based on MATLAB-SIMPLORER-MAXWELL multi-platform combination the simulation results shows that the actual charging curve is closer to the optimal charging curve with this scheme. The system greatly increases the charging speed while effectively suppressing the polarization reaction and temperature rise, which improves the charging quality of the lithium ion battery and prolongs the battery life. The system greatly increases the charging speed while effectively suppressing the polarization reaction and temperature rise, improving the charging quality of the lithium ion battery and prolonging the battery life. The research in this paper has theoretical research and practical application value for the establishment of TETS charging system platform for lithium ion battery.

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