Research on battery control method based on matrix rectifier

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Abstract. In this paper, a battery control method based on matrix rectifier is developed. The matrix rectifier is used to control the current of the input battery. Compared with the ordinary rectifier, it can greatly reduce the disturbance caused by the grid side and internal parameters and ensure the performance of the battery at all charging stages. In addition to stability, this control method can also compensate reactive power factor, and has better dynamic controllability.

I. Introduction

With the development of technology, lithium batteries are widely used in various commercial and industrial energy storage systems. Lithium batteries are a type of batteries, which mainly use lithium metal or lithium alloy as electrode materials, and they use non-aqueous electrolyte solutions. Among them, in the charging system of lithium batteries, the rectifier is a key component, which plays a very important role in the charging of lithium batteries. In the traditional technology, phase-controlled rectifier and uncontrolled rectification are usually used to rectify the AC power of the AC grid and then input into the battery to charge, but in this way, it is easy to produce a large output voltage ripple, and it is also easy to produce a large Harmonic, which is not conducive to the extension of the service life of the lithium battery and the improvement of the quality of the grid-side power; at the same time, the conventional technology's control strategy has poor dynamic performance and poor disturbance suppression capability. In order to solve the shortcomings of the above-mentioned traditional technologies, this paper has developed a battery control method based on matrix rectifiers, which uses a sliding mode control method to reduce harmonics on the grid side, suppress voltage disturbances, compensate for power factor, and have better dynamic control performance.

Among them, sliding mode control (English full name: sliding mode control, referred to as: SMC), alias is also called variable structure control, it is an unconventional nonlinear control, with the characteristics of control discontinuity. Compared with other control methods, the "structure" of the control system of this control method is usually not fixed but can determine the current state of the system (such as deviation and its various derivatives) in the dynamic process. And then purposefully continuously change according to the state of the system, so that the system can move in accordance with the preset "sliding mode" state trajectory. In addition, because the sliding mode can be designed and has nothing to do with the object parameters and their disturbances, the sliding mode control has the following advantages: (1) fast response to parameter changes; (2) insensitive to disturbances; (3) No system online identification is required; (4) Simple physical implementation, etc. Due to the above advantages, sliding mode control can well suppress the disturbance caused by the internal parameters of the power grid, and can also perform reactive power compensation and good dynamic performance.
2. composition of the system hardware

2.1 Composition of matrix rectifier
As shown in Figure 1, the matrix rectifier is mainly composed of a grid-side power supply, input and output filters, a main circuit and a lithium battery pack, among which the main circuit is a bidirectional switch constructed by 6 groups of conventional IGBT series diodes and then anti-parallel. According to the structure of the matrix rectifier, the matrix rectifier can ensure the bidirectional flow of energy.[1]

![Figure 1 Schematic diagram of the matrix rectifier](image1)

2.2 Structure of battery control device
As shown in FIG. 2, the battery control device is mainly composed of a sensor detection module, an error value determination unit, a modulation coefficient calculation unit, a space vector modulation unit, a power factor compensation calculation unit, and a power factor angle calculation unit. Among them, the error value determination unit, the modulation coefficient calculation unit, the space vector modulation unit, the power factor compensation calculation unit and the power factor angle calculation unit form a sliding mode control module.[2]

![Figure 2 Schematic diagram of the battery control device](image2)

3. Control method of battery control device
(1) Real-time detection of grid-side voltage and current and battery charging voltage and charging current through the sensor detection module.

(2) Determine the current charging stage of the battery according to the charging voltage and charging current;

Determine the size of the charging voltage. If the charging voltage is less than the pre-charging voltage, it is currently in the pre-charging phase, and the pre-charging reference charging current is preset in the pre-charging phase;

If the charging voltage is greater than the pre-charging voltage and less than the constant voltage charging voltage, it is currently in the constant current charging stage, and a constant current reference charging current is preset in the constant current charging stage;
If the charging voltage reaches the constant voltage charging voltage, it is currently in the constant voltage charging stage, and there is a constant voltage reference charging voltage in the constant voltage charging stage;[3]

During the constant voltage charging stage, if the charging current is less than the preset charging termination current, then charging ends.

(3) The error value determination unit processes the charging voltage or charging current from the preset voltage or preset current of the current charging stage to obtain the error value ec;

(4) The modulation coefficient calculation unit calculates the modulation coefficient m of the matrix rectifier according to the error value ec;

First, the sliding mode switching function is designed according to the error value ec. The sliding mode switching function is: $S_i = \varepsilon_i + c_1 \varepsilon_i$.

Where $\varepsilon_i$ is the error rate of change and $c_1$ is the first sliding mode parameter.

Then, the modulation coefficient m of the matrix rectifier is obtained according to the size of S1 and the sliding mode control function; the sliding mode control function is specifically:

According to the above sliding mode control function, m can only jump between 0 and 1. If the switching is too large, the chattering in sliding mode control is severe, and the output waveform quality is low, so the sliding mode control function is modified to a hyperbolic tangent function. To slow down the switching size of the switching items and reduce the sliding mode chattering.[4]

![Figure 3 Schematic diagram of the modified sliding mode control function](image)

As shown in Figure 3, the modified sliding mode control function is:

$m = m_{ref} + \frac{S_1}{|S_1| + \delta}$

Among them, $m \in [0, 1]$; $m_{ref}$ is the equivalent term, $\delta$ is the first positive constant, and $\sigma$ is the switching term. Among them, the positive constant here refers to a positive constant.

(4) The power factor angle calculation unit calculates the phase difference $\varphi_s$ and the voltage phase $\alpha$ of the grid side voltage and current according to the grid side voltage and current, and performs Clarke transformation on the grid side voltage and current, based on the Clarke transformed voltage $u_\alpha, u_\beta$ and current $i_\alpha, i_\beta$ calculate the sine and cosine values of voltage and current:[5]

$\sin \alpha = \frac{u_\alpha}{\sqrt{u_\alpha^2 + u_\beta^2}}$, $\cos \alpha = \frac{u_\beta}{\sqrt{u_\alpha^2 + u_\beta^2}}$, $\sin \beta = \frac{i_\beta}{\sqrt{i_\alpha^2 + i_\beta^2}}$, $\cos \beta = \frac{i_\alpha}{\sqrt{i_\alpha^2 + i_\beta^2}}$.

Calculate the power factor angle $\varphi_s$ on the grid side according to the relationship between the sine and cosine values and the power factor angle, where the power factor angle relationship is:

$\varphi_s = \alpha - \beta = \sin^{-1}(\sin \alpha \cos \beta - \sin \beta \cos \alpha)$

$$\alpha = \sin^{-1} \frac{u_\beta}{\sqrt{u_\alpha^2 + u_\beta^2}}.$$

(5) The power factor compensation calculation unit calculates the power factor $\varphi_s$ compensation angle $\Phi$, based on the power factor angle.
First, the power factor sliding mode switching function is obtained according to the power factor angle design. The power factor sliding mode switching function is specifically: 
\[ S_i = \dot{\varphi} + c_2 \varphi \]
, where \( \dot{\varphi} \) is the power factor angle change rate on the grid side, and \( c_2 \) is the second sliding mode parameter.

Secondly, the compensation angle is obtained according to the size of \( S_2 \) and the power factor sliding mode control function, where the power factor sliding mode control function is specifically:
\[ \varphi_l = \frac{S_i}{|S_i| + \lambda} \varphi_{\text{max}} \]

Where \( \lambda \) is the second positive constant and \( \varphi_{\text{max}} \) is the maximum compensation angle.

(6) The space vector modulation unit adopts current space vector modulation, and the action time of the vector corresponding to various switch combinations is determined according to the modulation coefficient \( m \), compensation angle and voltage phase, and the pulse signal is obtained according to the action time.

Taking the input as the positive phase sequence voltage as an example, when the input phase of the matrix rectifier is not open and the output line is not short-circuited, nine different switch combinations can be obtained, as shown in Table 1.

| Switch mode | \( S_1 \) \( S_2 \) \( S_3 \) | \( v_a \) | \( i_a \) | \( i_b \) | \( i_c \) |
|-------------|-----------------|-----|-----|-----|-----|
| 1           | 1 1 0 0 0 1     | \( v_a \) | 0   | \( -i_a \) | \( i_b \) |
| 2           | 0 1 0 0 0 1     | \( v_b \) | 1   | \( -i_b \) | \( i_c \) |
| 3           | 0 1 0 1 0 0     | \( v_b \) | 1   | \( -i_b \) | 0   | \( i_c \) |
| 4           | 0 0 1 1 0 0     | \( v_a \) | 0   | \( -i_a \) | \( i_b \) |
| 5           | 0 0 1 0 1 0     | \( v_a \) | 0   | \( -i_a \) | \( i_b \) |
| 6           | 1 0 0 0 1 0     | \( v_a \) | 1   | \( -i_a \) | 0   | \( i_c \) |
| 7           | 1 0 0 1 0 0     | \( v_a \) | 1   | \( -i_a \) | 0   | \( i_b \) |
| 8           | 0 1 0 0 1 0     | \( v_b \) | 0   | \( -i_b \) | \( i_c \) |
| 9           | 0 0 1 0 0 1     | \( v_b \) | 0   | \( -i_b \) | \( i_c \) |

Among them, Table 1 can be divided into six effective vectors I1-I6 and three zero vectors I7-I9.

![Figure 4 Schematic diagram of sector division](image)

As shown in Figure 4, the effective vector is divided into six sectors using the zero-crossing of the input phase voltage. Select two effective vectors and one zero vector synthesis reference vector \( \vec{I}_{\text{ref}} = \frac{T_0}{T_s} \vec{I}_0 + \frac{T_\beta}{T_s} \vec{I}_\beta + \frac{T_\alpha}{T_s} \vec{I}_\alpha \) respectively. The reference vector synthesis is:
Among them, the duty ratio of effective vector \( \vec{i}_a, \vec{i}_b \) and zero vector \( \vec{i}_0 \):

\[
d_{\alpha} = msin[60^\circ - \theta]; \\
d_{\beta} = msin\theta; \\
d_0 = 1 - d_{\alpha} - d_{\beta}; \theta = \text{mod}(\alpha - \phi_i, 60^\circ).
\]

Then, the three vectors \( \vec{i}_a, \vec{i}_b, \vec{i}_0 \) acting time of the synthesized reference vector in a control period are:

\[
T_{\alpha} = mT_s \sin(60^\circ - \theta); \\
T_{\beta} = mT_s\sin\theta; \\
T_0 = T_s - T_{\alpha} - T_{\beta};
\]

According to the duty ratio, the action time of the vector corresponding to various switch combinations is determined, the pulse signal is obtained according to the action time, and the corresponding bidirectional switch in the drive matrix rectifier is turned on.[7]

4. Conclusion
The battery control method based on matrix rectifier studied in this paper uses matrix rectifier to control the current input to the battery, and then uses sliding mode control to control the conduction of the bidirectional switch in the matrix rectifier. The sliding mode control method is closed-loop control. Compared with ordinary rectifier, it can not only suppress the grid side harmonics and the disturbance caused by internal parameters, to ensure the stability of each charging stage, but also can compensate the reactive power factor, with better dynamic control.

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