Research on Control Strategy of Working Mode Selection of Bidirectional Charge Piles in Multi-State

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Keywords: Multi-State, SOC, Bidirectional energy flow, Operating mode.

Abstract. This paper focuses on the duality of electric vehicle battery “charge-source”, proposes a control strategy of bidirectional charge piles in multi-state, to control bidirectional flow of energy between electric vehicle and micro grid. The strategy will preferentially select the operating mode input by the user. Otherwise, the charging or discharging operating mode will be automatically selected according to the SOC of the electric vehicle, the current grid operating status and the current electricity price, the method in this paper is verified by the comparison between the calculated and experimental results.

Introduction

Bidirectional flow of energy and information between electric vehicles and microgrids through power electronics. The desired results of peak clipping and valley filling are achieved[1]. The reference[1] analyzes the feasibility of V2G. Reference [2] AC/DC topology selects three-phase full-bridge structure, DC/DC topology adopts bidirectional half-bridge structure, adopts self-tuning fuzzy logic control algorithm, to select PQ or droop control as grid-connected strategy. In reference [3], the SVPWM algorithm is used to replace the traditional PWM algorithm to control AC/DC, and the virtual vector space is introduced. It has the advantages of high voltage utilization and fast dynamics. However, this method is more complicated and is not suitable for practical engineering applications. The reference[4] uses the voltage-current double closed-loop space vector control strategy to achieve energy bidirectional flow, but only analyzes the waveform of the grid side and DC bus during charge and discharge, does not consider whether the current harmonics meet grid-connection requirements. Reference [5-6] focuses on bidirectional AC/DC research on realize power factor correction and power conversion. The reference[7-8] is mainly for the study of non-isolated DC/DC in the latter stage.

In this paper, the two-stage charging pile is selected as the research object, and the control strategy of the power bidirectional flow converter is studied. Based on the existing research, the user selection module is added, and the user can charge or discharge according to the requirements. When the user does not input, the system automatically selects the working mode according to the actual working conditions.

System Overall Plan

Overall Structure of the System

The system structure of the V2G function in this paper is shown in Figure 1. The system consists of an electric vehicle battery pack, a power calculation unit, a converter and a smart microgrid. When an electric vehicle is connected to the charging pile, the working mode of the charging pile is first determined according to the user's choice; secondly, if the user input is not detected, the charging pile automatically selects the working mode according to the actual working condition.
System Circuit Structure Topology

The topology selected in this paper is shown in Figure 2. This topology consists of a bidirectional PWM rectifier and a buck-boost. In the figure, Q is the power switch IGBT, D is a freewheeling diode, and D1-D6 are connected in parallel with Q1-Q6 to provide reverse voltage blocking capability. Given the AC side grid voltage 380V, the frequency is 50Hz; the AC side filter capacitor L2-L4 is 0.5H; the DC bus side large capacitor C is 4000 μF; the battery side capacitor L1 is 0.5H; the battery is selected by Simulink's own lithium-ion model, open circuit voltage is 144V, rated capacity is 135Ah.

Control Strategy and Mode Selection

This article controls the AC/DC and DC/DC separately: when the battery is charging, the AC/DC operates in rectified mode and DC/DC operates in buck mode. Since the battery belongs to the power terminal under the state of charge, it is not necessary to maintain the DC bus voltage constant, so the energy calculation unit obtains the actual charging current \(I_{bat}\), comprises a current loop with the rated charging current \(I_{bat}^*\) to execute constant current charging on the battery; when the battery is charging, the AC/DC operates in the inverter mode, and the DC/DC operates in the boost mode. The battery is a slack terminal, and it is necessary to maintain the stability of the bus voltage. The energy calculation unit will obtain the actual discharge voltage of the battery \(U_{bat}\) and discharge current \(I_{bat}\) comprises a voltage and current double closed loop with rated discharge voltage \(U_{bat}^*\) and current \(I_{bat}^*\). The overall control block diagram of the system is shown in Figure 3.
The system model includes two parts: user input and no user input. The mode is automatically selected according to the flow chart shown in Figure 4. When the electric vehicle is connected to the charging pile, the system mode is determined to the user input. In Figure 4, the peak load state, the valley load state and the normal state are used to indicate the grid power consumption profit and loss; The price of electricity is used to indicate the status of real-time price; Use the value of SOC to indicate the charge and discharge range of the battery, The SOC>70% means that the battery is relatively full, and the battery tends to discharge, the SOC <30% indicates that the battery is relatively low, and can only meet the driving needs. The charging and discharging range of the SOC allows the user to modify according to his actual situation to better meet the needs of the user.

![Figure 4. System mode selection flow chart.](image)

When the system has no user input, the state of the charging pile is determined by the SOC, the power system state and the real-time price. In the simulation environment, except for the electrical SOC, the other two quantities cannot be directly obtained, so the following processing is performed: The power system state can be obtained by comparing the real-time voltage $U$ on the grid side with the rated grid voltage $U^*$. And here $U^*$ we take the effective value of Chinese power frequency 220V. When $U > U^*$, It can speculate the power surplus of the grid at this time, the grid is in the valley state; Conversely, the grid is in a peak load state. The level of real-time electricity price is an objective factor, based on the user's own judgment. (The reference [9] propose that compared with the disordered charging method, the user can significantly reduce the operating cost of the charging station and the charging cost of the electric vehicle user by independently responding to the charging price of the charging station.), In this paper replaces the electricity price as a known quantity. It is given by the user in advance.

Here we need to explain the following four points: a. When the grid is in peak load state and the electricity price is higher than the average electricity price, if the electric vehicle meets the daily driving demand, if there is no user input (the user does not have travel demand), the controller will not operate. This can improve the user's economic efficiency. The same is true when the grid is in the valley state. b. The 30% selected in the flow chart is set to meet the travel demand of the general user, and the user can modify the size of the value according to the length of the travel distance; c. In the discharge working state, in order to prevent over-discharge, add a limiting link, when the battery SOC is lower than 5%, the discharge is stopped; d. In the charging mode, in order to prevent high-current charging damage to the battery, when the battery SOC>90%, the charging pile is automatically switched to a small current trickle charge, at this time the rated charging current $I_{bat^*}=5A$. In the charging or discharging mode, the over-discharge or small-current charging conditions are judged. In order to simplify the flow chart, the labeling is performed only under the conditions of normal grid state and high electricity price.
Results Analysis

In order to verify the feasibility and correctness of the above theory, a system simulation model was built in SIMULINK.

Charging Mode Simulation Results

Because three constant AC voltage sources are used in the simulation instead of the microgrid, the grid operation state cannot be judged by the grid side voltage change. Therefore, the state of the grid is simulated by artificially given: by simulating grid valley load with voltage $U = 210V < U^*$. In this case, set the battery SOC to 20%, then input a signal with a lower electricity price, and then simulate, which is equivalent to the user input charging command. The results are shown in Figure 5. It can be seen from the figure that the voltage-current waveform of the grid side can achieve the same phase at $t=0.02s$, indicating that the adjustment time is short after the electric vehicle is connected to the charging pile in the charging mode; the lithium-ion battery voltage rises slowly to 144V at this time. Left and right, the DC bus voltage can be stabilized to 700V at $t=0.2s$, and the active power $P$ flows from the grid side to the battery side. The reactive power $Q$ can be stabilized near zero at $t=0.25s$, and the system realizes charging with unit power factor. Figure (c) shows the change in current during the rise of the SOC of the battery to 90%. It can be seen that the current is reduced from a constant 34A to 5A, achieving a small current trickle charge.

Discharging Mode Simulation Results

We then give a voltage $U = 230V > U^*$ to simulate the peak load state of the grid. In this case, set the battery SOC to 80%, input a signal with a higher electricity price, which is equivalent to the user input discharge command. The simulation results are shown in Figure 6. It can be seen from the discharge waveform that the voltage-current waveform of the grid side is 180° out of phase at $t=0.02s$, which means the reverse phase is realized; the discharge voltage of the battery is stable at about 144V, which can achieve constant voltage discharge, the DC bus voltage can be stabilized to 700V, Active power $P$ flows from the battery side to the grid side, the reactive power $Q$ can be stabilized near zero at $t=0.25s$. At this time, the system realizes discharge with unit power factor; the grid side current harmonic distortion rate is 3.02% (less than 5%), which meets the network access standard.

Based on the control strategy of bidirectional charge and discharge, this paper adds a working mode selection module. The module is based on the battery SOC state judgment, combined with the grid operating state and the current electricity price, to jointly determine the charging and discharging working mode of the V2G charging pile. The model can finally achieve the following functions: a. It can work in two states: user input and no user input. The user input is the first priority. When there is no user input, The V2G charging pile can independently determine the current working mode according to a preset process. Simulation results verify the correctness of the
independent judgment.b. By detecting the state of the battery SOC, it can prevent the occurrence and overdischarge, which can reduce the loss of the battery to a certain extent and prolong its service life. c. When the inverter is connected to the grid, the charging pile has a fast response speed, small current harmonics, high voltage utilization rate, and can meet the national standard grid connection requirements.

Acknowledgement

This research was financially supported by the National Natural Science Foundation of China(61563006), Guangxi Graduate Innovation Project(GKYC201801), Guangxi Graduate Innovation Project(YCSW2017203).

References


