Design and Research of Electric Energy Router Based on Double Sliding Mode Control

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Abstract: With the continuous popularization of the concept of the energy internet, the electric energy router, as a key device in the energy internet, has become a research hotspot. The research has designed an electric energy router with a DC bus structure, which is under the double sliding mode control of outer loop voltage and inner loop current. It is verified by PLECS simulation and comparative analysis of Buck circuit PID control and sliding mode control. Design the overall circuit, verify the feasibility of its structure through simulation, and analyze its working status in grid-connected and island mode. The results show that the power router of this architecture can automatically switch the operation mode, realize the free conversion of "source-network-charge-storage", and solve congestion and faults. Through the comparative analysis of PID and sliding mode control, it can be seen that the dual sliding mode control is more advantageous in terms of dynamic characteristics and response speed. The use of dual sliding mode control is simple to implement, which has better error adjustment characteristics and strong robustness, and the addition of distributed power generation can reduce environmental pollution.

1. Introduction
With the continuous increasing of new energy equipment and the gradual popularization of distributed power generation methods, the energy Internet has become an important trend in future development [1]. As a key device in the energy Internet, the power router has the functions of plug and play, power quality control, energy path selection and optimal scheduling [2], and will be an important research direction in the future home power distribution network. The control strategy of electric energy routers has also become an important part of the research of electric energy routers. Through combing the existing literature, the author found that the control methods of the electric energy router are relatively complicated, and the operation mode is not specific enough. In 2019, V. A. Freire et al. proposed a microgrid AC-DC household energy management (HEM) model predictive control method [3], but it cannot be modeled and analyzed. In 2019, Raghavendran et al. proposed an intelligent energy management system [4]. In order to balance the grid, energy storage added a battery storage system, but the control of battery charging and discharging was not involved.

This paper designs an electric energy router, and simulates and analyzes its working status. Aiming at the power quality control problem in the existing control methods in the electric energy router, an outer loop control voltage and an inner loop control current are proposed. The double sliding mode closed-loop control method is simulated by PLECS software and compared with the PID control method.

2. The structure of the electric energy router
The electric energy router proposed in this paper is a four-port electric energy router with a DC bus. The
external ports include photovoltaic interface, energy storage interface, DC load interface and AC grid interface. Its topology is shown in Figure 1. The 60V DC bus in the figure serves as the conversion center of the power router and has a power buffering function. The DC bus is connected to the grid through a two-way AC/DC circuit to realize grid-connected and islanding modes switching, and maintain the power balance of the power router system; the photovoltaic module passes. The Boost circuit is connected to the bus voltage; the energy storage module is connected to the bus through the bidirectional DC-DC module; the DC load is connected through the Buck step-down circuit. Among them, the photovoltaic working voltage is 18V, the power is 100W, the battery rated voltage is 12V, the rated capacity is 12AH, the load takes 48V/1.8A electric vehicle charger as an example and the DC bus voltage is 60V.

![Figure 1 Topology diagram of power router](image)

The advantage of this structure are: 1. The DC bus can give full play to the buffering role in power transmission, monitor the power of each interface and carry out effective power distribution.2. It can make full use of the advantages of distributed power generation to reduce grid consumption and reduce electricity prices costs by shaving peaks and filling valleys. 3. Real-time feedback of power generation and energy storage through the monitoring module and switch at any time.4. Ensure the reliability of the network and improve the power quality. 5. It can exchange power with the grid through AC/DC, switch the island/grid mode, reduce the loss caused by grid failure, ensure the stability of the power router and deliver the excess power to the grid or other users.

### 3. Operation mode and energy control strategy

#### 3.1 Operation mode

The operation mode of the electric energy router can be divided into two categories according to whether it is connected to the grid or not, and then into 4 modes according to the supply and demand relationship of load, energy storage and photovoltaic. The design of the corresponding energy control strategy will be carried out according to different energy supply and demand conditions, and the operation mode diagram is shown in Figure 2.
In the islanding mode, there is no energy exchange between the AC microgrid and the DC microgrid. Therefore, there are two energy flow modes. When \( P_{PV} > P_{LOAD} \), the photovoltaic power generation meets the DC load power and the excess photovoltaic power is used to charge the battery. When \( P_{PV} < P_{LOAD} \), photovoltaic power generation cannot meet the demand of DC load, photovoltaic and battery are used together to meet the demand of DC load power.

In the grid-connected mode, there is an energy exchange between the AC grid and the DC grid. There are also two energy flow modes. When \( P_{PV} + P_{BAT} > P_{LOAD} \), the power will be switched from the DC bus to the AC bus. Since photovoltaic and battery power generation is higher than the DC load demand, there will be a power imbalance between the DC microgrid and the AC grid. Therefore, the monitor sends a reference signal to the CPU to transfer power to the AC grid. When \( P_{PV} + P_{BAT} < P_{LOAD} \), the power generated by PV and BAT is lower than the load demand, and the power will be exchanged from the AC grid to the DC bus.

3.2 Control strategy
The power quality control of the energy storage part adopts double sliding mode variable structure control, the outer loop controls the voltage and the inner loop controls the current. Sliding mode variable control has the characteristics of easy realization, discontinuous control, fast dynamic response, insensitive to the outside, and strong robustness. This article takes Buck converter as an example, using dual sliding mode control to establish a sliding mode surface. By finding the relationship between sliding coefficient and dynamic response of the system, the sliding mode control parameters are designed.

Aiming at the problem that the switching frequency is not fixed in the traditional sliding mode variable structure control, a sliding mode variable control structure method based on PWM modulation is adopted. The sliding mode control quantity is compared with a fixed frequency triangle wave to determine the on and off of the MOSFET switch.

4. Simulation verification and analysis
PLECS software is used to simulate, compare the sliding mode variable control with PID control, and analyze the operation mode.

4.1 Analysis of sliding mode control strategy
The sliding mode variable structure analysis takes the Buck circuit as an example to simulate the charging mode of a DC bus 60V to a 12V/12AH battery. Use sliding mode control and PID control the circuits to observe the difference in output waveforms. The parameter setting is shown in Table 1, and
the simulation diagram of sliding mode control is shown in Figure 3.

Table 1 Circuit parameter setting

| Parameter Type       | Value |
|----------------------|-------|
| Input Voltage/V      | 60    |
| Output Voltage/V     | 12    |
| Inductance/𝜇H        | 150   |
| Capacitance/𝜇F       | 500   |
| Switch Tube Frequency/kHz | 50   |
| Load/Ω               | 8     |

![Figure 3 Simulation diagram of sliding mode variable control PLECS](image)

Compare and analyze output waveform of voltage under the two control modes. In the figure 4, the green marking line is the sliding mode control output voltage, the red marking line is the PID control output voltage, and the blue marking line is the reference voltage.

![Figure 4 Voltage output waveform](image)

![Figure 5 Partial amplification of output waveform](image)

The comparative analysis of Figure 4 and Figure 5 shows that the sliding mode control is stable at 0.4ms, while the PID control is stable at 1.2ms. When adopting the control method in this paper, the dynamic response characteristics of the system are better than PID-type sliding mode control in terms
of response speed and overshoot. The system of the control method in this paper has almost no static error and small ripple during steady-state operation, while the static error of the system using PID sliding mode control is relatively large.

4.2 Analysis and simulation of operation mode
This section is mainly used to analyze the free switching of the four modes in islanding and grid connection, and whether the power is balanced or not.

The simulation circuit diagram is shown in Figure 6. The rectifier and inverter part adopts a two-level topology with a double closed-loop control of voltage and current; Bidirectional DC-DC uses bidirectional Buck-Boost converter; the load part uses Buck step-down, and the photovoltaic part uses boost. The control of voltage and DC part adopts sliding mode control. The load part is connected in series with a voltage source and a resistor to simulate the magnitude and direction of the current.

(1) Mode 1
It can be seen from the output waveform of Figure 7 that the balance is reached after 0.03s, and the AC has no waveform output, indicating that there is no energy transfer between AC and DC. The PV output energy is all charged to the load and the battery. At this time, P_PV output power is 157W, P_LOAD is 40W, P_BAT charging power is 117W, P_AC output power is 0, and the system power is balanced.

Figure 7 Mode1 Input and output waveforms

Figure 8 Mode 3 Input and output waveforms
Mode 2
When the load is increased until its power is equal to the sum of photovoltaic and battery power, it will switch to operation mode 2. The output waveform shows that when the balance is reached, the AC has no waveform output, indicating that there is no energy transfer between AC and DC. In this case, PV and BAT together provide energy for the load, that is, P_PV+P_BAT=P_LOAD. P_PV output power is 157W, P_LOAD is 256W, P_BAT discharge power is 98W, and P_AC output power is 0. The sum of the power of PV and BAT is equal to the power of Load, and the power is balanced.

(3) Mode 3
When the load is increased until its power is greater than the sum of the photovoltaic and battery power, it will switch to operation mode 3. The AC output waveform in the figure is from scratch, indicating that mode 2 is switched to mode 3. As can be seen from the output waveform, the AC output starts. At this time, the photovoltaic, battery, and power grid meet the load energy, that is, P_LOAD=P_PV+P_BAT+P_AC. P_PV output power is 157W, P_LOAD is 485W, P_BAT discharge power is 98W, P_AC output power is 235W. The sum of the power of AC, PV and BAT is equal to the power of Load. It can also be seen from Figure 8 that the load increases at 0.69s, and the power reaches equilibrium at 0.78s.

(4) Mode 4
Reducing the load will make the PV output meet the battery and load, and there will be surplus. When supplying power to the power grid, the current flows from the DC bus to the AC power grid, that is, P_LOAD+P_AC=P_BAT+P_PV. P_PV output power is 157W, P_LOAD is 50W, P_BAT charging power is 98W, and P_AC input power is 200W.

5. Conclusion
This paper introduces and analyzes the topology, operation mode and power quality control method of the DC bus architecture power router studied, and verifies the effectiveness and feasibility of the power router function through simulation. A four-port power router with a DC bus structure is proposed, including photovoltaics, energy storage, DC loads and grid interfaces. The concept of multi-port power routers is explained, which provides a basis for the cascading of multiple power routers in the future. The structure can switch between multiple modes according to different situations, connect to distributed power generation to ensure the quality of power consumption, and perform simulation analysis on each mode through PLECS, which verifies the effectiveness of the scheme and provides a new idea for the construction of the energy Internet in the future. Besides, it has proposed a dual sliding mode control strategy of inner loop voltage and outer loop current. Taking Buck circuit as an example, PLECS was used to simulate and compared with PID control method to verify the effectiveness of the strategy, which is useful for voltage stability in the future. Sexual control provides a method. However, this article has not carried out physical testing. In the future, based on the above theoretical analysis and simulation, prototypes can be made and physical tests can be carried out to verify its performance.

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