Research on Coordinated Control Strategy of AC-DC Hybrid Microgrid Bidirectional Converter

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Abstract. Based on the improved droop control of the bidirectional converter controlled by the DC (direct current) side power quantity, a coordinated control scheme with energy storage is proposed. Not only can the two-way converter automatically and smoothly switch in the rectification, inverter, and idle modes, but also the energy storage device can perform coordinated control in the DC side idle mode to maintain the DC bus voltage stability. Using DC side power control, there is no need to switch control strategies to meet islanding and grid-connected modes. The simulation results show that improved droop control can reduce frequent actions of power electronic devices caused by small-range fluctuations in DC bus voltage and AC (alternating current) frequency. Coordinated control can make the DC bus voltage more stable, ensure stable operation of the AC and DC hybrid microgrid, and improve system reliability.

Keywords. AC-DC hybrid microgrid; bidirectional converter; improved droop control strategy; energy storage device; coordinated control

1. Introduction
The electric power network is transforming to distributed and diversified, and the flow of electric energy is also developing towards multi-directional flow [1,2]. In order to better solve the development of power networks and more and more renewable energy sources to be connected, microgrid technology has been greatly utilized [3,4]. In order to reduce the power loss and harmonic current of AC/DC or DC/AC converters in the microgrid, reduce the difficulty of control, and adapt to the access of various forms of renewable energy, the research of AC/DC hybrid microgrid is supported by researchers at home and abroad. Pay attention. It is urgent to study a more optimized bidirectional converter control strategy.

Based on the improved droop control strategy, paper proposes an improved droop control coordinated with energy storage. The same control strategy is used in both grid-connected and islanding operation modes, and the two-way exchange power is controlled based on the DC side power and idle on the DC side. Coordinated control of energy storage in the mode to realize the two-way exchange of energy in the hybrid microgrid.

2. Improve droop control strategy
The converter with improved droop control strategy on the AC and DC sides has three working states.

From the droop characteristics of the distributed power supply, the reference values $P^*_{dc}$ and $P^*_{ac}$ of the converter DC side and AC measurement calculated from the DC voltage and AC measurement frequency are:

$$P^*_{dc} = \begin{cases} 
  P^*_{ex} \frac{U_{ex} - U_{h2}}{U_{h2} - U_{h1}} (U_{h1} \leq U_{dc} < U_{h2}) \\
  0 \quad (U_{l1} < U_{dc} < U_{h1}) \\
  -P^*_{ex} \frac{U_{l2} - U_{l1}}{U_{h2} - U_{h1}} (U_{l2} \leq U_{dc} < U_{l1}) 
\end{cases}$$

(1)

In the formula, $P^*_{ex}$ is the rated power of the bidirectional converter; $U_{h2}$ and $U_{l2}$ are the upper and lower limits of the DC bus voltage change. If the DC bus voltage fluctuation exceeds the limit, the bidirectional converter can only transmit energy according to the rated power; the DC bus voltage is between $U_{l1}-U_{h1}$. The exchange power on the DC side is zero during the time.

$$P^*_{ac} = \begin{cases} 
  -P^*_{ex} \frac{f_{h2} - f_{h1}}{f_{h2} - f_{l2}} (f_{h1} \leq f < f_{h2}) \\
  0 \quad (f_{l1} < f < f_{h1}) \\
  P^*_{ex} \frac{f_{l1} - f_{l2}}{f_{h2} - f_{l2}} (f_{l2} \leq f < f_{l1}) 
\end{cases}$$

(2)

In the formula, $f_{l2}$ and $f_{h2}$ are the upper and lower limits of the AC bus frequency change; when the AC bus frequency is between $f_{l1}$ and $f_{h1}$, the exchange power on the AC side is zero.

Then, the converter exchange power reference value is:

$$P^*_{ex} = t * P^*_{ac} + (1-t) * P^*_{dc}$$

(3)

Generally, the value of $t$ is 0-1, and its value is related to the capacity of the microgrid.

### 3. Energy storage coordination control system

In the AC/DC hybrid microgrid system, the output power of each distributed power generation unit and the power consumed by the load are random. Small changes in the two or other disturbances in the system will cause an imbalance in the power of the microgrid system. Frequent switching of bidirectional power converters. Therefore, in order to avoid this problem, the energy storage system is controlled based on the improved droop control strategy. However, due to the limited capacity of the energy storage system, it participates in the auxiliary adjustment of the system power balance in the idle mode of the bidirectional power converter. When the capacity of the system is insufficient, the energy storage battery is in a discharging state to supplement the shortfall in the system; when the system has sufficient energy, the energy storage battery is in a charging state to store energy. When a large power imbalance occurs in the system, and the adjustment capability range of the energy storage is exceeded, the two-way power converter will start to participate in the adjustment. The cooperation process of the two is shown in Figure 1.

![Figure 1. Control block diagram of the energy storage system](image-url)
When the DC bus voltage fluctuates in a small range, that is, when the turn-on voltage of the bidirectional power converter is not reached, the bidirectional power converter is in the idle mode. The system will preferentially use the charging and discharging of the energy storage system for regulation, so as to maintain the stability of the DC bus voltage. If the stability of the system still cannot be maintained, the bidirectional converter will be turned on to adjust power balance of the system.

The improved droop power control block diagram of the bidirectional converter is shown in Figure 2.

\[ P_{\text{ex}}/U_{\text{dc}} \]

Figure 2. AC/DC microgrid control block diagram

In Figure 2, the PWM (Pulse width modulation) signal for controlling the bidirectional converter is generated through the double closed loop of the current. The control strategy finally achieves the desired effect by controlling the magnitude and direction of the DC side current of the bidirectional converter.

As shown in Figure 3, the adjustment of the energy storage system is mainly realized by a bidirectional DC-DC converter. The energy storage system only starts in the idle mode of the bidirectional AC/DC power converter. The energy storage coordinated control system mainly uses the bidirectional DC-DC power converter to realize the bidirectional flow of energy to control the charging and discharging of the energy storage battery and maintain the stability of the DC bus voltage. In order to have good steady-state and dynamic performance, the energy storage system adopts a double closed-loop control method of voltage outer loop and current inner loop. The control goal of the energy storage system is the stability of the DC bus voltage. The control method is double closed-loop control. The outer loop uses DC bus voltage feedback to stabilize the DC bus voltage. The voltage outer loop is adjusted by the PI controller to output the reference value of the current inner loop, \( I_{\text{bref}} \).

\[ U_{\text{dc ref}} \]

Figure 3. Energy storage system control method
4. Experimental results and analysis

Build a simulation model to verify the effectiveness of this control strategy. The simulation result of energy storage coordinated control is shown in Figure 4.

![Simulation Results](image)

**Figure 4.** System coordinated operation results

- **0.0-0.1s:** \( U_{dc} = 800 \text{V} \), the bidirectional converter is in shutdown state, and the system is in idle state;
- **0.1-0.3s:** \( U_{dc} < 780 \text{V} \), heavy load operation on the DC microgrid side, bidirectional converter working in rectification state, and the energy storage system is blocked;
- **0.3-0.5s:** \( U_{dc} > 820 \text{V} \), the DC microgrid side runs at light load, the bidirectional converter starts to work in the inverter state, and the energy storage system is blocked;
- **0.5-0.7s:** AC side heavy load operation, resulting in a decrease in AC side frequency and increased inversion of the bidirectional converter, \( U_{dc} < 820 \text{V} \), the energy storage system is in a charging state, \( I_b < 0 \);
- **0.7-0.8s:** The system runs under full rated load, the bidirectional converter is in idle mode, and the energy storage system is in idle state, \( U_{dc} = 800 \text{V}, I_b = 0 \);
- **0.8-1.0s:** DC side heavy load operation, \( 780 \text{V} < U_{dc} < 800 \text{V} \), the bidirectional converter is in shutdown state, the energy storage system is discharged, \( I_b > 0 \);
- **1.0-1.2s:** DC side light load operation, \( 800 \text{V} < U_{dc} < 820 \text{V} \), the bidirectional converter is in shutdown state, the energy storage system is charging, \( I_b < 0 \).

In summary, the bidirectional converter between the AC and DC buses not only determines whether to act or what state it is in based solely on the changes in DC bus voltage and frequency, but also combines the energy storage system to coordinate and control the AC and DC hybrid microgrid.

5. Conclusion
The coordinated control of the AC/DC hybrid microgrid bidirectional converter can stabilize the DC voltage and AC frequency, and ensure the stable and reliable operation of the AC/DC hybrid microgrid. One control strategy is used to satisfy multiple operation modes, and the idle mode reduces unnecessary frequent start-up of the converter caused by small fluctuations in DC voltage or AC frequency. In the idle mode, the energy storage system is used in conjunction with the bidirectional converter to reduce the fluctuation of the DC side DC bus voltage and the AC side frequency in the island mode.

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