Research on Observer-Based Bidirectional DC-DC Converter Current Prediction Strategy

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Abstract. In a DC microgrid system containing distributed power, factors such as output fluctuations and load switching of distributed power can cause DC bus voltage fluctuations. In order to increase the capacity and improve the stability of hybrid photovoltaic energy storage system, taking into account the nonlinear characteristics of bi-directional set DC-DC converter, this paper proposes an observer-based bi-directional set DC-DC converter current prediction strategy. Without additional sensors, a feedforward control channel based on a non-linear disturbance observer is added to the DC bus voltage control outer loop to compute system interference through using the disturbance observer, the disturbance feed-forward is compensated into the expected value, thereby improving the inductance the fast following performance of current expectation. MATLAB/Simulink simulation, the results show that the observer-based Bi-directional set DC-DC converter predictive current control processes and policies can restrain the voltage jump of DC bus effectively and improve the system's rapidity and anti-interference ability under disturbances.

1. Introduction
In a DC microgrid system containing distributed power sources such as photovoltaics, changes in distributed power output power, sudden load changes, and access to non-linear loads may all has a great influence on designed dc voltage on bus, which causes the voltage value of a DC bus to be too high. The normal operation of all converters in the system will be affected during operation. The DC-DC converter is an intermediate element that connects the energy storage device and the bus DC voltage. It can adjust the direction of energy flow according to the needs of the load and reasonably distribute the excess energy in the system. The more people value it.

Refs. [1-3] discusses the DC bus voltage stability control strategy under transient conditions in the DC microgrid, and specifically points out the limitations of the PI control strategy in the application of nonlinear power electronic converters. Sliding mode controller realizes the control of the Bi-directional set DC-DC converter, which effectively improves the dynamic performance and stable operation ability of the system, but the chattering problem brought by the sliding mode controller itself will restrict the increase of the system frequency.

Ref. [4] adopts a control method that combines hysteresis control and adaptive control to control the hybrid energy storage device in the fuel cell system. This method effectively suppresses the DC bus voltage fluctuations caused by load changes, but it has not verified the feasibility of this method for distributed power disturbances.

Ref. [5] applies an optimized auto-disturbance control method to the isolated Bi-directional set DC-DC converter. This method has many adjustable parameters and complicated tuning.
The voltage beating of DC bus caused by the output power change of PV power supply is discussed. Load abrupt transition and nonlinear load access in energy storage photovoltaics systems, the observer-based bi-directional set DC-DC converter predictive current. The set control strategy can effectively suppress the fluctuation of designed dc voltage on bus, and the speed and stability of the system are improved when the system is disturbed.

2. Bi-directional Set DC-DC Converter
In the active photovoltaic energy storage design system, the energy storage medium is connected to the system through a set of bi-directional set DC-DC converters with half-bridge structure. It is shown in figure 1 [6].

![Figure 1](image1.png)

**Figure 1.** the connection half-bridge Bi-directional set DC-DC converter.

Among them, $U_{dc}$ is the bus DC voltage, capacitor C is the bus dc capacitor, L is the inductance, $U_b$ is the battery voltage, and the power switch tubes S1 and S2 are IGBTs.

According to the relationship between the load operation requires energy with photovoltaic system output energy, the bi-directional set DC-DC converter can work all kinds of patterns. When the energy required for the load operation is greater than the photovoltaic output energy, the battery ACTS as a power source to provide insufficient energy. When the energy required for the load operation is less than the photovoltaic output energy, the battery is charged as a storage unit to absorb the excess output of the photovoltaic system.

3. Interference Observer Design
In the active photovoltaic energy storage design system, the control structure of DC bus control system is current and voltage double closed-loop control [7-8], and its structure is shown in figure 2.

![Figure 2](image2.png)

**Figure 2.** Bi-directional set DC-DC block diagram.

Among them, $U_{dc-ref}$ is the given value of DC bus, $i_s$ is the output current on DC bus side, $i_o$ is the equivalent load current, $G_{upi}(s)$ is the transfer function of closed loop voltage PI controller,
$G_i(s)$ is the transfer function of closed loop current system, and the proportional coefficient $k = \frac{U_{dc}}{U_d}$. Available from the control block diagram:

$$U_{dc} = \frac{1}{sC} \frac{k G_{app}(s) G_i(s)}{1 + \frac{1}{sC} k G_{app}(s) G_i(s)} U_{dc-ref} - \frac{1}{sC + k G_{app}(s) G_i(s)} i_o$$  \hspace{1cm} (1)

$$i_L = \frac{k G_{app}(s) G_i(s)}{1 + \frac{1}{sC} k G_{app}(s) G_i(s)} U_{dc-ref} - \frac{1}{sC} \frac{k G_{app}(s) G_i(s)}{1 + \frac{1}{sC} k G_{app}(s) G_i(s)} i_o$$  \hspace{1cm} (2)

It can be seen from equations (1) and (2) that whether it is the bus DC voltage or the battery output current of the system, they are not only related to DC bus reference voltage, but also affected by the load current in the system. When there is power disturbance $i_o$ on the DC bus, such as DC load, sudden change of DC side distributed power, etc., it will cause the DC bus voltage instability. The stability margin and dynamic response, it can also restrain the surge and fluctuation of DC bus voltage effectively.

Equivalent load current $i_o$ is equivalent to an interference signal outside the Control system. Before the introduction of the compensation signal, once the equivalent load current changes, it is first reflected to the current designed dc voltage on bus through the bus support capacitance, resulting in the bus voltage feedback value deviating from the expected value, and the disturbance is further reflected to the inductor current through the outer loop PI controller on the expected value; then adjusted by the inner loop controller to eliminate the disturbance caused by the equivalent load current $i_o$ . Although this adjustment method can ultimately maintain the bus voltage stability, the entire adjustment process takes a long time. To this end, feed-forward control is introduced in the voltage outer loop control loop, and the equivalent load current $i_o$ is used as a disturbance term to compensate the output of the outer loop controller, so that it can be quickly reflected in the current inner loop without being adjusted by the voltage outer loop. The corresponding disturbance is quickly eliminated by the predictive current controller of the inner loop. The designed diagram of system is shown in figure 3 [9-10].

![Diagram](image)

**Figure 3.** The DC-DC converter based on feedforward of a nonlinear disturbance observer.

In figure 3, NDO is a nonlinear interference observer module, $G_f(s)$ is the feedforward function, which can be derived from the control block diagram of system:

$$U_{dc} = \frac{1}{sC} \frac{k G_u(s) G_i(s)}{1 + \frac{1}{sC} k G_u(s) G_i(s)} U_{dc-ref} - \frac{1}{sC + k G_u(s) G_i(s)} i_o + \frac{k G_f(s) G_i(s)}{sC + k G_u(s) G_i(s)} i_o^\wedge$$  \hspace{1cm} (3)
Equation (3) consists of three parts. The first part reflects the expected tracking performance of the output designed dc voltage on bus. The second part is the disturbance characteristic of equivalent load current to designed dc voltage on bus. The third part is based on interference the feedforward tracking item of the observer. When the parameters $k$ and $G_i(s)$ are selected properly, the effect of the feedforward compensation of the output tracking value of the disturbance observer can be used to offset the influence of the load current disturbance on designed dc voltage on bus. Therefore, the designed diagram of the bi-directional set DC-DC converter based on the external disturbance observer is shown in figure 4.

Figure 4. Overall control structure diagram of PCC method based on disturbance observer.

4. Simulation Verification
In Matlab/Simulink, the overall simulation model of the control system of the Bi-directional set DC-DC converter based on disturbance observer is built. In the simulation, the working conditions of sudden load were simulated, and the CCS-PCC+NDO method and CCS-PCC method were compared and verified. The Bi-directional set DC-DC conversion works alternately, and the battery works in the corresponding charge and discharge state. The voltage waveform of DC bus in case of load mutation is shown in figure 5, with a sudden load increase in 0.12s and a sudden decrease load in 0.24s. Figure 6 is the DC bus voltage waveform after CCS-PCC+NDO method and CCS-PCC method control under power supply fluctuation conditions. Figure 7 is the inductor current waveform after adopting two control methods. Figure 8 is the equivalent load current waveform under the two control strategies. Figure 9 shows the output waveform of the nonlinear disturbance observer.

Figure 5. Before being controlled $U_{dc}$.  
Figure 6. After being controlled $U_{dc}$.
Figure 7. Output $i_L$.

Figure 8. Output $i_o$.

Figure 9. Output waveform of nonlinear disturbance observer.

It can be seen from figure 6 that when the load switching causes the DC bus voltage to fluctuate as shown in figures 5, either the CCS-PCC method or the CCS-PCC+NDO method can stabilize that the expected voltage of the dc bus is 100V, however, when the load is switched, the bus voltage overshoot under CCS-PCC+NDO method is less than 3%, and the adjustment time is within 5ms, while the bus voltage overshoot under CCS-PCC method exceeds 6%, and the adjustment time can reach 18ms. Figure 7 shows that the current $i_L$ of inductor is positive or negative, and the battery works in the corresponding charging and discharging state. It can be seen from figures 8 and 9 that the non-linear interference observer can quickly follow the equivalent load current in the CCS-PCC+NDO method, which improves the system's rapidity and anti-interference ability under disturbance.

5. Conclusion
This paper proposes a Bi-directional set DC-DC converter predictive current based on nonlinear disturbance observer. Without additional sensors, a feedforward control channel based on a non-linear disturbance observer is added to the DC bus voltage control outer loop to compute system interference through using the disturbance observer, the disturbance feed-forward is compensated into the expected value, thereby improving the inductance. The fast following performance of current expectation. Compared with the traditional predictive current control strategy, this method achieves rapid tracking of disturbances without increasing costs, and further improves the speed and anti-interference ability of the system under disturbances.

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