Stability Analysis of Buck Converter Based on Passivity-Based Stability Criterion

Yajing Zhang 1, Jinyao Si 1, Xiu-Teng Wang 2, Jianguo Li 1 and Hongyan Zhao 3,*

1 School of Automation, Beijing Information Science and Technology University, Beijing 100192, China; zhangyajing@bistu.edu.cn (Y.Z.); sijinyao1030@yeah.net (J.S.); lijianguo@bistu.edu.cn (J.L.)
2 Branch of Resource and Environment, China National Institute of Standardization, Beijing 100191, China; wangxt@cnis.ac.cn
3 College of Mechanical & Energy Engineering, Beijing University of Technology, Beijing 100124, China
* Correspondence: zhaohy@bjut.edu.cn

Abstract: Recently, the stability of DC microgrids has attracted increasing attention. The traditional stability analysis method cannot meet the requirements for the complexity and bidirectional energy flow of the system. In this paper, a passivity-based stability criterion (PBSC) is proposed to analyze the stability of the cascade system. In order to realize the passivity of the system, an improved feedback control method based on the traditional double-loop control strategy is proposed, which will improve the stability region and guarantee the passivity of the system. Moreover, a Buck-CPL simulation model is established based on MATLAB/Simulink R2008, and the correctness of the theoretical analysis is verified by experiments.

Keywords: passivity-based stability criterion (PBSC); stability analysis; Buck converter; CPL

1. Introduction

The flexible microgrid structure has arisen during a historic moment to integrate new energy sources, such as distributed generation (DG) systems and energy storage systems (ESSs), in a coordinated manner. Unlike the AC grid, the DC microgrid does not need to track the phase and frequency of the voltage or consider the eddy current loss in the distribution line and the reactive energy absorbed by the line [1]. Therefore, the DC microgrid has the advantages of simple control, high efficiency, flexibility, low construction cost [2], and broader application prospects in electric vehicles, residential load power supply and other fields [3]. In DC microgrids, the bus voltage becomes the only standard by which to measure the power balance of system, since the system does not need to consider reactive power [4]. In the DC microgrid, new energy sources such as DG and ESSs are usually connected to the DC bus through the source converters. At the same time, the loads are usually connected to the DC bus through closed-loop controlled load converters, and they present constant power load characteristics from the input terminal, which are regarded as constant power loads (CPLs). However, the CPLs exhibit negative impedance characteristics at their inputs, which will amplify the disturbance, including positive feedback, and destabilize microgrid systems [5]. The interaction between multi-converters can also lead to oscillation and even instability of DC microgrids. Therefore, it is of great significance to study the small-signal stability of DC microgrids to ensure the stable operation of DC microgrids.

At present, impedance-based methods are usually used to analyze the small-signal stability of DC microgrids. This approach based on impedance allows direct stability criteria to be defined for each individual subsystem through convenient impedance specifications [6]. Initially, the Middlebrook impedance ratio criterion was proposed for stability
analysis. On this basis, a series of stability criteria were derived, including Gain Margin and Phase Margin (GMPM), Opposing Argument (OA) criterion, energy source analysis consortium criterion (ESACC), root exponential stability criterion (RESC), maximum peak criterion (MPC), Modified Phase Margin and Opposing Argument (MPMOA) [7–9] and so on. These criteria divide the system into source and load subsystems and set different restricted areas for the Nyquist curve of the impedance ratio between source and load [10]. This makes them potentially assume a unidirectional power flow, but it is not applicable to the systems which contain ESSs. In order to solve the above problems, the system is no longer divided into source and load subsystems. The converters in the system are classified as bus voltage-controlled converters (BVCCs) and bus current controlled converters (BCCCs); meanwhile, the system stability is judged by the general impedance stability criterion listed in [11]. However, this method needs to meet the premise that each converter is stable when it works alone. Secondly, when the power flow direction of the system changes, the converters in the system need to be reclassified and the input or output impedance needs to be recalculated. Therefore, the stability analysis is complex. Traditional stability is a condition that implies boundedness for dynamic closed system. If an autonomous closed-loop system is interconnected with another, its stability may be affected [12]. The Lyapunov direct method is the analytical method used to analyze the disturbance stability of the system. However, the acquisition of the Lyapunov function does not have an established method, and the criterion conditions may be conservative [13]. In addition, the artificial intelligence algorithm [14], singular perturbation theory [15], the dynamic phasor [16] method and other methods can also be used for isolated DC microgrid stability analyses.

On the basis of the large signal method, numerous advanced nonlinear control techniques have been developed [17], such as the sliding mode method (SMM) [18], predictive methods [19], fuzzy methods [20,21] and so on. These methods have received a great deal of attention for their simple structure and high robustness. The comparative analysis of the model, implementation complexity and performance of this method are shown in Table 1. It can be seen that the nonlinear control techniques have better performance; however, the model and complexity are more complex than in the traditional methods.

![Table 1. Comparative analysis of the control methods.](image)

Passivity is a more general condition of boundedness, which is applicable to open dynamical systems. The boundedness of passive systems still holds if the passive system interconnects with other passive systems. The Passivity-Based Stability Criterion (PBSC) was proposed for the DC power distribution system based on the passivity of the bus impedance [22]. It stated that if the overall bus impedance is passive, then the system is stable. Furthermore, the PBSC has the characteristic of passivity, as the system obtained by a parallel connection or negative feedback connection of two passive systems is also passive and stable. Therefore, the passivity and stability of the whole system can be ensured by designing each subsystem in the DC microgrid as a passive module [23]. Since there is no power flow assumption, the PBSC is also applicable when the power flow changes. To date, the PBSC has been applied to stability analyses in multiple scenarios. Reference [24] takes multi-bus medium-voltage DC distribution systems as the research object, applies the PBSC to analyze the passivity of each interacting bus impedance in
medium-voltage DC systems, proposes a new technology to evaluate the total line impedance damping of the system and designs positive feedforward (PFF) control to ensure that the Nyquist profile of the bus impedance is included within the boundary of the specified allowable impedance region. Reference [25] takes voltage source converters as the research object, applies the PBSC to analyze the input admittance passivity of voltage source converters and increases the filter resistance to make the system input admittance passive. Reference [26] takes multiple parallel converters in offshore wind farms as the research object, applies the PBSC to evaluate the overall system stability and reduces the resonance risk of LCL filters by adding active damping technology based on virtual resistors. Reference [27] focuses on civilian DC systems with bidirectional power flow, applies PBSC to analyze the passivity of the system and adopts feedforward control to make the input admittance of the Buck converter passive. Reference [28] applies generalized PBSC to a dual-component DC power load power system to achieve stability in interconnected power systems. Reference [29] applies PBSC to a closed-loop system of a row of cyclically controlled vehicles and improves the passive stability of the system through feedforward and feedback methods. Reference [30] applies PBSC to the grid-connected system of controlled active and reactive power injection devices by modifying the existing controller to make the system passive.

In order to reduce the complexity when analyzing the stability of the system, the passivity-based stability criterion (PBSC) is proposed to improve the stability analysis of the DC microgrid. What is more, this criterion could also be suitable for the bidirectional energy flow system, such as the energy storage system, electric vehicle charging and so on. If the subsystems of the DC microgrid are designed to be passive, then the whole DC microgrid system will be passive. In addition, the stability of the system will be ensured. In this paper, a Buck-CPL subsystem of DC microgrids is chosen as an example for the stability analysis, which is commonly used in DC microgrids. Further, on the basis of the classical double-loop control scheme, an improved feedback control method is proposed to improve the stability of the system.

The structure of this paper is as follows. The proposed PBSC method is introduced in Section 2. In Section 3, the detailed mathematical model of the Buck converter is established, and its passivity is analyzed. In Section 4, an improved control strategy is proposed to meet the requirements of PBSC and improve the stability of the system. In Section 5, the simulation is carried out in MATLAB/Simulink to verify the effectiveness of the proposed improved control strategy. Finally, Section 6 summarizes the main contributions of this paper.

2. Passivity-Based Stability Criterion

The concept of system passivity originates from the law of energy conservation. Suppose the input vector of the system is \( u(t) \), the output vector is \( y(t) \) and the energy function is \( H[x(t)] \). The system satisfies the energy balance Equation:

\[
\frac{\int_0^T \left( H[x(t)] - H[x(0)] \right) dt}{\text{energy stored}} + \frac{\int_0^T d(t) dt}{\text{energy dissipated}} = \int_0^T \left( \int_0^t u^T(\tau) y(\tau) d\tau \right) dt
\]

where \( d(t) \) represents the dissipated energy of the system, and the integral \( \int_0^T u^T(\tau) y(\tau) d\tau \) represents the external energy supplied to the system. The energy stored in the system is the external supply energy minus the system dissipated energy. The system will satisfy the following inequalities if the dissipated energy of a system \( d(t) \) is positive.

\[
H[x(t)] - H[x(0)] \leq \int_0^T u^T(\tau) y(\tau) d\tau
\]

Meanwhile, the system will be passive if the energy function satisfies \( H[x(t)] \geq 0 \). The essence of a passive system is energy dissipation, and the initial energy, \( H[x(t)] \), of the
system will tend to balance under the action of dissipated energy, \( d[x(t)] \). Therefore, the passive system will stabilize.

For a single-port linear network, the network is passive if and only if the externally supplied energy, \( w(t) \), is nonnegative. The energy of the signal in the time domain is transformed into the frequency domain by Parseval’s theorem

\[
\int_{-\infty}^{\infty} I^*(t) u(t) dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} U(j\omega) I^*(j\omega) d\omega \\
= \frac{1}{2\pi} \int_{-\infty}^{\infty} I^*(j\omega) Z(j\omega) I(j\omega) d\omega \geq 0
\]

(3)

where \( U(j\omega) = I(j\omega) Z(j\omega) \), \( i(t) \) and \( u(t) \) are Fourier transforms of \( I(j\omega) \) and \( U(j\omega) \), respectively. The * represents a conjugate complex number.

It can be seen from (3) that if the real part of \( Z(j\omega) \) is positive, and the supply energy \( w(t) > 0 \), then the network is passive and stable. Therefore, the system is passive if and only if \( Z(s) \) has no right half plane (RHP) pole, and \( \text{Re}[Z(j\omega)] \geq 0 \), where \( \text{Re}[Z(j\omega)] \geq 0 \) can be converted to \( 90^\circ \geq \text{arg}[Z(j\omega)] \geq -90^\circ \). Since the admittance model is easier to apply to engineering practice, the impedance condition is converted into the admittance condition as

1. \( Y(s) \) has no right half plane zeros.
2. \( \text{Re}[Y(j\omega)] \geq 0 \) or \( 90^\circ \geq \text{arg}[Y(j\omega)] \geq -90^\circ \).

The passivity condition of linear circuits is also applicable for nonlinear circuits which can be linearized locally.

3. Model and Passivity Analysis of the Buck-CPL Subsystem

In the DC microgrid, the loads are usually connected to the DC bus through closed-loop controlled load converters, and they present constant power load characteristics from the input terminal, which are regarded as constant power loads (CPLs), as shown in Figure 1 circled by the red dashed line.

Take the Buck-CPL subsystem as an example. In this paper, the classical drop control in the DC microgrid is used to adjust the stability of the Buck-CPL subsystem. The traditional control method of the Buck converter refers to drop control, and its control block diagram is shown in Figure 2, where \( L \) and \( r \) represent the inductor and parasitic resistance, respectively, \( v_s \) is the input voltage, \( v_{\text{bus}} \) is the DC bus voltage and \( i_o \) is the output current. \( v_{\text{ref}} \) is the reference value of the DC bus voltage. \( i_{\text{ref}} \) is the reference value of output current, \( V_{\text{bus}} \) is the rated value of the DC bus voltage and \( d \) represents the duty cycle. It should be noted that the ideal switch models do not take into account losses in the converter components, and thus it is not possible to determine the switching loss. The detailed device models, such as the model of the diode–IGBT, can be used for the analysis of switching losses [31,32].
In order to determine the characteristics of the Buck converter, the averaged model is used to obtain the result in the shortest time. The small-signal equivalent model of the Buck converter is shown in Figure 3. In the figure, \( D \) is the steady-state value of the duty cycle, \( \Delta d \) represents the small disturbance signal of the duty cycle and \( v_s \) and \( i_L \) represent the steady-state values of the input voltage and inductance current, respectively.

The small-signal equivalent model in Figure 3 is obtained by the KVL Equation

\[
v_{dc} = Dv_s + V_s \Delta d - (Ls + ri_o)
\]  

(4)

The closed-loop control small-signal block diagram for traditional control obtained from Figure 2 and Equation (4) is shown in Figure 4.

The Buck admittance model is obtained from Figure 4.

\[
Y_i = -\frac{i_o}{v_{dc}} = \frac{a_3s^2 + a_2s + a_1}{b_3s^3 + b_2s^2 + b_1s + b_0}
\]  

(5)

where

\[
D
\]

\[
\Delta d
\]

\[
v_s
\]

\[
i_L
\]

\[
v_{dc}
\]

\[
i_o
\]

\[
R_d
\]

\[
V_{bus}
\]

\[
P11
\]

\[
P12
\]

\[
Current
\]

\[
Regulator
\]

\[
Voltage
\]

\[
Regulator
\]

\[
Drop
\]

\[
Control
\]
\[
\begin{align*}
\alpha_2 &= 1 + V_p k_{p1} k_{p2} \\
\alpha_1 &= V_i k_{p1} k_{i2} + V_i k_{p2} k_{i1} \\
\alpha_0 &= V_i k_{i1} k_{i2} \\
\beta_3 &= L \\
\beta_2 &= R_d V_s k_{p1} k_{i2} + V_i k_{p2} k_{i1} + V_i k_{i2} \\
\beta_1 &= R_d V_s k_{p1} k_{i2} + R_d V_s k_{p2} k_{i1} + V_i k_{i2} \\
\beta_0 &= R_d V_s k_{p1} k_{i2}
\end{align*}
\]

where \( R_d \) represents the drop coefficient, \( k_{p1} \) and \( k_{i1} \) are the proportional and integral coefficients of the PI1 controller, respectively, and \( k_{p2} \) and \( k_{i2} \) are the proportional and integral coefficients of the PI2 controller, respectively.

When \( s \) in Equation (5) approaches 0 or infinity, respectively, the admittance \( Y_1 \) of the Buck converter at low frequency and high frequency is

\[
\lim_{s \to 0} Y_1 = \frac{1}{R_d} \quad \lim_{s \to \infty} Y_1 = 0
\]

First, we set the steady-state value of DC bus voltage to \( V_{dc} \). Then, the admittance of ideal CPL is \(-\frac{P_{cpl}}{V_{dc}^2}\). The overall admittance of the subsystem composed of the Buck converter and CPL is \( Y_s = Y_1 - P / V_{dc}^2 \).

It can be seen from Equation (6) that the admittance value of the Buck converter’s admittance model in the high frequency band is 0, while the CPL has the negative admittance property, which means that the total admittance of the Buck-CPL system in the high frequency band is likely to be negative, leading to the system being non-passive. Figure 5 draws the Nyquist diagram of the system admittance under different controller parameters to further intuitively analyze the passivity of the total admittance of the system. As shown in Section 2, if the Nyquist curve of the total admittance is fully located in the closed RHP, it is proved that the system is passive. As can be seen in Figure 5, most Nyquist curves are in the right half-plane. However, no matter how the controller parameters are modified, there are still a small number of Nyquist curves in the left half-plane. In Figure 5, the red cross sign is the negative first-order zero point and the different colors represent the results under different parameters, which marked at the top of the graph. This shows that the system admittance has a non-passive part and is independent of the controller parameters. This is consistent with the law obtained from Equation (6).

![Figure 5. Nyquist diagram of system output admittance. (a) \( R_d \) increases; (b) \( k_p \) increases.](image)

### 4. Improved Control Strategy

In order to solve the problem that the total admittance of the system is not passive, a closed-loop control chart conforming to passivity is designed by improving the output
admittance model. On the basis of the original voltage and current double closed-loop, the differential link is added to the voltage feedback, and the improved control block diagram is shown in Figure 6. The transfer function of the improved control is \( G(s) = ks + 1 \).

The small-signal model of the closed-loop system after the improved control is shown in Figure 7.

The improved admittance model of the Buck converter is

\[
Y_2 = -\frac{i_2}{\Delta v_{dc}} = \frac{a_3 s^3 + a_2 s^2 + a_1 s + a_0}{b_3 s^3 + b_2 s^2 + b_1 s + b_0}
\]  

(7)

where

\[
\begin{align*}
a_3 &= V_s k_i k_p k_{12} \\
a_2 &= V_s k_i k_p k_{12} + V_s k_i k_{p2} k_{11} + V_s k_i k_{p2} + 1 \\
a_1 &= V_s k_i k_{12} + V_s k_p k_{12} + V_s k_p k_{11} \\
a_0 &= V_s k_{12} \\
b_3 &= L \\
b_2 &= R_g V_s k_p k_{22} + V_s k_{12} + r \\
b_1 &= R_g V_s k_p k_{22} + R_s V_s k_p k_{11} + V_s k_{12} \\
b_0 &= R_s V_s k_{12}
\end{align*}
\]

When \( s \) in Equation (7) tends to 0 or infinity, respectively, the admittance \( Y_2 \) of the Buck converter at low frequency and high frequency is

\[
\begin{align*}
\lim_{s \to 0} Y_2 &= \frac{1}{R_d} \\
\lim_{s \to \infty} Y_2 &= \frac{V_s k_p k_{22}}{L}
\end{align*}
\]  

(8)

In order to ensure the passivity of the Buck-CPL subsystem, the controller parameters need to be satisfied.

\[
\begin{align*}
0 &\leq R_d \leq \frac{V_{dc}^2}{P} \\
V_s k_p k_{22} &\geq \frac{PL}{V_s^2 V_i}
\end{align*}
\]  

(9)

It can be seen from Equation (9) that the admittance of the Buck converter in the high frequency band is no longer 0 after adding the feedback differential link, thus improving the passivity of the admittance of the Buck converter in the high frequency band.
The comparison between Figure 5 and Figure 8 can also verify that the improved control makes the system admittance gradually shift to the right, thus improving the passivity and stability of the system. In Figure 8, the dashed black line is the coordinate axis.

![Nyquist Diagram](image)

**Figure 8.** The improved Nyquist diagram of the output admittance using the proposed method. (a) $R_d$ increases; (b) $k_F$ increases; (c) $k_i$ increases.

The step responses of traditional control and improved control are shown in Figure 9.

![Step Response](image)

**Figure 9.** The unit step response of the output admittance.

It can be seen from Figure 9 that the overshoot of the unit step response of traditional control is 20% and the adjustment time is 0.4 s. In comparison, the unit step response of
improved control has no overshoot, the response speed is faster and the adjustment time reduces to 0.2 s.

5. Simulation Validation

Computer simulations played a key role in the process of designing the Buck converter [33]. Different simulation software and models of the components may need different system control parameters, which may need to be fine-tuned. In this paper, a Buck-CPL simulation model was built using MATLAB R2008. In order to use the presented model in practice, it should be included in the analyzed specific parameters of the system. The specific parameters of the Buck converter are shown in Table 2.

Table 2. The Buck converter parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage $v_s$</td>
<td>100 (V)</td>
</tr>
<tr>
<td>Output voltage $v_{dc}$</td>
<td>60 (V)</td>
</tr>
<tr>
<td>Parasitic resistance $r$</td>
<td>0.12 (Ω)</td>
</tr>
<tr>
<td>Inductance $L$</td>
<td>8 (mH)</td>
</tr>
<tr>
<td>Capacitance $C$</td>
<td>4600 (μF)</td>
</tr>
</tbody>
</table>

Figure 10 shows the waveforms of the bus voltage and inductance current under the traditional control and the improved control of the system, respectively. The comparison shows that the improved control strategy improves the stability margin of the system. The controller parameters of the Buck converter are shown in Table 3. Figure 10a shows the divergent oscillations of the system with traditional control and Figure 10b,c show the waveforms with different values of $k_T$ under the improved control strategy. It is concluded that the system continues experiencing divergent oscillations when $k_T = 50e^{-7}$. When the value of $k_T = 1e^{-3}$ satisfies the passive condition, the system begins to converge, and the improved control strategy can effectively improve the system stability and enhance the system stability margin.

![Waveforms](image1)

Figure 10. Comparison waveform diagram. (a) Traditional control; (b) improved control $k_T = 50e^{-5}$; (c) improved control $k_T = 10e^{-4}$. 
Table 3. Control parameters of the Buck converter.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Traditional Control</th>
<th>Improved Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{d2}$</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>$k_{p21}$</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>$k_{i21}$</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>$k_{p22}$</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>$k_{i22}$</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$k_F$</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

5.1. Simulation of the Improved Control Strategy for the Buck Converter with CPL

Figure 11 shows the dynamic performance comparison waveform of the system using traditional control and improved control when the load power changes suddenly. It can be seen that the system overshoot is reduced by 4.3 V under the improved control strategy, which has been significantly improved. The comparison shows that the improved control strategy improves the dynamic characteristics of the system.

Figure 11. Comparison waveform under load disturbance. (a) Traditional control; (b) improved control.

Different control strategies of the Buck converter were investigated. The simulation waveforms of input voltage $v_s$, the bus voltage $v_{dc}$ and the inductor current $i_{L2}$ are shown in Figure 12 when the desired value of the DC bus voltage increases. The corresponding simulation of waveforms of the Buck converter at the time when the desired value of bus voltage decreases is shown in Figure 13. At this time, the voltage loop proportionality coefficient $k_{p1}$ is 0.3, the integration coefficient $k_{i1}$ is 300, the current loop proportionality coefficient $k_{p2}$ is 0.05, the integration coefficient $k_{i2}$ is 200, and $k_F = 0.003$ in the improved control.

Figure 12. Simulation waveforms of the Buck converter with a DC bus voltage increase. (a) Traditional control; (b) improved control.
Figure 13. Simulation waveforms of the Buck converter with a DC bus voltage decrease. (a) Traditional control; (b) improved control.

As shown in Figure 12a, when the Buck converter adopts the traditional control strategy, the maximum offset of the system bus voltage compared with the steady state value is 12 V, the overshoot is 15% and it is stabilized at 80 V after 0.16 s of oscillation after the bus voltage is increased from 60 V to 80 V, and the maximum offset of the system inductance current compared with the steady-state value is 5A and it is stabilized at 3A after 0.16 s of oscillation. When the Buck converter adopts the improved control strategy, the system waveform is shown in Figure 12b, where the bus voltage is stabilized at 80 V and 0.06 s. After a sudden increase in the bus voltage expectation value from 60 V to 80 V the bus voltage stops overshooting. The system inductor current has a maximum offset of 2.5A compared with the final steady-state value and is stabilized at 3A after 0.06 s.

As shown in Figure 13a, when the Buck converter adopts the traditional control strategy, the bus voltage desired value suddenly decreases from 80 V to 60 V compared with the steady-state value, where the maximum offset of the system bus voltage is 15 V and stabilizes at 60 V after 0.2 s of oscillation, and the system inductor current falls to 0A, after which the oscillations converge and stabilize at 4A after 0.2 s of oscillation. When the Buck converter adopts the improved control strategy, the system waveforms are shown in Figure 13b. The system voltage is stabilized at 60 V after 0.06 s of oscillation and no overshooting after a sudden decrease in the desired bus voltage from 80 V to 60 V, and the system inductor current falls to 1.5A and converges and finally stabilizes at 4A after 0.06 s.

Therefore, compared with the traditional control strategy, when the Buck converter adopts the improved control strategy, the stability margin of the system is improved, and when the system is subjected to perturbation, it can quickly recover to the steady state with better dynamic performance. The simulation results are consistent with the theoretical analysis, thus proving the effectiveness of the improved control strategy.

5.2. Experimental Validation of Buck-CPL

To validate the correctness of the simulation analysis, the experimental platform of Buck-CPL subsystem was built as shown in Figure 14.
Figure 14. Experimental platform of the Buck-CPL system.

Figure 15 gives the comparative waveforms of the bus voltage and output current of the Buck-CPL system under traditional control and improved control. It can be seen that when the system adopts the improved control strategy, the system meets the passive condition and is in a stable state, while after transforming to the traditional control, due to the fact that its total system conductance is not passive at this time and is in a critical stable state, the system appears to have divergent oscillations after the switching phenomenon. Therefore, the improved control strategy can improve the stability margin of the system.

Figure 15. Experiment waveforms in steady state of traditional control and improved control.

Different control strategies of the Buck converter are given. The experimental waveforms of input voltage $v_s$, the bus voltage $v_{dc}$ and the inductor current $i_{L2}$ are shown in Figure 16 when the desired value of DC bus voltage increases. The corresponding experimental waveforms of the Buck converter at the time when the desired value of bus voltage decreases are shown in Figure 17.
In Figure 16a, when the Buck converter adopts the traditional control strategy, the bus voltage desired value increases from 60 V to 80 V. Compared with the steady-state value, the maximum offset of the system bus voltage is 10 V, the overshoot is 12.5% and it is stabilized at 80 V after 0.36 s of oscillation. The maximum offset of the system inductance current is 6A; it is stabilized at 3A after 0.36 s of oscillation. When the Buck converter adopts the improved control strategy, the system waveform is shown in Figure 16b; the bus voltage is stabilized at 80 V after 0.16 s when the bus voltage expectation value increases from 60 V to 80 V. The bus voltage does not overshoot; the system inductance current has a maximum offset of 3.5A compared with the steady-state value, which is stabilized at 3A after 0.16 s. The simulation and experiment change rule are consistent; when the system adopts the improved control strategy, the system anti-interference ability is improved and the dynamic performance is better.

According to Figure 17a, when the Buck converter adopts the traditional control strategy, the bus voltage expectation value decreases from 80 V to 60 V compared with the steady state value, and the maximum offset of the system bus voltage is 15 V and stabilizes at 60 V after 0.36 s of oscillation. The system inductor current falls to 0A before the oscillation converges and stabilizes at 4A after 0.36 s of oscillation. When the Buck converter adopts the improved control strategy, the system waveform is shown in Figure 17b; the desired value of the bus voltage decreases from 80 V to 60 V, the bus voltage is stabilized at 60 V after 0.16 s and there is no overshooting of bus voltage. The system inductor current falls to 1A and then converges and stabilizes at 4A after 0.16 s. The system oscillation converges after 0A and stabilizes at 4A after 0.36 s of oscillation, and the system inductance current is stabilized at 4A. Therefore, when the system adopts the improved control strategy, the system anti-interference capability is improved and the dynamic performance is better. Therefore, the passive margin of the system is increased when the Buck converter adopts the improved control strategy and has better interference immunity.
6. Conclusions

In this paper, the PBSC is proposed to analyze the stability of the DC microgrid, and the Buck-CPL subsystem is analyzed as an example. In order to realize the passivity of the system, an improved feedback control method based on the traditional double-loop control strategy is proposed, which will improve the stability region and the dynamic characteristics of the system. The effectiveness of the theoretical analysis is verified by a simulation and experiments.

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References


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