Control strategy of hybrid energy storage system based on virtual DC generator to suppress DC bus voltage fluctuation

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Abstract. In order to eliminate the impact of sudden changes in light intensity and load on the DC microgrid system, based on the analysis of the principles and advantages of the virtual DC generator (VDG), the application of the virtual DC generator to the battery of the hybrid energy storage system is adopted. In the control strategy, it improve the ability of the hybrid energy storage system to suppress DC bus fluctuations. The Matlab/Simulink simulation results show that when the light intensity and load change suddenly, the DC microgrid bus voltage fluctuation amplitude of the virtual motor droop control is 6.1V, 39V, which is significantly smaller than the conventional droop control DC bus voltage fluctuation amplitude 8.7 V, 50.6V. The simulation results show that the control strategy proposed in this paper can improve the ability of the hybrid energy storage system to suppress DC microgrid bus voltage fluctuations.

1. Introduction
DC microgrid is a form of power grid that combines distributed power sources, energy storage devices, loads, and protection and monitoring devices[1]. Compared with the AC microgrid, the DC microgrid does not need to consider the frequency and phase of the bus voltage when it is connected to the grid, the power distribution only needs to consider the active power, it has the advantages of simpler control and higher system reliability, Therefore, it has been widely used in recent years[2]. As in the DC microgrid, the distributed power sources, energy storage devices and loads are all connected to the public DC bus through power electronic converters. Therefore, whether the DC bus voltage is stable becomes a measure of the stable and safe operation of the DC microgrid[3]. However, distributed power sources such as photovoltaics and wind power and the power of loads have great randomness and volatility. These power fluctuations, especially short-term power shocks, will cause large fluctuations in the DC bus voltage, which can easily lead to The collapse of the DC microgrid[4]. Therefore, it is necessary to take effective control measures for the DC microgrid bus voltage to suppress its fluctuation.

For the suppression of microgrid bus voltage fluctuations, scholars at home and abroad have done many fruitful researches. Among them, the idea of virtual synchronous generator (VSG) was proposed in the European VSYNC project[5]. Due to the great advantages of VSG technology, more and more people are devoted to the research of virtual synchronous generator technology[6]. However, VSG technology is mainly applied to AC microgrid, and there is very little research on virtual inertia control[7] (ie virtual DC motor) technology in DC microgrid. Literature [8] based on the study of DC motor characteristics, proposed a control strategy for energy storage converters that simulate DC motor
characteristics, so that the energy storage converter has the port characteristics of DC generators, and
the DC voltage bus can be enhanced through virtual DC motor control. Literature [9] studied the virtual
DC generator control of load or battery, and effectively improved the bus voltage stability of wind-
storage DC microgrid through the virtual DC generator control strategy. Hybrid energy storage system
is one of the most common electrical energy storage and management units in DC microgrids, but none
of the studies in the above documents involve implementing virtual DC motor control strategies in
hybrid energy storage systems to improve the ability to suppress DC bus fluctuations.

Aiming at the suppression of DC microgrid bus voltage fluctuations, this paper takes the energy
storage interface converter of the battery in the hybrid energy storage system as the control object, and
controls the power output of the battery through the virtual DC generator, in order to improve the hybrid
energy storage system and suppress the DC microgrid bus fluctuation ability. Based on the analysis of
the inertial working mechanism of the DC generator, the control strategy of the energy storage interface
converter of the virtual DC generator is established. Finally, the optical storage DC microgrid VDG
control droop control is built on the Matlab/Simulink software simulation platform. The model verifies
the superiority and feasibility of the VDG control method proposed in this paper.

2. Structure of DC microgrid system

The topology of the DC microgrid studied in this paper is shown in Fig. 1. It can be seen from Fig. 1
that the microgrid studied in this article is a solar storage DC microgrid, which is composed of a
photovoltaic system, a hybrid energy storage system and a load. Among them, photovoltaic cells always
use MPPT control, supercapacitors use ordinary droop control, and the battery adds a virtual DC
generator link to the double closed loop in the droop control.

The control strategy of this microgrid adopts droop control with plug and play characteristics, and
its equivalent model is shown in Fig. 2. In the figure, \( u_{dcref} \) is the no-load voltage of the converter,
\( u_{dci} \), \( u_{dcj} \) are the output voltages of DC/DC converters i and j, respectively, \( u_{bus} \) are the DC bus voltage,
\( R_{load} \) are the load resistances, and \( R_i, R_j \) are the virtual resistances of the converters i and j respectively.

From Fig. 2, the expression of droop control is

\[
\begin{align*}
    u_{dci} &= u_{dcref} - R_i i_{dci} \\
    u_{dcj} &= u_{dcref} - R_j i_{dcj}
\end{align*}
\]

(1)

When the line impedance is not taken into account, the voltage relationship satisfies
\( u_{dci} = u_{dcj} = u_{bus} \), and the relationship between the output current of the DC/DC converter i and j is
obtained from equation (1) as

\[
\frac{i_{dci}}{i_{dcj}} = \frac{R_j}{R_i}
\]

(2)

It can be seen from equation (2) that the output current of the energy storage unit is inversely
proportional to the virtual resistance of the droop control. In the droop control mode, each power output
unit responds to the power demand on the bus according to the droop coefficient.
3. Virtual DC generator and Its control strategy

3.1. Inertial characteristics of DC generators

The input and output circuit of the DC generator is shown in Fig. 3. In the figure, $T_m$ is the mechanical torque of the DC motor; $T_e$ is the electromagnetic torque of the DC motor; $E_a$ is the armature electromotive force of the DC motor; $R_a$ is the total equivalent resistance of the armature circuit; $U_O$ is terminal voltage; $I_a$ is the armature current.

The mechanical rotation equation of the DC motor is

$$T_m - T_e = J \frac{d\omega}{dt} + D(\omega - \omega_0)$$

(3)

Where $J$ is the rotor moment of inertia; $\omega$ is the mechanical angular velocity of the DC motor; $D$ is the damping coefficient of the DC motor; $\omega_0$ is the initial value of the mechanical angular velocity.

From equation (3), when the mechanical power of the DC motor changes suddenly, the mechanical angular velocity $\omega$ of the DC generator changes slowly due to the action of the moment of inertia $J$ and the damping coefficient $D$.

The expression of the armature electromotive force is

$$E_a = C_T \varphi \omega$$

(4)

Among them, $\varphi$ is the magnetic flux; $C_T$ is the torque coefficient.

It can be seen from equation (4) that when $\omega$ changes slowly, the induced potential $E_a$ of the DC generator and the output power of the DC generator change smoothly, which effectively suppresses the influence of sudden changes in mechanical power on the output voltage of the DC generator.

When the input mechanical power of the DC generator rises suddenly, the change curve of the input mechanical power and the output electric power of the DC generator is shown in Fig. 4. In the figure, $P_m$ and $P_e$ are the input mechanical power and output electromagnetic torque of the DC generator.

As can be seen from Fig. 4, when the input power step of the DC generator suddenly rises, the output power change curve of the DC generator rises and changes at a certain inertia and slow rate.
3.2. Virtual DC generator control strategy

The principle of the virtual direct current generator (VDC) is to control the input and output of the DC/DC converter through a control strategy, so that the DC/DC converter virtualizes the characteristics of the direct current generator. The mathematical model of the above control strategy is established in accordance with the mechanical equation and electromagnetic equation of the DC generator.

The structure of virtual DC generator control strategy is mainly composed of voltage compensation link, virtual DC generator control link and current tracking link. Among them:

1) Voltage compensation link. The DC microgrid adopts droop control, and its bus voltage changes little, so the voltage compensation link directly uses the bus voltage. Its structure is shown in Fig. 5. In the figure, \( U_{\text{ref}} \) is the reference value of the DC/DC converter output voltage (that is, the bus Voltage reference value), \( U_0 \) is the actual output voltage value.

2) Virtual DC generator control link. Its structure is shown in Fig. 6. In the figure, \( \Delta P \) is the difference of the input mechanical power of the virtual motor (see Fig. 5 for its value); \( P_{\text{ref}} \) is the reference value of the output power of the DC/DC converter; \( \Delta \omega \) is the variation of mechanical power due to \( \Delta P \) The resulting change in the mechanical angular velocity of the DC generator.

3) Current tracking link. The current tracking link is a common voltage source current tracking link, and its structure is shown in Fig. 7. \( I_{\text{ref}} \) is the reference value of the output current of the DC/DC converter.
4. Simulation results and analysis

In order to fully demonstrate the advantages of using the virtual generator control strategy, this paper builds a DC microgrid simulation model including photovoltaic and hybrid energy storage that uses a droop control strategy, including two types of batteries without virtual DC generators and virtual DC generators. The simulation model of droop control (that is, the conventional droop control, the droop control of the virtual DC generator in this paper), and the simulation comparison analysis.

4.1. Mutation of light intensity

When the light intensity changes suddenly, the parameter transformation curve of the DC microgrid is shown in Fig. 8.
In the figure, $U_{dc_1}$ and $U_{dc_2}$ are the DC bus voltage when the conventional droop control and the virtual DC generator are used. $S_{bat_1}$ and $S_{bat_2}$ are the battery SOC parameters when the conventional droop control and the virtual DC generator are used.

It can be seen from Fig. 8 that the battery is in a discharged state due to the weak light intensity. When the light intensity changes as shown in Fig. 8(a), when the battery in the hybrid energy storage system adopts conventional droop control, the change of DC microgrid bus voltage is shown in Fig. 8(b), which is 699.3 in 5s. When $V$ rises to 706.9V, it drops from 703.7V to 695V in 6s, and the maximum change of bus voltage is 8.7V; when the battery adopts the droop control of virtual motor, the change of DC microgrid bus voltage is shown in Fig. 8(c). It rises from 699V to 705V in 5s, and drops from 703.4V to 697.3V in 6s. The maximum change in bus voltage is 6.1V.

It can be seen that when the light intensity changes, the droop control bus voltage fluctuation of the virtual DC generator control is smaller than that of the ordinary droop control, which reduces the bus voltage change rate by 29.89%. This illustrates the effect of virtual DC generator control due to conventional droop control.

### 4.2. Load mutation

When the load changes suddenly, the changes of various parameters of the DC microgrid are shown in Fig. 9.
It can be seen from Fig. 9 that when the load has a negative pulse change as shown in Fig. 9(a), when the battery in the hybrid energy storage system adopts conventional droop control, the change of DC microgrid bus voltage is shown in Fig. 9(b). In 5s, the voltage drops from 699.7V to 649.1V and rises from 677.2V to 724.7V in 6s, the maximum change of the bus voltage is 50.6V; when the battery adopts the droop control of the virtual motor, the change of the DC microgrid bus voltage is shown in Fig. 9(c). It shows that the bus voltage drops from 699.5V to 662.2V in 5s and rises from 673V to 712V in 6s, and the maximum change in bus voltage is 39V.

It can be seen that when the load resistance changes, the droop control bus voltage fluctuation of the virtual DC generator control is smaller than that of the ordinary droop control, which reduces the bus...
voltage change rate by 22.92%. This illustrates the effect of virtual DC generator control due to conventional droop control.

5. Conclusion
This paper analyzes the inertial characteristics and advantages of the actual DC generator, establishes the mathematical model of the virtual DC generator through the mechanical equation and electromagnetic equation of the DC generator, builds the optical storage DC microgrid model, and compares and analyzes the conventional Droop control, the DC microgrid of droop control of the virtual motor in this paper. Through the analysis of this paper, the following conclusions can be drawn: 1) Compared with the conventional control method, the virtual DC generator control method has a sudden change in the input power when the output power of the conventional control method changes suddenly, while the virtual DC generator output power changes smoothly; 2) When the light intensity or load resistance changes in pulses, the DC microgrid bus voltage fluctuation amplitude using virtual motor droop control is significantly smaller than that of the DC microgrid using conventional droop control.

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