Coordinated control strategy of DC microgrid for hydrogen production load

Yingjun Guo¹, Fanyi Deng¹, Zhe Shi¹, Hexu Sun¹
¹Hebei University Of Science & Technology, Shijiazhuang050018, China
guoyj_hebust@163.com

ABSTRACT: In order to solve the problem of wind abandonment and light abandonment in DC microgrid, adding hydrogen production equipment in DC microgrid can effectively alleviate this problem. In the DC microgrid for hydrogen production load, a hierarchical control strategy of DC bus voltage is proposed based on the consideration of charging state, aiming at the fluctuation of DC bus voltage. The operation of the system is divided into seven modes, each of which adopts different control strategies. Finally, a model is built on the PSCAD/EMTDC simulation software and the experimental platform of new energy generation. The simulation and experimental results verify the effectiveness and feasibility of the proposed control strategy.

1. Introduction
The DC microgrid has the advantages that the AC microgrid can't match in operation and control [1], which can make more efficient and effective use of distributed generation. In view of the bus voltage fluctuations existing in the DC microgrid, domestic and foreign scholars have carried out fruitful research work.

In the paper[2-5], for the reasons of bus voltage fluctuation, a variety of control methods to improve the characteristics of DC microgrid are compared. Different control methods are used to achieve the expected results, but the key characteristics of battery state of charge (SOC) are not considered. The paper[6-9] introduces the comprehensive coordination mechanism of diesel engines, gas turbines and energy storage systems in the microgrid, but the bus voltage regulation effect is general. Paper[10-12] designed a variety of system operation modes for DC microgrids containing photovoltaic(PV) or wind power generation and energy storage devices, and proposed a system operation control strategy. However, the hydrogen production equipment has not been considered to alleviate the problem of abandoned wind and light in the current microgrid.

In this paper, hydrogen production equipment and fuel cell unit are added to the DC microgrid containing PV power generation[13], which improves the problem of abandoned electricity and energy storage. Aiming at the fluctuation of DC bus voltage, the control strategy of coordinated operation of the system under different mode is proposed based on the SOC of the battery to ensure the stable operation of the system under various working conditions.

2. The system structure of DC microgrid
In this paper, hydrogen storage energy is used as energy buffer carrier, and combined with PV power generation as the background. This paper established a DC microgrid system as shown in Fig.1.
a) PV unit. The system consists of a PV unit as the main power generation unit connected to the DC bus through a unidirectional DC/DC converter. For a stable DC microgrid, the PV unit needs to operate in three modes: maximum power tracking (MPPT) mode, constant voltage (CVC) mode, and shutdown mode. The DC bus voltage is stabilized by switching between the three modes.

b) Energy storage unit. The battery acts as an energy storage unit and is connected to the DC bus via a bidirectional DC/DC converter. The battery charging and discharging control method used in this paper is shown in Fig.2. The method not only considers the current value of the battery charge and discharge, but also considers the SOC of the battery at the same time. The purpose is to prolong the service life of the battery and prevent the battery from being damaged due to overcharge or overdischarge during charging and discharging.

c) Load unit. The system consists of two kinds of loads. The hydrogen production equipment is used as the main load. The hydrogen produced can be supplied to the hydrogen refueling station and used in industry. When the DC bus voltage is insufficient, the fuel cell can consume hydrogen to generate electric energy to maintain the DC bus voltage stability. The water produced after combustion can continue to be used for hydrogen production and repeated use[14]. In addition, there are some secondary loads in the system. When the DC bus voltage is insufficient, the secondary load can be cut off from the system to maintain the DC bus voltage stability.

3. The system control of DC microgrid

3.1. The system control structure of DC microgrid
The system control in this paper is to control the PV unit and the battery energy storage unit. When necessary, the fuel cell is required as the backup power source. They work in a variety of operating modes to stabilize the DC bus voltage. The structural diagram of control system is shown in Fig.3.

3.2. The control method of DC microgrid
The stability of the bus voltage determines whether the power flow of each part of the DC microgrid is balanced. Therefore, according to the DC bus voltage fluctuation, the voltage stratification mode and coordinated control strategy are adopted. The system operation control is divided into seven modes, each mode adopting different control methods.
Due to the weather, there is no light and the PV unit is not working properly. The energy storage unit begins to discharge to ensure hydrogen production. In an emergency, the fuel cell can also be used to power the hydrogen plant.

In order to balance the internal energy flow of the system, the secondary load is initially powered. When the battery capacity reaches SOC max, the adjustment capacity is lost. The DC bus voltage will continue to rise and the system will enter mode 3 operation. In order to balance the internal energy flow of the system, the secondary load is initially powered.

Mode 4(ΔUdc > b3): When the battery is fully charged, the hydrogen production equipment has been operating at the maximum power, and the power supply to the secondary load has also started, the voltage is still higher than the system specified value. The PV unit switches from MPPT mode to CVC mode to ensure the stability of the DC bus voltage.

Mode 5(a1≤ΔUdc < a2): When the DC bus voltage decreases, the system begins to enter mode 5 operation. The energy storage unit will regulate the DC bus voltage by discharging.

Mode 6(a1≤ΔUdc < a2): Due to the weather, the PV power generation decreased, and the battery capacity reached SOC min. At this time, it is necessary to cut off the secondary load and reduce the power consumption of the hydrogen producing equipment. Fuel cell can also be used to power hydrogen production equipment to ensure hydrogen production.

Mode 7(ΔUdc < a3): Due to the weather, there is no light and the PV unit is not working properly. The energy storage unit begins to discharge to ensure hydrogen production. In an emergency, the fuel cell can also be activated to supply power to the hydrogen plant.

The energy storage unit will regulate the DC bus voltage by discharging. When the battery capacity reaches SOC max, the adjustment capacity is lost. The DC bus voltage will continue to rise and the system will enter mode 3 operation. In order to balance the internal energy flow of the system, the secondary load is initially powered.

When the battery capacity reaches SOC max, the adjustment capacity is lost. The DC bus voltage will continue to rise and the system will enter mode 3 operation. In order to balance the internal energy flow of the system, the secondary load is initially powered.

Fig. 4 is a standard diagram of mode switching judgment, and ΔUdc is the difference between the actual value of the system bus voltage and the reference value. The operating mode judgment coefficients are a1, a2, a3, b1, b2 and b3, where a1 > a2 > a3 are negative value, and b1 < b2 < b3 are positive value, and their selection should be prevented from being too large or too small. When the value is too large, the DC bus voltage changes greatly, but the corresponding unit is not put into operation, resulting in a decline in power quality and affecting the load supply. When the value is too small, small fluctuations will cause frequent switching between modes, resulting in an increase in the transient process, which is not conducive to stable operation of the system.

The following is a detailed analysis of the operation strategy of each unit in each mode.

Mode 1 (a1≤ΔUdc ≤ b1): In this range, the bus voltage fluctuation is not large, and the DC/DC converter in the PV unit is mainly used to balance the bus voltage.

Mode 2 (b1 < ΔUdc ≤ b2): When the system bus voltage continues to increase, the system enters mode 2 operation. At this time, the PV unit operates in the MPPT mode, and the battery starts to charge.

Mode 3 (b2 < ΔUdc ≤ b3): When the battery capacity reaches SOC max, the adjustment capacity is lost. The DC bus voltage will continue to rise and the system will enter mode 3 operation. In order to balance the internal energy flow of the system, the secondary load is initially powered.

Mode 4 (ΔUdc > b3): When the battery is fully charged, the hydrogen production equipment has been operating at the maximum power, and the power supply to the secondary load has also started, the voltage is still higher than the system specified value. The PV unit switches from MPPT mode to CVC mode to ensure the stability of the DC bus voltage.

Mode 5 (a1≤ΔUdc < a2): When the DC bus voltage decreases, the system begins to enter mode 5 operation. The energy storage unit will regulate the DC bus voltage by discharging.

Mode 6 (a1≤ΔUdc < a2): Due to the weather, the PV power generation decreased, and the battery capacity reached SOC min. At this time, it is necessary to cut off the secondary load and reduce the power consumption of the hydrogen producing equipment. Fuel cell can also be used to power hydrogen production equipment to ensure hydrogen production.

Mode 7 (ΔUdc < a3): Due to the weather, there is no light and the PV unit is not working properly. The energy storage unit begins to discharge to ensure hydrogen production. In an emergency, the fuel cell can also be activated to supply power to the hydrogen plant.
4. Simulation and experiment of DC microgrid

4.1. Simulation analysis
According to the national standard of "Power Quality Supply Voltage Deviation", the DC bus voltage is set to 400V, and the fluctuation range is allowed to be ± 5%. In this paper, seven modes are set for the DC bus voltage layer control. The voltage range of each mode is shown in Table 1.

| Mode  | Value       | Mode  | Value       |
|-------|-------------|-------|-------------|
| Mode 1| 395V~405V   | Mode 5| 390V~395V   |
| Mode 2| 405V~410V   | Mode 6| 385V~390V   |
| Mode 3| 410V~415V   | Mode 7| 380V~385V   |
| Mode 4| 415V~420V   |       |             |

Based on PSCAD/EMTDC simulation software, the DC microgrid system structure is constructed. According to the control strategy proposed above, the simulation waveforms in different modes are obtained. Since the voltage fluctuation of mode 1 is controlled by the DC/DC converter, this paper only simulates the latter six modes.

The simulation results when the DC bus voltage rises are shown in Fig.5. In Fig.5(a) the DC bus voltage fluctuates at 405V~410V. At this time, the battery is charged to restore the voltage to the rated value. In Fig.5(b) the SOC of battery reaches the upper limit and can no longer continue charging. The voltage rises to 410V~415V. At this point, power is supplied to the secondary load to absorb the DC bus power. In Fig.5(c) the secondary load has started to supply power, and the SOC of battery reaches the upper limit. The voltage fluctuates at 415V~420V. The PV unit switches from the MPPT mode to the CVC mode to stabilize the voltage. It can be seen from Fig.5 that when the voltage rises, the coordinated control strategy can restore the voltage to the rated value.

The simulation results when the DC bus voltage is reduced are shown in Fig. 6. When the DC bus voltage is reduced, the secondary load is not supplied. In Fig.6(a) the DC bus voltage fluctuates at 390V~395V. The PV unit is still in MPPT mode. The battery will raise the DC bus voltage to the rated value through discharge. In Fig.6(b) due to the weather, the PV power generation decreases. The SOC of battery reaches the lowest value, and can no longer continue to discharge. DC bus voltage fluctuates at 385V~390V. At this time, the DC bus voltage is stabilized by reducing the power consumption of the hydrogen production equipment. The fuel cell can also be used to power hydrogen production equipment to maintain hydrogen production. In Fig.6(c) the PV unit is not working properly because there is no illumination due to weather. DC bus voltage fluctuates at 380V~385V. At this point, the...
energy storage unit starts to discharge. In an emergency, the fuel cell can also be activated to stabilize the DC bus voltage. It can be seen from Fig. 6 that when the voltage is reduced, the coordinated control strategy can restore the voltage to the rated value.

![Simulation](image1.png)

(a) (b) (c)

Figure 6. Simulation results of DC bus voltage drop.

4.2. Experimental verification

The DC microgrid shown in Fig.1 is built on the new energy power generation experimental platform, as shown in Fig.7. The experimental results are shown in Fig.8.

![Experimental platform](image2.png)

Figure 7. Experimental platform.

![Experimental results](image3.png)

Figure 8. Experimental results.

Fig.8 shows the change of DC bus voltage, PV voltage and battery current when $b_1 < \Delta U_{dc} < b_2$. It can be seen from Fig. 8 that when the DC bus voltage fluctuates, the coordinated control strategy of this paper can quickly restore the DC bus voltage to the rated value.

The above simulation and experimental results show that the proposed voltage fluctuation stratification control strategy is reasonable and feasible, which can stabilize the bus voltage fluctuation and ensure the power quality. Compared with the paper [3-6], this strategy can minimize the frequent charge and discharge of the battery caused by the irregular fluctuation of the bus voltage. Moreover, the power loss of the power electronic switching device can be reduced, and the life of the system is prolonged.
5. Conclusion
This paper adds hydrogen production equipment and fuel cell unit to the DC microgrid, which improves the existing problems of abandoned electricity and energy storage. Aiming at the fluctuation of DC bus voltage, the control strategy of coordinated operation of the system under different layers is proposed. Finally, the correctness of the control strategy proposed in this paper is verified by simulation and experiment. The control strategy achieved the purpose of suppressing bus voltage fluctuations, meeting the power quality requirements of voltage fluctuations. The control method adopted in this paper is simple and effective, and has certain engineering application value.

Acknowledgment
This work was supported by Hebei "Wind Power/Photovoltaic Coupled Hydrogen Production and Comprehensive Utilization Engineering Laboratory" and Hebei 'Project Titan' Innovation and Entrepreneurship project fund. Hebei Science and Technology Department project which code 16214510D and Hebei Education Department project which code QN2017313 and QN2016109.

References
[1] Kurohane K, Senjyu T, Yona A  A high quality power supply system with DC smart grid 2010 Transmission and Distribution Conference and Exposition 2010 1-6
[2] Zhuoli Zhao, Ping Yang, Chengli Zheng  Review on dynamic stability research of microgrid 2017 Transaction of China Electrotechnical Society 32 111-22
[3] Yi Wang, Lirong Zhang, Heming Li Hierarchi-cal coordinated control of wind turbine-based DC microgrid 2013 Proceedings of the CSEE 33 16-25
[4] Chengshan Wang, Wei Li, Yifeng Wang DC bus voltage fluctuation classification and restraint methods review for DC microgrid 2017 Proceedings of the CSEE 37 84-97
[5] Na Zhi, Hui Zhang, Xi Xiao Research on the improved droop control strategy for improving the dynamic characteristics of DC microgrid 2016 Transaction of China Electrotechnical Society 31 31-9
[6] TyinC, Wu H, Locment F Energy management of DC microgrid based on photovoltaic combined with diesel generator and supercapacitor 2017 Energy Conversion and Management 132 14-27
[7] Zhaoxia Xiao, Shuang Jia, Jianguo Zhu Tie-line power flow control strategy for a grid-connected microgrid containing wind, photovoltaic and battery 2017 Transaction of China Electrotechnical Society 32 169-79
[8] Shuai Wang, Jiandong Duan, Li Sun Power balance control based on super-capacitor energy storage for micro-turbine power generation system 2017 Electric Power Automation Equipment 37 126-33
[9] Jingjing Zhao, Xue Lv Frequency regulation of the wind/photovoltaic/dieselmicrogrid based on DFIG cooperative strategy with variable coefficients between virtual inertia and over-speed control 2015 Transaction of China Electrotechnical Society 31 59-68
[10] Jiaying Liu, Xiaoming Han, Lei Wang Operation and control strategy of DC microgrid 2014 Power System Technology 38 2356-62
[11] Chen D, Xu L, Yao L Z  DC voltage variation based autonomous control of DC microgrids 2013 IEEE Transactions on Power Delivery 28 637-48
[12] Sun K, Zhang L, Josep M G A distributed control strategy based on DC bus signaling for modular photovoltaic generation systems with battery energy storage 2011 IEEE Transactions on Power Electronics 26 3032-45
[13] Yingjun Guo, Zhe Shi, Yajie Guo, Fanyi Deng, Hexu Sun Modeling and control of DC microgrid system based on hydrogen production load 2019 J. Phys.:Conf. Ser. 1187 022013
[14] Chengxian Luo The status quo of hydrogen production from renewable electricity in the world 2017 SINO-Global Energy 22 25-32